# PROCEEDINGS

OF

# THE CANADIAN INSTITUTE,

TORONTO,

BEING A CONTINUATION OF "THE CANADIAN JOURNAL OF SCIENCE, LITERATURE AND HISTORY."

NEW SERIES. VOLUME II.

1883-1884.

TORONTO

PRINTED FOR THE CANADIAN INSTITUTE

BY COPP, CLARK & CO., COLBORNE STREET.

1884.

# ERRATA.

PAGE 127, § 1, foot of page, *dele* the words "which is concluded in the present issue of the Journal of Mathematics."

> NOTE.—The Paper of Prof. Young, on PRINCIPLES OF THE SOLUTION OF EQUATIONS OF THE HIGHER DEGREES, and the RESOLUTION OF SOLVABLE EQUATIONS OF THE FIFTH DEGREE, which was read before the Canadian Institute on the 3rd March, 1883, appeared subsequently in the *American Journal of Mathematics*, from which it was set up for publication in the "Proceedings."

PAGE 180, lines 19, 22, 26, for "Hinos," read "Ainos."

" 243, line 23, for "D rer," read "Dürer."

" 250, line 11, for "C. C., F. R. S. C." read "C. E., F. R. S. E."

MARCH, 1884.

VOL. II. FASCICULUS No 1.

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TORONTO:
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# PROCEEDINGS

OF

# THE CANADIAN INSTITUTE,

SESSION 1883—1884.

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## FIRST ORDINARY MEETING.

The First Ordinary Meeting of the Session 1883-84 was held on Saturday, November 3rd, in the Library of the Institute, the President, J. M. Buchan, M. A., in the chair.

The minutes of last meeting were read and confirmed.

The following list of exchanges, donations and purchases received from April 1st to November 3rd, 1883, was presented :

### I.—DONATIONS.

1. Report of the Superintendent of the U. S. Coast and Geodetic Survey, showing the progress of the work during the fiscal year ending June, 1880.
2. The Bystander, N. S., No. 1, January, 1883, by James Bain, jun., Esq.
3. Report of the Commissioner of Agriculture for the United States, for the years 1881 and 1882.
4. Statutes of Ontario for 1883.
5. The Canadian Parliamentary Companion for 1883, by J. A. Gemmill, Esq.
6. A glacial striated stone from boulder clay, shore of Lake Erie, Kingsville, Essex Co., presented by David Boyle, Esq.
7. Annual Reports of the Commissioner of Agriculture and Public Works for the Province of Ontario. on Agriculture, and the Arts, for 1872, 1873, 1874, 1876, 1877, 1878, 1879, 1880, 1881, 1882, (10 vols.) per Professor Buckland.
8. Report of the Superintendent of Insurance for the Dominion of Canada for the year 1882 ; from the Superintendent of Insurance, Dominion of Canada.
9. Catalogue of the Library of the Peabody Institute of the city of Baltimore, Vol. I., containing letters A to C ; from the Board of Trustees of the Peabody Institute.
10. Check List of Insects of the Dominion of Canada, compiled by the Natural History Society of Toronto ; from the compilers.

11. Journal of the Anthropological Institute of Great Britain and Ireland, 11 Nos. of various volumes to complete a set; from the Anthropological Institute.
12. Report of Canadian Archives, by Douglas Brymner, Esq., Archivist, 1882; from the Department of Agriculture, Ottawa.
13. Mémoires de la Société Académique Indo-Chinoise de Paris. Four publications from the above Society.
14. The Literary Bulletin (11 Nos.) and Bibliographical Contributions (7 Nos.) of the Harvard University Library; from the Librarian.
15. Four reports of the Peabody Institute, city of Baltimore.
16. Historical collections of the Essex Institute, 12 volumes and parts, completing a set; 13 pamphlets from the same institution.
17. Proceedings of the Academy of Natural Sciences, Philadelphia, 10 parts and volumes to complete a set.
18. The Worcester Society of Antiquity, 5 Nos., completing a set.
19. The Journal of the Linnean Society, No. 70, Vol. XIII., completing a set.
20. The Journal of the Royal Dublin Society, 8 volumes and numbers to complete a set.
21. Annals of the Lyceum of Natural History, New York, 9 volumes and numbers; Transactions of the N. Y. Academy of Sciences, 7 numbers, completing sets; from the N. Y. Academy of Sciences.
22. From the Royal Geographical Society: The Journal of the Society, Vols. 47 and 48; the "Proceedings," 8 numbers, completing sets.
23. The Museum of Comparative Zoology at Harvard College, 4 numbers.
24. Proceedings of the Royal Colonial Institute, 5 volumes.
25. Leeds Philosophical and Literary Society, six Annual Reports, and seven pamphlets on various subjects.
26. Transactions of the Royal Scottish Society of Arts, 19 parts, to complete a set.
27. La Société des Ingénieurs Civils, Paris: 12 Nos. Mémoires et Compte Rendu des Travaux de la Société for 1882.
28. The Smithsonian Institute, Washington: 6 Vols. Smithsonian Contributions to Knowledge, Vols. 18—23, completing a set; 17 Vols. Smithsonian Miscellaneous Collections, Vols. 11 to 27 inclusive; 15 Vols. of Annual Reports of the Board of Regents of the Smithsonian Institution for various years.
29. Victoria Institute: Vols. 6 to 16 of the Journal of the Transactions, to complete set; sent to Messrs. Campbell & Son for transmission.
30. Institution of Civil Engineers: Vol. 57, to complete set.
31. The Canadian Entomologist, 3 Nos. to complete a set.

## II.—EXCHANGES.

CANADA:

The Canadian Entomologist, Nos. 4 to 8, 1883.

Canadian Naturalist, Vol. 10, No. 8.

Bulletin of the Natural History Society of Quebec, No. 2.

The Canadian Practitioner, Nos. 5—11.

Transactions of the Literary and Historical Society of Quebec, session of 1882-83.

The Weekly Health Bulletin, issued by the Board of Health of Ontario.

The Monthly Weather Review of the Meteorological Service, Dominion of Canada, April to September, 1883.

Report of the Meteorological Service, Dominion of Canada, for the year ending December 31, 1882.

Manitoba Historical and Scientific Society, Winnipeg, Catalogue of 340 Specimens from their Collection.

Report and Collections of the Nova Scotia Historical Society for the years 1882-83.

UNITED STATES OF AMERICA :

The Journal of the Franklin Institute, Philadelphia, April to November, 8 Nos.

The American Journal of Science, April to November, 8 Nos.

Transactions of the Connecticut Academy of Arts and Sciences, 5 Vols., from the commencement in 1867, to 1882.

Proceedings of the Boston Society of Natural History, Vol. 21, Part 4, Vol. 22, Part 1.

Memoirs of the Boston Society of Natural History, Vol. 3, Nos. 6 and 7.

Science, from the commencement to No. 38.

Proceedings of the American Antiquarian Society, Vol. 2, Parts 2 and 3.

Bulletin of the Philosophical Society of Washington, Vols. 4 and 5, 1880-82.

The Pennsylvania Magazine of History and Biography, Vol. 7, Nos. 1, 2 Vol. 6, No. 4 ; and Vol. 3, No. 2.

Bulletin of the American Museum of Natural History, Vol. 1, Nos. 2, 3, 4, and 14th Annual Report.

Scientific Proceedings of the Ohio Mechanics' Institute, Vol. 1, No. 4, and Vol. 2, No. 2.

Worcester Society of Antiquity, No. 18, and No. 12, Part 4 ; No. 3, 1877 ; No. 12, 1880 ; No. 19, 1882.

Bulletin of the Museum of Comparative Zoology, Cambridge, Mass. Vol. 10, Nos. 5 and 6.

Journal of Speculative Philosophy, Vol. 17, Nos. 1 and 2.

Account of the Semi-Centennial Celebration of the City of Buffalo.

Report of the Director of the Observatory of Yale College for 1882-83.

Harvard University Bulletin, No. 26.

MEXICO :

Tomo 3, Entrega 2ª and 4ª.

ENGLAND :

Transactions of the Manchester Geological Society, Vol. 17, Parts 5, 6 and 7.

Proceedings of the Royal Geographical Society, April to October, 1883.

Journal of the Royal Microscopical Society, April to October.

Institution of Civil Engineers, Vols. 71, 72, 73.

Transactions of the Royal Scottish Society of Arts, Vol. 10, Part 5.

Journal of the Transactions of the Victoria Institute, April to October.

Journal of the Anthropological Institute, April to October, 1882.

Transactions and Proceedings of the Botanical Society of Edinburgh, session 1882-83.

Scientific Roll for 1883.

Proceedings of the Royal Colonial Institute, 1882-83.

Report and Proceedings of the Belfast Naturalists' Field Club.

Annual Report of the Leeds Philosophical and Literary Society for 1882-83,

Transactions of the Edinburgh Geological Society, 1882.

Journal of the Linnean Society.

Proceedings of the Royal Irish Academy, Nos. 9 and 10, Dec., 1882, June, 1883.

Transactions of the Royal Irish Academy, Nos. 11, 12, 13.

INDIA:

Records of the Geological Society of India, Vols. 15 and 22.

Memoirs of the Geological Survey of India, Vol. 19.

Palæontologia Indica, Series 10, Vol. 2; Series 14, Vols. 1 and 3.

NEW SOUTH WALES:

Report of the Department of Mines.

Minerals of New South Wales.

New South Wales in 1881.

Journal of the Royal Society of New South Wales.

NEW ZEALAND:

Transactions and Proceedings of the New Zealand Institute for 1882.

FRANCE:

Mémoires de la Société Nationale, des Sciences Naturelles de Cherbourg, Vol. 23, 1881.

Bulletin de la Société Geologique de France, 1879—1883, 16 Nos.

Mémoires et Compte Rendu de la Société des Ingénieurs Civils, April to October, 1883.

SWEDEN:

Acta Universitatis Lundensis, Vols. 15, &c., 7 Vols.

GERMANY AND AUSTRIA:

Göttingen—Nachrichten von der K. Gesellschaft der Wissenschaften, Nos. 1—23, 1882.

München—Sitzungsberichte der Mathematisch-Physikalischen Classe der K. B. Akademie der Wisssenschaften zu München, Hefte 2, 3, 4, 5, Band 12, 1882.

Sitzungsberichte der Philosophischen, Philologischen und Historischen, Classe K. B. Akademie der Wissenschaften zu München, 1882, Hefte 1, 2, 3, Band 1; Hefte 1, 2, 3, Band 2; 1881, 4 and 5.

Astronomische, Magnetische und Meteorologische, Beobachtungen an der K. K. Sternwarte, for 1882-3.

Wien—Jahrbuch der K. K. Geologischen Reichsanstalt for 1882.

Verhandlungen der K. K. Geologischen Reichsanstalt, Nos. 12–18.

HOLLAND:

Haarlem, Archives Du Musée Teyler, Série 2, 3 Part, 1882.

Archives Neerlandaises des Sciences Exactes et Naturelles, 1882, June 17, 3, 4 and 5 Pts.: 1883, June 18, 1 Pt.

COPENHAGEN:

Oversigt over det K. Danske Videnskabernes Selskabs 1882.

Bulletin for 1882, No. 2.

## III.—PURCHASES.

Life of Sir William Logan, by Harrington.

The Canadian Naturalist and Geologist. Vols. 1, 5 and 7 to complete sets.

The Journal of Speculative Philosophy, Nos. 1, 2 and 3, Vol. 10 ; No. 3, Vol. 11 ; Nos. 1, 2 and 3, Vol. 12 ; No. 1, Vol. 13 ; No. 3, Vol. 14.

The Bystander, Nos. 2, 3 and 4.

The American Journal of Science ; 31 numbers to complete set.

And the various Periodicals mentioned in the last Annual Report, from April to November, 1883.

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The President then delivered his Inaugural Address on

# COMPLEXION, CLIMATE AND RACE.

MEMBERS OF THE CANADIAN INSTITUTE, LADIES AND GENTLEMEN :

I appear before you this evening to read the introductory paper of the session, but before doing so I wish to express my sense of the honour which my fellow members have conferred upon me by electing me a second time to the high office of President of the Canadian Institute. I wish likewise to acknowledge the heartiness of the aid and support which they gave to the Institute during last session, and to express the hope that the same unselfish and disinterested feelings which have hitherto prompted them to encourage what is done here for the advancement of science and the diffusion of knowledge may continue to operate in their breasts. The increase in membership, and the general success of the Institute during last winter, give rise in my mind, to good auguries for its prosperity during the session which commences to-night. Though the Council was unable during last session to accomplish everything that could have been wished, I think all will agree that it effected a great deal ; and I confidently anticipate that much of the work which is not yet finished will be overtaken before next May. The labour of putting our library and collections in order has proved much more serious than was anticipated, but a very large part of the work has been done, and our active and efficient Assistant-Secretary, Mr. Young, has already put them so far into shape, that he is now in a position to say what we do, and do not possess, in most departments. I may add that the number of periodicals which we take, and that of societies with which we exchange publications have been considerably increased, and that, in consequence, our facilities for affording the student of any special branch of knowledge an acquaintance with what the rest of the world is doing in it, are much improved. It may also be stated, that arrangements have been made whereby it is expected that a fuller and more regular printed report of our proceedings will be given to our members.

It seems to me that it would be inappropriate not to say a word on this occasion about the results that have flowed from a proposal made by Mr Sandford Fleming in a communication read before the Institute two or three years ago. I refer to the proposal to adopt certain meridians as standards of time—a proposal which is to take practical effect during the present month over a great part of this continent. The members of the Institute, seeing that they have in their corporate capacity twice memoralized the government, and taken other action in this matter, and in their separate capacities have seconded Mr. Fleming whenever they have had opportunity to do so, cannot but feel pleased that so much has been accomplished; and while I give utterance to that feeling of pleasure, I am sure that I am also speaking the mind of the Institute, when I express the hope, that this partial adoption of Mr. Fleming's scheme on this continent, may be but the prelude to its adoption in its entirety throughout the world.

Some years ago I had the honour to communicate to the Institute the general views at which I had then arrived in regard to the very difficult subject of the relations of complexion and climate. Though I cannot pretend that the partial solution which I then offered, was, even as far as it went, entirely satisfactory, I still think that it embodied an element of truth. Since that time, I have gained, if not increased light, at least additional information, and it has occurred to me that a new paper on the subject, written, not so much with the object of advancing any special views which I may hold, as with that of pointing out the nature of the difficulties which crop up when one attempts to elucidate it, and the character of the questions, with the solution of which its elucidation is connected, might prove to be of some popular interest.

This topic belongs to the domain of Anthropology, a science which has lately come into existence. The anthropologist might take for his motto that oft-quoted line of Pope's

"The proper study of mankind is man,"

but he would give it a meaning and an application which would astonish its author. Anthropology literally means, the science of man, and, if the term were construed in the full extent of its meaning, it would embrace all other sciences. It is not, however, so used, but is employed to designate the science which deals with the natural history of man. That is to say, Anthropology is a branch of Zoology. The great poet of the age of Queen Anne thought, and expressed the thought that the proper study of mankind is man, with the implication that it is his moral nature which is especially worthy of investigation ; the anthropologist of to-day, without leaving man's moral nature out of account, feels more at home in questions about the shape and size of skulls, the height, weight, and colour of different races, the character of their hair, the peculiarities of the different parts of their skeletons, the relations of languages, and the development of civilization on the earth.

There is no one of the differences which separate one tribe or nation from another more striking than that of colour. In consequence, men are often classified in popular parlance into white and coloured. Blumenbach, about a century ago, divided mankind on the basis of colour into five races : the Caucasian or white, the Mongolian or yellow, the American or red, the Malay or brown, and the Ethiopian or black ; and this classification has, in virtue of its simplicity, until recently been very generally accepted. It is, however, scientifically worthless. The so-called Red race varies in colour from chocolate brown to dark white. There are Chinese, Japanese and Coreans, which races, according to Blumenbach, are Mongolian, as white as many so-called Caucasians ; and the Zulus of Southern Africa, though ranked as Ethiopians, present examples of every variety of complexion from yellow to black.

In place of Blumenbach's system a great number of classifications have been offered. These may be divided into those based on language, and those based on physical peculiarities. Both are alike unsatisfactory ; the former because they often bring together tribes and nations of very different appearance ; the latter because they separate races having related languages, and connect races whose languages are extremely different. In the Indo-European family, which is a division with a linguistic basis, are included the bronze-coloured Hindoo and the blonde Scandinavian. Among the Xanthochroi, or blonde whites of Huxley, a race set apart on the basis of its physical characteristics, are included the Mingrelians of Circassia, the Scandinavians, and the Finns, three races speaking radically unlike languages, while the Samoyedes, whose language is related to that of the Finns, and the Persians and Hindoos whose tongues resemble that of the Scandinavians, are relegated to other classes.

From facts which have occurred, and facts which we may see daily occurring in this country and the neighboring republic, we are led to the conclusion that the language a man speaks is not good evidence as to his descent. The descendants of the Dutch settlers of New York speak English. The Negroes of the South speak either English or French. On the other hand physical peculiarities change very slowly, if at all. The Spaniard of South America, the Englishman of Virginia, the Frenchman of Quebec seem to be precisely the same physically as the Spaniard of Spain, the Englishman of England, and the Frenchman of France. If the white race darkens within the tropics, or the Negro blanches under the influence of frost, the process is very slow. It would therefore seem the part of wisdom to accept a classification based on physical peculiarities. The most approved classification is that of Huxley, which is founded on the character of the hair and colour of the skin. He divides all mankind into Ulotrichi, that is, those possessing crisp or woolly hair, and Leiotrichi, or those possessing smooth hair. The colour of the former, that is, of the Ulotrichi, or the woolly-haired division of mankind, "varies from yellow-brown to the darkest hue known among men." Their "hair and eyes are normally dark, and with only a few exceptions (among the Andaman Islanders) they are dolichocephalic," that is, long-headed. "The Negroes and Bushmen of ultra-Saharal Africa, and the Negritos of the Malay Peninsula and Archipelago and of the Papuan Islands are the members of this Negroid stock."

The Leiotrichi, that is, the smooth-haired division of mankind, are divisible into four groups, typified respectively by the Australians, the Chinese, the Swedes, and the Spaniards.

1. The first of these, namely the Australioid group, have dark skins, dark eyes, "wavy black hair, and eminently long skulls with well developed brow ridges, and projecting jaws." This group includes the native Australians and Tasmanians, and some races found in India in the Dekhan. Professor Huxley is inclined to consider the ancient Egyptians a modification of this type.

2. The second, or Mongoloid group, have for the most part "yellowish-brown or reddish-brown skins, and dark eyes, the hair being long, black and straight." Their skulls range between the extremes of long-headedness and broad-headedness. The group includes "the Mongol, Tibetan, Chinese, Polynesian, Esquimaux and American races."

3. The third, or Xanthochroic group, have "pale skins, blue eyes, and abundant fair hair. Their skulls, like those of the Mongoloid group, range between the extremes" of long and broad-headedness. "The Slavonians, Teutons, Scandinavians and the fair Celtic-speaking people are the chief representatives" of this type, but it extends "into North Africa and Western Asia."

4. The dark whites, or Melanochroi, constitute the fourth group. They are "pale-complexioned people with dark hair and eyes, and generally long, but sometimes broad skulls." The group includes "the Iberians or Basques and 'Dark Celts' of Western Europe, and the dark-complexioned white people of the shores of the Mediterranean and of Western Asia and Persia." Professor Huxley is inclined to hold that the Melanochroi are not a distinct group, but result from a mixture of Australioids and Xanthochroi, or fair whites.

It will be noticed that this classification brings together the widely separated Negroes and Negritos, neither of which races is maritime. The Australians are likewise ranked with the Todas and some other tribes of the Dekhan, though neither branch has reached a stage of civilization that would enable it to build ships and cross seas. From what Professor Huxley says in regard to the origin of the Melanochroi, or dark whites, it seems fair to infer that he would explain these difficulties by the hypothesis of a once continuous belt of Negro population from New Guinea to Africa, and a once continuous belt of Australioid populations from Australia to Britain. As these two belts cover to a great extent the same ground, we have another difficulty which we must solve by assuming the intrusion of either the one race or the other, and either Australioid or Negro conquest.

These difficulties suggest, that possibly after all, Huxley's classification does not indicate relationship or common descent. The Negroes and Negritos may resemble each other, not because they are of the same stock, but on account of the fact that the sum total of their surroundings, or in other words, of their environment, is similar, and produces similar effects upon those subjected to it. That is to say, the Negrito of Malacca and the Philippine Islands may resemble the Yoloff and the Bantu of Africa, because his climate and mode of life are similar. If this is not the case, it is singular, that, over the vast area in which either the Negrito or the Australian must have supplanted the other, there should be no evidence of mixture of race, no remains of a mixed race evidently sprung from the union of the two. You may say to me, that one race exterminated the other. I say that in early times it was impossible to conquer and exterminate a race over a vast area. It is hardly possible now for a very civilized to extirpate a very uncivilized race over a large tract of country. Much less was it possible then, when all the devilish enginery of modern war had not been invented, and the process of killing one's fellow was slow, and very far from sure.

We shall be still more doubtful of the value of the preceding classification as a guide to community of descent, when we notice how the shape of the skull, which one would think would be as fixed as the colour of the skin or the character of the hair, varies in all but the Australioid division. We know that abundance of good food will increase the size of many of the lower animals, and that by a process of artificial selection from among the varieties naturally produced we can change almost any character to an indefinite extent. May it not possibly be the case that the shape of the skull, and the colour of the skin, hair, and eyes and other physical characters may be the results of that natural selection which Darwin puts forward as the operative cause in originating species.

A great deal of light would be thrown on the question we have just raised, if it could be clearly shown that some physical character was either independent of, or dependent on the environment. For various reasons the character of colour seems to give greater promise of results than any other. We have a greater abundance of information in regard to it than any other, and it seems at any rate at first sight to vary according to a law.

"The colour of the skin" in the different races "varies from the very pale reddish brown of the so-called white races, through all shades of yellow and red brown to olive and chocolate, which may be so dark as to look black." That of the hair, varies from the flaxen of some northern races, to a very deep brown or bluish black. That of the eyes varies from a very light blue through different shades of blue, or grey, or green, to a more or less dark brown. Fair hair, and blue, green, or grey eyes, are never found except in conjunction with a white skin. The yellow hair reported as seen in some countries in conjunction with a dark skin, is the result of the use of a bleaching agent. Light eyes may occur with dark hair and a fair skin, and dark eyes with a fair skin and fair hair. The great majority of mankind have dark eyes, dark hair, and a more or less dark skin, and Huxley's Xanthochroi, or the blonde whites of Northern Europe, are the race that departs farthest from the common type.

According to Professor Huxley, there must once have been somewhere an unmixed blonde white race, by mixing with which the Australioids of the Mediterranean region and Great Britain became blanched to their present hue. There is not, however, what one would think there ought to be on that theory, any country or part of a country inhabited only by blondes. Probably the country with the greatest proportion of fair whites in it, is Southern Sweden; but here there is no inconsiderable admixture of men of the dark white race. On the contrary, there are countries inhabited solely by Melanochroi or dark whites. Such for example are Persia and Northern Arabia. These facts, namely, that there is no tribe or nation of unmixed blondes, while there are some of unmixed brunette whites, would seem to indicate, that the fairness of the people in the native country of the white race, is due to climatic causes, which produce their maximum effect in those parts where there are most blondes.

At first sight nothing appears plainer than that complexion is a result of climate.

The very dark races are near the equator, the light-colored ones in the temperate zones. The explanation seems to be at least as old as Homer that darkness of skin results from the intensity of the sun's rays. In his poems the term Æthiopes, meaning burnt faces, the root of our word Ethiopian, is used to designate an African tribe. But a very slight extension of our knowledge shows that this theory does not explain the facts. Side by side in the same country, as, for example, India, we find races of differing color who, apparently, have occupied the same soil for many centuries. On the forty-fourth parallel of latitude, which runs a little north of this city, we find, in the old world, the European brunette, the blonde Circassian, and the yellow Mongol, while on this continent we have the brown reddish or yellowish Indian. On the equator itself we have the African Negro, the brown Malay of Borneo, and the yellow Tupi of the valley of the Amazons. North of the blonde Russian is found the yellow Samoyede, south of the brown men of equatorial Sumatra and Java live the blacks of Australia, and the two darkest native races of this continent live near the mouth of the Colorado and that of the La Plata, each of which points is, speaking roughly, about thirty degrees distant from the equator.

The people of the eastern continent, south of the Tropic of Cancer, are for the most part brown or black. Divide what is north of the tropics into two halves by the seventy-fifth parallel of longitude and those to the west are white, those to the east yellow. The inhabitants of the islands of the Pacific vary from the light yellow of the Japanese to the chocolate brown of the Papuans. In America the Haidah Islanders and the aborigines of the neighboring parts of Alaska are almost white, the California and Arizona Indians are dark brown; the Tupis and Guaranis that occupy the valleys of the Orinoco and the Amazons, are yellow; the Peruvians, and the aborigines of La Plata and Patagonia, are brown. The darkest of these, the Charrnas, who lived near the mouth of the La Plata, have sometimes been described as black.

The variations within a short distance are often very striking. There is more dark hair in Wales than in England in the same latitude, but the proportions of dark eyes are reversed. In Wales, in Ireland, and in Brittany, dark hair and blue eyes are very frequently combined, and this has been supposed to be due to Celtic influence. In Ireland, according to Poesche, ninety per cent of the people have bluish-gray eyes. In Teutonic countries blue eyes are more abundant than gray; in Slavonic countries the reverse is the case. In Switzerland the people of the mountains are darker than those of the valleys. In Bavaria the inhabitants of the low-lying country, near the Danube, are the darkest. In Transcaucasia those who live near the Black Sea are blonde, those near the Caspian yellow,—between, there are dark whites. Blondes are found sporadically among a large number of the races of the Northern Hemisphere. That some of the extinct Guanches of the Canary Islands were blonde, is proved by their mummies. If we may trust the recently discovered picture of the mother of King Amenhotep IV., who reigned in Egypt, probably 1700 B.C., she was a blonde. At any rate, fair-haired and light-eyed people occur at this day in considerable numbers among the inhabitants of the mountainous parts of the Barbary States. The Jews, almost everywhere, present specimens of the blonde and brunette types. The Ghelankis at the south end of the Caspian, the Nestorians of Persia, and the Kurds of the highlands between Turkey and Persia, are partially blonde. Many of the Turcomans who live just east of the Caspian Sea, though Turk by race and language, are blonde; while the Persians to the south and the Tadjiks to the east, though Indo-European in speech, are brunette. Some of the Indo-European tribes in Afghanistan, and on the upper Indus, afford specimens of fair-haired and blue-eyed men. In short we may say that Xanthochroi occur from the Arctic Ocean to the Sahara, and from the Atlantic to the Indus, in greater or smaller numbers, and that occasionally beyond these confines, among the Chinese or Coreans, or even the Indians of Northwest America, individuals may be met with, of pure blood, who exhibit either light eyes or fair hair. For example, the Spanish discoverers of the Thlinkeets of Alaska, expressly note the fact that some of them had blue eyes. "Eran de color blanco y habia muchos con ojos azules." They were of a white color and there were many with blue eyes, says Perez. According to the Abbé David there is to be met with in Sétchuan, one of the northwestern provinces of China, an aboriginal race with light eyes and hair often chestnut or yellowish.

During the last twenty-five years considerable quantities of statistics, relating to the colour of the hair, eyes, and skin, have been collected in various countries. In Great Britain Dr. Beddoe's figures show that the number of blondes increases as we go north; in France the fairest part of the population is in the north and north-east; in Belgium in the north; in Gallicia, a part of Poland, the people are fairer in the north. In Germany the observations made on school children show that Schleswig-Holstein, the northernmost province, is the fairest. The next fairest is not, as might be expected, the next most northerly province, East Prussia, but Pomerania, and the third in the list is Hanover. The geographical position of these provinces naturally leads to the inference that the Scandinavian Peninsula is the seat of the fairest population in the world. The blonde centre is probably somewhere in the southern half of that peninsula, as the Lapps in the north, though partly fair, are partly brunette. In every direction north, south, east, or west from this central point the proportion of blondes decreases, and that of brunettes increases.

Many theories have been advanced to account for these anomalies. The common explanation is that they are due to race. If so, how is it that we have no aboriginal blondes between the tropics, and no aboriginal blacks north of 35° N. L. It has been thought that civilization produces fairness; but this view is refuted by many facts, the civilized Peruvian Indians, for instance, being darker than their savage congeners on the Amazons. It has been asserted that the upper classes are fairer than the lower; but, though this is the case in Europe and India, the opposite state of things existed in the Sandwich Islands, and still exists in some parts of Africa. A mountain climate has been supposed to produce a light complexion, but the highlanders of Scotland and Switzerland are darker than the natives of the plains of the same countries. Indeed, a pretty good case could be made out for the theory that low, flat countries produce fair complexions. South America, for example, which has no aboriginal negroes, is much less raised above the level of the sea than Africa. But neither is this theory consonant with all the facts.

The explanation has been sought in differences of diet, and it has been conjectured that a superabundance of carbon in the food might lead to the deposit of some of it in the skin. Races then, that live largely upon fat or oily food ought, on this hypothesis, to be darker than others in the same latitude. But there are no facts to show that the Welsh or the Irish live more on carbonaceous food than the English or the Dutch, and yet there is a considerable difference in complexion. Dr. Livingstone thought that a moist climate produces dark skins; D'Orbigny considers it the cause of fairness. Poesche, in his work on the Aryans, seems to consider fairness to be due to the absence from the soil of the elements from which the pigment that gives the yellow, brown, or black shade to the skin is formed.

Darwin, Professor Huxley, M. de Quatrefages and others think it probable that racial distinctions owe their origin to the selective operation of the prevailing diseases of particular climates. Assuming, what is amply supported by facts, that individuals slightly diverging in different directions from the type are constantly being produced, it is obvious that if a dark or a light complexion be correlated with power to resist a particular disease or group of diseases, a white race may, by natural selection, be gradually developed from a coloured one, or *vice versa*. M. de Quatrefages has suggested that the malarial fevers of Africa have wrought this effect there, and that phthisis has been the agent in the north of Europe. It certainly is the case that the tropical regions of Africa are very unhealthy for whites, and that the Negro dies out north of the parallel of 40° in both hemispheres; but this does not show that both races might not be acclimatized by slow degrees without loss of colour. In other words, no reason has been shown for thinking that it is to the complexion, and not to some other racial peculiarity that the relative immunity from certain maladies is due.

Of these various views, I am inclined to hold that that of D'Orbigny and Schomburgh is most in accordance with the facts. Europe which is the seat of the white man is the moistest of the continents; the fairest of North American Indians live on the humid coast and islands of Southern Alaska and Northern British Columbia; where there are unbroken forest regions in South America, and therefore a comparatively moist climate, the aborigines are yellow; where prairies and droughts prevail, they are brown. As compared with Hindostan, Farther India is moist, and its inhabitants are less sombre in hue. The brown men of Sumatra, Borneo, Java, and Celebes inhabit forest-covered, and therefore comparatively humid islands, the black races of Papua and Australia roam over grass-clad plains, whose existence proves the relative dryness of the air. But neither is this hypothesis in accord with all the facts. The co-existence of races of different hues in India, and of the brown Malays, and black Negritos in the Philippines and Malacca, cannot be explained by it. The west coast of Great Britain is incomparably the damper, but yet the inhabitants of the east are decidedly the fairer.

Some portion of these, and similar facts, may be explained by supposing that certain introduced races have not become completely acclimatized. It might, for example, be held that this is the cause of the relative fairness of the higher castes in India. It might too, be held that if many thousands of years were allowed, the blonde inhabitants of Great Britain and Ireland would disappear, and be replaced by a homogeneous race of dark whites, similar to the pre-Celtic inhabitants of those islands. There is some evidence tending to support this view. In particular, I may mention Dr. Beddoe's observations on the colour of the eyes of women, from which it appears, that the proportion of dark-eyed women in England is growing larger.

Another explanation of some of these facts, that possesses a certain degree of probability, is, that difference of colour in the same country is due to mode of life. It may be maintained that the Samangs of Malaca, and the Aëtas of the Philippine Islands are darker than the other inhabitants, because the poorness of their dwellings, and their consequent practically constant exposure to sun or wind, renders it an advantage for them to be dark.

Another explanation to which I shall make reference later, is that humidity is probably not the sole climatic influence that operates.

I may say here that I do not attach importance to the direct influence of climatic conditions. It is, indeed, a matter of common observation that these produce considerable effects on the individual. Pruner-Bey, for example, states that he has noticed that "the European acclimated in Egypt acquires after some time a tawny skin, and in Abyssinia a bronzed skin; he becomes pallid on the coast of Arabia, cachectic white in Syria, clear brown in the deserts of Arabia, and ruddy in the Syrian mountains." But there is no proof that these cutaneous changes are inherited. If, however, it can be shown that a particular kind of skin is better than others for resisting the deleterious influences of a given climate, it stands to reason that those members of a race whose skins vary in the direction of this type, will, in each generation have the best chance of surviving and begetting children, and that by the continued increment of successive variations in the same direction, the skin and the climate will ultimately be brought into accord.

The skin consists of two layers: the inner, dense and fibrous, furnished with blood vessels and nerves, called the derma or true skin; the outer, horny, nerveless and bloodless, called the epidermis, cuticle, or scarf-skin. The cells which compose the latter originate in the *rete Malpighii*, its lowest part, are gradually forced outward by new cells and finally exfoliate. In some of these epidermic cells a pigment is found which varies in different races, but always contains a yellow element. The hue of the skin does not depend on this colouring matter alone, but is a compound effect resulting from the white of the dermis, the red of the blood in the minute vessels near the surface, the colour and quantity of the pigment, and the thickness of the cuticle. Where the cuticle is thick, the colour of the pigment will predominate over the other elements on account of the greater depth of pigment-cells. Where it is thin, and the colouring matter light, the tint of the skin will be much affected by any change in the supply of blood to the capillaries at the surface of the body. This is the reason why the whites alone can turn pale and blush.

Closely related to the pigment of the skin are the colouring matters of the eye and hair. Dark-skinned people usually have black eyes and hair; fair hair and blue eyes are seldom found except in conjunction with a fair skin; and the eyes and hair of albinoes, in whom the pigment of the skin is wanting, are likewise destitute of colouring matter. The pink hue of their eyes is due to minute blood-vessels, whose colour is masked in ordinary organs by the pigment of the iris.

It is noteworthy that the colouring matters of the epidermis and the iris serve a very important purpose; they protect the tender underlying parts from the injurious effects of too much heat and light. Albinoes everywhere find it necessary to protect their skins and eyes from the action of the sun's rays. In warm countries they seldom go out except at night. There is this difference between them and other men, that long-continued exposure to the sun, which ordinarily develops a condition of the skin capable of resisting its rays, does not do so in their case. It may here be remarked that, the greater the quantity of the pigment, the less transparent will the epidermis be, and the more effective will it be as a protective agency. On the contrary, the smaller the quantity, the greater the transparency, and the less the protection.

Under certain circumstances the exposed parts of our bodies become tanned, that is to say, an increase in the colouring matter which they contain takes place. Dark whites tan brown, fair whites tan red. The change is caused by the influence of the sun or wind, and is obviously protective in its character, as the unpleasant feelings which result from the first exposure do not recur when we have become thoroughly tanned. This fact, I believe, contains the key which explains the distribution of colour among the races. The climate, or the mode of existence of most races, renders it an advantage to them to begin life more or less deeply tanned.

As an excretory organ, it is the function of the skin to discharge water, carbonic acid and urea—the first in large, the others in small quantities. Perspiration, or the excreting of water with some saline matter in solution, is effected in two ways. In the first place, sudoriparous glands, imbedded in the true skin, secrete sweat from the blood. This is conveyed to the air by minute ducts passing through the epidermis. It is obvious that, the less transparent the outer skin, the less light and heat will be transmitted to excite these glands into activity. In the second place, there is a continual transudation of sweat from the minute vessels of the surface of the body through the epidermis at every point. The thicker or more oily the scarfskin, the less will the amount of this transudation be. If it be both thick and oily, as in many dark races, the quantity transuded will be reduced to a minimum ; if it be thin and not oily, as in the fairest members of the white race, transudation will be copious.

The amount of transuded sweat depends, however, not only on the thinness of the cuticle, but also on the degree to which the air in contact with the body is saturated with moisture; for there is a limit to the quantity of vapour which the air can absorb. This limit varies with the temperature, warm air absorbing more than cold. It is also to be remarked that perspiration relieves the body of heat as well as of moisture, and that a dark skin may serve as a means of radiating heat in climates in which a large loss of moisture is a disadvantage. Such being the nature of the skin, I now proceed to inquire what kind of it will best suit particular regions. For this purpose climates may be classified as—

I. Arctic.
II. Moist temperate.
III. Dry temperate.
IV. Moist tropical.
V. Dry tropical.

1. When the skin is exposed to great cold, perspiration by transudation is accelerated. The frosty air, being raised many degrees in temperature by cóntact with the body, becomes very dry, and greedily drinks in its moisture. At the same time the body loses not only the heat which the air carries off, but also that which is rendered latent by the evaporation of the sweat. As a protection against the injury which a too rapid loss of perspiration and heat may inflict in an arctic climate, a thick integument is desirable. It is, I believe, the fact that arctic races have thick skins. At any rate M. de Quatrefages says that cases of dry rough skins occur most frequently among the polar tribes. This I take to be a result of the thickness of the

cuticle, just as, on the older parts of a tree, I take the roughness of the bark to be a consequence of its thickness.

But why should the eyes, skin and hair of the Polar tribes be darker than those of the blonde Europeans who live to the south of them? I suggest that it is on account of their perpetual or almost perpetual snows. It is a well-known fact that the rays of the sun reflected from the Arctic snows tan Europeans and produce snow-blindness in them. From these effects the natives enjoy, I understand, comparative immunity, which I think it fair to attribute to the colour of their skins and eyes. The hair, being anatomically a part of the skin, varies with it in colour.

II. By a moist temperate climate I mean one occurring in a temperate zone in which the air constantly contains a large amount of moisture. Humidity does not to any considerable extent depend on the amount of the annual rainfall. The annual rainfall of London is twenty and one-half inches, that of Toronto twenty-seven inches; yet the air of the former place is incomparably more humid. Countries in which the air is generally moist are distinguished from others in the same latitude by the limited range of the thermometer. This is due partly to the fact that the vapour of water cannot be so rapidly heated or cooled as air, and partly to the check which the presence of haze, mist, or cloud in the atmosphere puts upon radiation. A moist temperate climate is also warmer than others in the same latitude, for it owes its existence in every case to breezes from warm seas. Breezes from cold seas cannot produce a true humid temperate climate, because when they strike the land in summer they will be raised in temperature and rendered dry.

In humid temperate climates, since the rays of the sun, falling obliquely through a moisture-laden atmosphere, lose much of their light and heat, much pigment is not needed. The vapour-clogged air does not facilitate perspiration, therefore a thin epidermis is desirable. The combination of a thin epidermis with little pigment will give a white complexion.

The best example of a moist temperate climate is furnished by the countries lying around the North and Baltic Seas, which are apparently the native land of Huxley's Xanthochroi. The central part of this district, namely Southern Sweden, is probably the place where there are most blondes. But Great Britain, though more humid, is less blonde than Germany Denmark and Sweden in the same latitudes, and in Great Britain and Ireland, though the humidity increases, the fairness of the population diminishes as we go west. Two explanations of this difficulty besides that of race, which last from the point of view of this paper is no explanation at all, have suggested themselves to me. One is that, as wind is a tanning agent, it may possibly be the case that Ireland is more windy than England, and England than Denmark and North Germany. But I have no facts to either bear out or overthrow this hypothesis. The second is that the fairest type of blonde is produced by the humidity caused by evaporation from fresh or nearly fresh water. A glance at the map shows that the greater part of the blonde area is low and swampy, and that the eastern and fairest part of it derives much of its vapour from the half-fresh Baltic Sea. This hypothesis is supported to some extent by the case of Mingrelia, the westernmost part of Transcaucasia, and the source whence the unspeakable Turk obtained the blonde beauties with which he used to stock his harem, the moisture of this country being derived from the half-fresh waters of the Black Sea.

III. By a dry temperate climate I mean one occurring in a temperate zone in which the atmosphere is usually dry. Countries in which this climate prevails are distinguished from others in the same latitude by the greater range of the thermometer. Their summers are hot and their winters cold. As a protection against the greater heat and brightness of the sun, a less transparent cuticle than that which serves the purpose in humid temperate regions is necessary. To prevent the too rapid withdrawal of the fluid contents of the capillaries by the dry air a thick epidermis is required. The combination of a thick cuticle with a quantity of pigment such as will satisfactorily modify the intensity of the sun's rays will produce various shades of yellow and brown.

A good example of a dry temperate climate is furnished by the prairie regions of North America. The aborigines of this district were brown with the exception of the Mandans, among whom a curious kind of albinism seems to have been astonishingly prevalent.

IV.—By a moist tropical climate, I mean one occurring in or near the torrid zone, in which there is no dry season. In such a climate vegetation will be luxuriant all the year round, and man will live in the shade of dense forests, in a steaming and enervating atmosphere, where the temperature will be high, but will vary little. Though the rays of the sun will descend vertically upon him, yet their power will be diminished by the vapour contained in the air, and he will not need so dense a pigment to protect him as the inhabitants of other tropical regions. Add to this, that a thin epidermis will facilitate the perspiration which a moisture-laden atmosphere tends to check, and we come to the conclusion that the natives of such countries will be distinguished by comparatively fair complexions.

As an example of a moist tropical climate we may take the valley of the Amazons and point to the fact that its aborgines are lighter in colour than those of rainless Peru.

V.—On the contrary in a rainless tropical climate, or in one with a well-marked dry season, the rays of a vertical sun will continually or for considerable periods descend in all their power, and the densest pigment and the thickest scarfskin will be needed. In rainless Nubia, for example, the inhabitants, whether of Semitic, Hamitic, or Negro stock, are alike black.

The part of Africa south of the Great Desert, will exemplify the case of a tropical climate with a dry season. This immense region consists essentially of a strip of low coast land, and an immense level central depressed surface with a more or less elevated rim surrounding it. The inhabitants of the coast and the central depression are very black, those of the rim lighter in color. Dr. Livingstone attributed this to the greater humidity of the lower regions. But it is obvious from theoretical considerations that the elevated rim must be more humid than any other part of the continent. During the dry season, the sea-breezes, when they strike the coast, will be raised in temperature and consequently deposit no moisture until cooled by being forced upward when they come against some elevated land. The meterological observations of travellers show the facts to accord with this view.

There are black men in Africa, in India, and in Australia and some of the adjacent islands, because these countries all have long, pronounced dry seasons. Owing to the peculiar formation of the continent of America, its tropical regions are, for the most part, very humid, and consequently very dark natives are found within them only in Peru, which possesses a very dry climate.

An immense number of facts might be adduced in support of this theory ; but there are some which it fails to explain. Nevertheless, so great is the mass of evidence showing that humidity has been an efficient agent in producing fairness that I must hold to the belief that there is something in the views which I have just attempted to express. Yet, whatever may have been the causes which have given rise to the diversity of complexion that exists among mankind, it is clear that the colour of each race is now so fixed, that climatic influences change it very slowly. Neither the negro nor the white man on this continent has varied much in the direction of the Indian. Both white and negro have, however, been here only a few centuries. A much longer time has elapsed since the populous and frozen North sent her barbarian hordes across Rhene and the Danaw to destroy the Roman empire, but yet, wherever we have historical reasons for expecting to discover traces of German blood, we find a relatively large number of blondes. The land of the conquered countries, as a matter of course, fell into the hands of the German invaders, and from them sprang a new aristocracy. It is remarkable that. to this day, the nobility and gentry of every part of Christian Europe are exceptionally fair. The conquerors naturally settled in the greatest numbers in the most fertile parts; it is precisely in the mountains and the other comparatively infertile districts that the brunette whites are most numerous. In Switzerland, for example, there is a greater percentage of blondes in the more level parts in the centre, than in Mount Jura on the west, or the Rhaetian Alps on the east. Similar facts meet us in England and France. Wherever there is reason to believe that there has been a settlement of Germans or Scandinavians, the complexions are to this day comparatively fair. The nine centuries that have elapsed since the Northmen settled in Normandy have not made their descendants as dark as the neighbouring Bretons; nor have thirteen hundred years made the West Saxon of Somerset and Gloucester similar in complexion to the Welshman of Glamorgan and Caermarthen.

Facts like these have led many ethnologists and anthropologists to conclude, perhaps, too hastily, that colour is the least variable of all the characters that mark a race. This, if true, leads with considerable probability, to the hitherto little noticed, but most important conclusion, that the original seat of the Aryan race was in Europe, and on or near the shores of the Baltic Sea. I propose now to ask your attention while I show how this conclusion follows, and very briefly enquire whether what is known from other sources about the Aryans is consonant with it.

It is well-known that philological investigation has established that nearly all the European, and some of the more important Asiatic languages are descended from a common source, and that these are at the same time related to each other in such an intimate manner and so widely different from all other languages, that scientific men feel justified in setting them apart in a family by themselves. To this family belong the Celtic, Teutonic, Slavonic, and Romance languages, together with the Greek, the Armenian, the Persian, the Hindi, and others. The language whence all these have sprung is the Aryan, and it follows as an almost necessary corollary, that wherever an Aryan language is now spoken, there must be some admixture, however slight, of Aryan blood. There is therefore a community of speech between all Englishmen and all Hindoos, accompanied by a community of blood between some of each race.

With the exception of the Aryans of India, the Aryan races are white, and, as the sacred books of the Hindoos represent their ancestors as an intrusive race in conflict with dark aborigines, it is fair to assume that their present colour is due to an admixture of non-Aryan blood, this postulate of course being always granted that climate has no appreciable effect upon the colour of a race that has once established for itself a separate and distinct type. But as has already been stated, there are two white races, the brunette and the blonde. These are intermingled in various proportions in almost every country in which whites are to be found. We have seen that the blondes are most numerous on the shores of the Baltic and North Seas, and that in whatever direction, whether north, south, east, or west one recedes from these shores, the proportion of brunettes increases. Now, assuming that racial peculiarities are unchanged, except by intermixture, were the original Indo-Europeans a blonde or a brunette race, or one composed like most of the modern Indo-European nations of an intermixture of the two?

The following facts seem to show that the original Indo-Europeans must have been either purely or largely blonde. There are only three Indo-European races, the Hindoos, the Persians, and the Armenians, in which no blondes occur, and these occupy countries too far south to be the original home of the race, since a variety of evidence shows that it must have been situated in a tolerably cold climate.

Among all the others blondes occur in greater or smaller proportions. In western Europe, wherever we have a large proportion of dark whites, we have a good deal of evidence to show that there has been a mixture of the Indo-Europeans with the previous occupants of the soil. In Italy there were, in historic times, Etruscans and Ligurians, one, or both of which races were non-Aryan. In England, France, and Spain the evidence is strong that supports the theory that there is still a large amount of Iberian or Basque blood in the population.

Now, if the original Aryans were blonde it is natural to look for their seat where there is to-day the largest fair-white population, that is, in the neighborhood of the Baltic and North Seas. Here, as a matter of fact, we find the Lithuanians, whose language of all living languages most closely approximates to the original Indo-European. Our Aryan ancestors were pre-eminently a cattle-rearing race, and there is a strong probability that the domestic cattle of Europe are descended from its native wild stocks. As they knew something of the sea, and apparently nothing of the camel or tiger, it does not appear probable that Eastern Turkestan was their original home. Western Turkestan, though bordering on a sea, is precluded by the infertility of its soil, and its utter unsuitability to the kind of life we know the Aryans must have led. It is probably true that the Persians and Hindoos lived together at one time in Eastern Turkestan, but that does not prove that they had not come there from some other place. Indeed, the hypothesis that Turkestan was the original seat of the Aryans, seems to have no better foundation than the belief that the west has been peopled from the east. It may be true that the first men who lived in Europe came from Asia. But that must have been at a period antecedent even to the very remote date at which the Aryan race developed its special characteristics. Within the historical period, at any rate, there have been as many advances of Europeans into Asia as of Asiatics into Europe. At the very beginning of written history we hear of a Persian invasion of European Russia in retaliation for a previous invasion of Persia by Scythians from Russia. After the Persians' failure to establish themselves in Europe, the Greeks established themselves in Asia and hellenized it more or less completely to the head waters of the Ganges. The reaction came when the Huns and Saracens penetrated to France. From the battle of Tours, in which Charles the Hammer turned back the Mohammedans, to the siege of Vienna, two hundred years ago, the contest between the west and east went on with varying results; but since John Sobieski drove the Turks out of Austria the tide has turned. The Turk is on the eve of being driven out of Europe, half of Asia belongs to Russia and England, and European ideas and blood are everywhere changing the character of that continent. As far as history informs us, population has moved as often from the west to the east as from the east to the west.

The first opponent of the Asiatic origin of the Indo-Europeans, as far as I know, was one Schulz, who published a book on the source of the German race in 1826. The next considerable protest came from Omalius d'Halloy, who objected mainly on physiological grounds. He was followed by that eminently original thinker and suggestive writer, R. G. Latham, whose objections were philological. His argument is very clearly put in the following words:

"Where we have two branches of the same division of speech separated from each other, one of which is the larger in area and the more diversified by varieties, and the other smaller and comparatively homogeneous, the presumption is in favour of the latter being derived from the former rather than the former from the latter. To deduce the Indo-Europeans of Europe from the Indo-Europeans of Asia, in ethnology, is like deriving the reptiles of Great Britain from those of Ireland in herpetology."

Since he wrote these words his views have been adopted by a number of Germans, among whom may be mentioned Geiger, Cuno, and Benfey. The two former of these, with perhaps some excess of patriotism, place the cradle of the Indo-European race in the heart of Germany. Oscar Peschel places it in the Caucasus, but this is evidently a compromise. Poesche places it in the Rokitno Swamp in the neighbourhood of Pinsk in West Russia. There is here about the upper waters of the Dnieper an immense swampy region, which is said on the authority of a Russian traveller, Mainow, to be remarkable on account of the general lack of colour in all organic nature. Cases of albinism are very frequent, the horses are almost all gray or light yellow, the leaves of the trees are pale, and everything is dull and colourless.

My conclusions are:—

1. That the causes which in early times developed the existing differences of colour were partly or wholly climatic.

2. That two of these were distance from the equator and moistness of the air.

3. That there were other causes which have not been discovered.

4. That the colour characteristics of existing races change very slowly, if at all, under the influence of new climatic conditions.

5. That the agreement of two races in colour is no proof of community of origin.

6. That the chief, perhaps the only point of origin of the blonde race was in Northern Europe.

7. That the Indo-Europeans were largely blonde, and that their original home was near the Baltic Sea.

After the address, Prof. Ramsay Wright, of University College, exhibited some new microscope objectives, by Gundlach, of Rochester, U. S., and by Zeuss, of Jena.

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## SECOND ORDINARY MEETING.

The Second Ordinary Meeting of the Session 1883-1884, was held on Saturday, November 10th, in the lecture-room, the President in the chair.

The minutes of last meeting were read and confirmed.

The following gentlemen were balloted for, and duly elected members.

Alan Macdougall, C. E., F. R. S. E. ; Messrs. John McAree, Harry Walker, Frederick T. Butler, James Jardine, G. H. Robinson, M.A., J. M. Clark, B.A., A. S. Johnston, B.A., T. G. Campbell, B.A., John Squair, B.A., H. R. Fairclough, B. A., J. Warren Reid, B. A., J. C. Robertson, B. A., Capt. Gamble Geddes, A. D. C.

The following donations and exchanges received since last meeting, were announced :

1. Minutes and Proceedings of the Institute of Civil Engineers, London, Vol. 74 Series 1882-'83, part 4. Brief Subject Index to Minutes and Proceedings of the Institute of Civil Engineers, vols. 59 to 74. Series 1879-80 to 1882-83.
2. Transactions and Proceedings of the New Zealand Institute for 1868, 1872, 1873, 1874. Vols. 1, 5, 6, and 7.
3. The Canadian Entomologist, vol. xx. No. 9 for September, 1883.

A paper entitled "The Literature of English-speaking Canada" was then read by C. Pelham Mulvany, M.A., M.D., T.C.D. Among the writers reviewed were Prof. Watson, Mr. Le Sueur, Mr. Grant Allen, Prof. Dawson, Mr. R. W. Phipps, Dr. Canniff, Principal Grant, Mr. Charles Dent, Mr. J. E. Collins, Mr. George Stewart, Mr. C. G. D. Roberts, "Seranus," "Espérance," and Mr. P. Thompson. In discussing the paper Mr. Geo. Murray noticed the omission of the names of Dr. Rolph, Mr. Charles Lindsay, and especially the late Mr. W. J. Rattray.

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## THIRD ORDINARY MEETING.

The Third Ordinary Meeting of Session 1883-84 was held on Saturday, November 17th, the President in the chair.

The minutes of last meeting were read and confirmed.

Mr. Henry P. Gisborne was elected a member.

The following exchange was announced as received since last meeting :

Proceedings of the Royal Geographical Society, N. S., Vol. V., No. 11, for November, 1883.

Mr. W. A. Douglas, B. A., then read a paper on "LAND AND LABOUR," in which a distinction was drawn between property in land and property in other things. We had adopted the system of land tenure that prevailed in Western Europe, and by this system the greater part of society were practically deprived of any right to the surface of the earth. Of two settlers in the North-West, for example, one secures a section which becomes a farm, the other a section which becomes the site of a town ; after twenty years the farm sells for $30 or $50 an acre, the town site for $10,000 or $100,000 an acre. It is more than likely that the owner of the town-lot had done less toil for his reward than the farmer. There was a great distinction between trade in land and trade in other commodities. A man or a number of men take a piece of worthless rock, they subject it to smelting, rolling, etc., and convert it into a knife or a steam-engine. Here they have added to the utility and have increased wealth. They have furnished a service. Every addition to that utility has been at the cost of muscle and brain. The owner of a piece of land that eventually becomes the site of a town can show no service for his demands. The land of the globe is in fixed quantity, while the populatiou demanding land is not fixed, but on this continent is rapidly increasing. In conclusion Mr. Douglas said: "If I have represented with any approach to truth the effects of our present system of land tenure, then the conclusion must be inevitable that we are acting with wicked recklessness in our new territories in alienating with a haste as though to retain possession would be equal to a plague or a deluge. A second conclusion is that our methods of taxation are radically wrong. Instead of taking revenue from the rewards of idleness, we are now doing everything in our power to diminish the reward of labour, and actually impose taxes as penalties to prevent the extension of that system of exchange by which labour seeks to produce its utmost by resorting to the best suited locations."

An animated discussion then followed, in which Dr. Mulvany, Mr. William Houston, Mr. George Murray, Prof. Ellis and Mr. Creelman took part.

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## FOURTH ORDINARY MEETING.

The Fourth Ordinary Meeting of the Session 1883-84 was held on Saturday, November 24th, the President in the chair.

The minutes of last meeting were read and confirmed.

Mr. J. E. Collins was elected a member.

The following exchanges were announced:

1. Science, vol. 2, No. 41, for November 16, 1883.
2. Monthly Weather Review for October, 1883.
3. Journal of the Anthropological Institute, vol. 13, No. 2, for November, 1883.
4. List of Members of the Anthropological Institute, corrected to November, 1883.

Mr. D. A. O'Sullivan, M A., then read a paper entitled :—

## OUR FEDERAL UNION,

Of which the following are extracts :

I think I shall be within the spirit and letter of the constitution of this Institute in discussing the Federal Union of Canada, in the way I propose to myself in this paper. The science of speculative politics, in which the defects in any constitution may be discovered, and remedies proposed for their removal, is probably undesirable except in purely political societies. At all events it is not the subject here proposed for consideration. * * * I shall draw attention simply to the fundamental law of our Canadian Confederation, and confine myself to our constitutional existence as it is, and not speculate as to what it might have been, and be better than it is. * * *

To say that there has been a Federal Union in Canada—using the words in their strict sense—is in my opinion incorrect. The provinces which form that Union in Canada are not and were not sovereign states – they were not even possessed of reserved powers in legislation—they strictly were not relatively independent colonies of the Empire. The States of the Union, before their admission into the Union, were colonial possessions, and they retain to this day the reserved powers of legislation. Even they are not sovereign states, though it took a war to decide that point. They are, however, much nearer to the possession of sovereign power than the provinces of our Federation. * * *

It will be seen from an historical glance at the United States what took place in this respect. Their *quasi* sovereign states, in the year 1777, bound by a compact which was called a confederation, soon learned how useless was such a compact, which had no executive force, and out of which the members might come and go at liberty. Accordingly a convention of some ten years later met and arranged on the terms of an indissoluble union, from which, having once entered, secession was impossible without resorting to means outside of the proposed terms or constitution. Nine States came in and adopted it, and in a short time every State of the old and obsolete coufederation, every old colony of Great Britain was ranged under one flag and as one nation. * * *

In the British North American Colonies confederation has been talked of since the first year of this century. In 1800, 1814, in 1822, in 1825, in Lord Durham's time, in 1859 and in 1864, there have been projects of union. Of the conventions of this latter year in Quebec and Charlottetown, it will be sufficient to say that three Provinces undertook finally to deal with the question of a federation. These were not pretended to be sovereign in any sense and not at all in the sense in which the present Dominion may be said to be sovereign. These Provinces took all their rights as colonies in their hands and said in effect to the Mother Country, "We resign our present charters; we have agreed to a new state of things; wipe out the past, and ratify the arrangements we propose to make for the future." The old colonies then passed away, and in their place came one new colony of the Empire, with one parliament to make laws for the peace, order and good government of its people. The charter provides for the government of Canada. The new Canada was then divided up into as many Provinces as there were formerly colonies, with the same or probably the same geographical boundaries. The re-casting of the new Provinces of Canada from the aggregated former colonies of the empire is something not to be lost sight of—their *status* has been entirely altered—their powers of legislation are limited and the reserved powers taken from them—their ability to secede from the union out of the question—their rights to be considered sovereign states entirely untenable on any legal ground. The concession of legislative powers to the central government was done in a manner totally different from what was done in the United States, and it would be a confusion of language to speak of the present provinces conceding powers to any government before they possessed any themselves. The interposition of a statute like the Act of Confederation of 1867 between the old colonies and the new provinces may not appear of great moment to persons other than lawyers; but nevertheless it is as material as any document can be which regulates and governs the parties affected. It is like the partnership deed or joint stock charter of a new firm or company—it is to be looked to in the first instance—it is that which gives us such rights and privileges as we now possess; it is the law before all others, except imperial legislation, that must be regarded and obeyed. * * *

With us the Provinces were merged into the new Dominion—gave up their names and their charters, and submitted to be governed by one parliament at Ottawa. They were re-cast, re-created and formed into Provinces of the Dominion—no longer separate colonies of the empire, but constituent elements of the new larger colony. The powers given to the Provinces were enumerated powers—many of their ancient rights were gone or become obsolete, and henceforth they were new creatures, supreme in their own local rights, but having no capacity to increase their own stature by one cubit. * *

The main feature of every Federation is how far its constituent provinces approach to sovereign States. The autonomy of our Canadian provinces is perhaps the lowest in the scale of power that can be exemplified in history. The list of subjects assigned to the Central Government at Ottawa is fully more than double that assigned to the Provinces, and every unenumerated matter goes to swell the central list. And not only that, but the larger list embraces the important matters. When the autonomy of a Province is spoken of, or the home rule of a Province asserted, it must be with large qualifications. The home rule of an obedient wife to her husband is not an inappropriate comparison but like all other comparisons is not to be pursued too far. * * *

For good or for evil, so far as our written constitution goes, the people of Canada have agreed to be governed by one Parliament—to have laws made for the peace, order and good government of Canada—but for convenience sake the Provinces have the exclusive right to legislate on certain defined subjects. The legislation is kept under a species of control in the Courts, which is also exercised over Dominion legislation, and the other the veto power of the Governor General of Canada. The Lieutenant-Governor of each province is an official of the Government of Canada, and is sent to preside over the local Legislatures with certain powers over the legislation and with executive control. The subordination of the Provinces to the Dominion is provided for—at least on paper, and their whole duty is the transacting of the Local government assigned to them. The provinces are independent of each other, but are unable to enter into any engagements other than the constitution provides for them. This is far from being in the position of *quasi* independent states, and indeed inter-provincial dealings are removed much further than before the union of 1867. * * *

So much for the Legislative power. The judicial power is totally different from what obtains in England. In the main—except as to certain powers of the Supreme Court at Washington it is analogous to the judicial power in the United States. A judge in England cannot ignore a statute so long as it is on the books. It binds him—he may evade it or misinterpret it, but before the Constitution he has no power to query it. Such is not the case here or in the United States.

With us, as with them, the Constitution is the basis of legislative authority; it lies at the foundation of all law, and is a rule and commission by which both legislators and judges are to proceed. If the legislatures transgress their constitutional bounds the courts must correct them. But the judiciary has no control over legislature, and no power whatever to question its purpose or animus so long as such legislation is kept within its defined limits. The judiciary is, therefore, not a subordinate but a co-ordinate branch of the government of this country. It may keep the executive even within its authority by refusing to give the sanction of law to whatever it may do beyond it, and by holding the agents and instruments of its unlawful action to strict accountability.

A judge in a Division Court, as well as a judge in the Supreme Court, may be bound to ignore a statute, if not passed by the proper Legislature or Parliament. Every act of any of our legislatures repugnant to the Constitution is absolutely void, and cannot become law of the land. There is a presumption in favour of its validity, however, until the contrary is established.

The executive power in Canada is peculiar and merits a remark. Whilst the legislative powers of the Provinces and the Dominion are sharply defined, and whilst the judicial or administrative powers are little capable of creating a difference of opinion, it is impossible to say that the Act of 1867 is "not conflicting," or at least embarrassing in respect of the executive. In the British Constitution the sovereign is the apex of authority; the King or Queen theoretically summons the Parliament, which makes or is responsible for all the laws in the realm—appoints the judges who administer these laws, and the executive authority is vested in her. The same Queen in Canada is the same power, and summons the Parliament at Ottawa, appoints the judges as a general rule, with one trifling exception, and the executive government and authority of and over Canada is vested in her. This, of course, applies only to the Federal Government, but from other expressions and from one express section in the same Act, several of the Provinces claim that Her Majesty is a necessary element in their Provincial Legislatures; that she is the executive in the Provincial Legislatures. These Provinces are Ontario, Quebec, Manitoba and British Columbia, and they use the same forms *mutatis mutandis* of enacting laws as are used at Ottawa or at Westminister. * * *

It is conceded that the Queen has no immediate power over Provincial Legislation, as the veto on it must come from Ottawa and not from England. When, therefore, Her Majesty passes an Act in the Provinces referred to, Her Majesty's representative at Ottawa may disallow it—a proceeding likely to endanger the well-known doctrine of principal and agent, but from which happily no serious results have yet happened. * * *

I have now called attention to the three great divisions of government—the executive, the judicial and the legislative. In the latter two of these we resemble the Constitution of the United States—in the former and as to the Dominion Parliament generally, we offer an example of a reduced copy of the British Constitution. We labour under the disadvantages of every people living under a written constitution—defined, limited and inflexible—but we have the advantages which a certain amount of definiteness always affords. We have not been an easy people to govern in the past, and it is likely that we will be no better in the future.

The inhabitants of the Dominion scattered from ocean to ocean—men of different countries and languages—different religions and races—are difficult to govern consecutively in the same way for any great length of time. Six changes we have had since Quebec fell, and our ablest men will now tell you that the next few years are going to decide largely the fate of the Dominion.

It may be impossible to keep in union elements that are ill-assorted or antagonistic, but the continued existence of Canada as a Federation will be due to the united good sense of the whole people rather than to the absence of defects of any constitution binding them together."

In the discussion which followed Mr. George Murray, Mr. William Houston, Mr. Alexander Marling, and Mr. William Anderson took part.

## FIFTH ORDINARY MEETING.

The Fifth Ordinary Meeting of Session 1883-84 was held on Saturday, December 1st, 1883, the President in the chair.

The minutes of last meeting were read and confirmed.

The following exchanges were announced :

1. Proceedings of the Royal Colonial Institute, Vol 14, 1882-83.
2. Journal of the Linnean Society of London.
   Botany, Vol. 19, No. 122.
   " Vol. 20, Nos. 123 to 129.
   Zoology, Vol. 16. Nos. 95 and 96.
   " Vol. 17, Nos. 97, 98, 99, 100.
   Proceedings of the Linnean Society from November, 1880, to June, 1882.
   Lists of the Linnean Society for October, 1881, and October, 1882.
3. Science, Vol. 2, No. 42, for November 23, 1883.
4. Catalogue of Canadian Plants, Part 1, Polypetalæ, by John Macoun, M.A.
5. Minutes and Proceedings of the Institution of Civil Engineers, Vol. 57, Session 1878-79.
6. Science Record, Vol. 2, No. 1, Nov. 15, 1883.
7. Mémoires et Compte Rendu des Travaux de la Société des Ingénieurs Civils, September, 1883.
8. Journal of Speculative Philosophy, Vol. 17, No. 3.
9. Report of the Smithsonian Institution for 1881.
10. Schriften der Physikalisch—ökonomischen Gesellschaft, zu Königsberg, for 1882, first and second parts.

Mr. J. Herbert Mason then read a paper on "Transfer of Land." The object of the paper was to call attention to the cumbrous and expensive character of the present method of land transfer, and to urge the adoption of the so-called "Torrens System." The following members took part in the extended discussion which followed : Mr. Geo. E. Shaw, Mr. J. C. Hamilton, Mr. Geo. Murray, Mr. W. A. Douglas, Mr. D. Blain, Mr. J. A. Patterson, Mr. Jas. Bain, jun., and Mr. Oliver Howland.

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## THE SIXTH ORDINARY MEETING.

The Sixth Ordinary Meeting of the Session. 1883-84 was held on Saturday, December 8th, 1883. The First Vice-President, Mr. George Murray in the chair.

The minutes of last meeting were read and confirmed.

Mr. M. McLaughlin was elected a member.

The following exchanges were announced :

1. The American Journal of Science, Vol. 26, No. 156 for December, 1883.
2. Journal of the Franklin Institute for December, 1883.
3. The Canada Practitioner, December, 1883.
4. On the Osteology and Development of Syngnathus Peckianus, (Storer) by J. Playfair McMurrich.
5. Journal of the Royal Dublin Society, Vol. 2, 1858-'59.
6. Sitzungsberichte und Abhandlungen der Naturwissenschaftlichen Gesell schaft "Isis" in Dresden, Januar bis Juni.
7. Science Vol. 2, (No. 43, November 30, 1883.)
8. Constitution and By-Laws of the Chicago Historical Society, 1882-83.
9. Second Annual Report of the United States Geological Survey for 1880-'81.
10. Twelfth Annual Report of the U. S. Geological and Geographical Survey of New Territories; a Report of the Progress in the Exploration of Wyoming and Idaho for 1878 by F. C. Hayden ; U. S. Geologist, Parts 1 and 2.
11. Maps and Panoramas to the above.
12. United States Geological Survey, Monograph 2 ; Territory History of the Grand Cañon District by Clarence C. Dutton.
13. Atlas to accompany the same.
14. Bulletin of the U. S. Geological Survey, No. 1.
15. Magazine of American History of December, 1883.
16. The Scientific Transactions of the Royal Dublin Society, Vol. 1, (Series 2), Parts 15, 16, 17, 18, 19 for January, February, August and November, 1882.
17. Scientific Proceedings of the Royal Dublin Society, Vol. 3, (N. S.), August, 1882, Part 5.
18. Verhandelingen der K. Akademie Van Wetenschappen, Twee en Twintigste Deel.
19. Verslagen en Mededeelingen der K. Akademie Van Wetenschappen, Afdeeling Natuurkunde, Tweede Reeks, 17th Deel, Parts 1, 2, 3.
20. Jaarboek Van de K. Akademie Van Wetenschappen, Amsterdam, 1881.
21. Memoirs of the Geological Survey of India, (Palæontologia Indica), Series 10, Vol. 2, Part 5.
22. Jahrbuch der K. K. Geologischen Reichsanstalt, 1883, Band 33, Numbers 1, 2, 3, January to September, 1883.
23. Oversigt over det Kongelige Danske Videnskabernes Selskabs, Forhandling og dets Medlemmers Arbejder i Aaret, 1882, No. 3, 1882, and No. 1, 1883, Kjobenhavn.
24. Mémoirés de la Société Royale des Antiquaires du Nord, Nouvelle Série, 1882-83, 1884 Copenhague.
25. 22 und 23 Berichte uber die Thätigkeit des Offenbacher Vereins für Naturkunde vom 29 April, 1880, bis 4 Mai, 1882, Offenbach a. M., 1883.
26. Tillaeg til Aarboger for Nordisk Oldkyndighed og Historie, 1881, Kjobenhavn, 1882.
27. Papers, Proceedings, and Report of the Royal Society of Tasmania, 1881.
28. Verhandlungen der K. K. Zoologisch-Botanischen Gesellschaft in Wien, 32 Band, 1882.
29. Offenes Schreiben auf Herrn Baron Osten Sacken's "Critical Review" Meiner Arbeit über die Notacanthen, Von Prof. Dr. Friedrich Brauer.

30. Sitzungsberichte der K. böhmischen Gesellschaft der Wissenschaften in Prag, 1881.
31. Jahresbericht der K. böhmischen Gesellschaft der Wissenschaften in Prag, 17 Juni, 1881, do. 10 Juni, 1882.
32. Anales del Museo Nacional de México, Tomo 3, Entrega 3, México, 1883.
33. Journal of the Royal Geological Society of Ireland, Vol. 16, Part 2, 1881-82.
34. Proceedings of the Cambridge Philosophical Society, Vol. 4, Parts 2, 3, 4, 5, 1881-82.
35. Transactions of the Cambridge Philosophical Society, Vol. 13, Part 2, 1882.
36. Abhandlungen herausgegeben von naturwissenschaftlichen Verein zu Bremen, 8 Band, 1 Heft, Bremen, 1883.
37. Mittheilungen der K. K. Geographischen Gesellschaft in Wien, 1882, 25 Band.
38. Sitzungsberichte der Naturwissenschaftlichen Gesellschaft, "Isis" in Dresden.

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| Jahrgang, | 1868, | Nos. 1, 2, 3, 7, 8, 9, 10, 11, 12, | 3 Nos. |
| " | 1869, | " 1—12, | 4 Nos. |
| " | 1870, | " 4—12, | 3 " |
| " | 1871, | " 1—12, | 4 " |
| " | 1872, | " 1—12, | 4 " |
| " | 1873, | " 1—12, | 2 " |
| " | 1874, | " 1—12, | 3 " |
| " | 1875, | " 1—12, | 2 " |
| " | 1876, | " 1—12, | 2 " |
| " | 1877, | " 1—12, | 3 " |
| " | 1878, | " 1—12, | 2 " |

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Mr. J. M. Clark, B. A., then read a paper entitled :—

## SOME THOUGHTS ON THERMOTICS.

In the following paper it is proposed to consider in a few of their many aspects, the nature of heat, the laws of its propagation, its causes and its effects, noticing its correlation to the other forms of energy, and some more or less important applications of what we shall give some reasons for considering the true theory of heat to some of the problems of Chemistry, Geology and Meteorology. Heat being that in material bodies, which causes in us the sensation by virtue of which we call bodies hot or cold, hotter or colder, it is important at the outset to understand what that something in the physical world is. Prof. Tait, the eminent Natural Philosopher, in his valuable historical sketch of the Theories of Heat, says, that in the physical world, besides the inevitable Time and Space, there are but four elementary ideas, namely :—Matter, Force, Position and Motion. This statement seems open to very serious objection. Though time may from one point of view be regarded as one of the conceptual elements of motion, and as such has been justly denominated the "great independent variable," yet to the physicist it cannot be regarded as by any means an elementary idea. This will be apparent if we remember the conventional measure of time universally employed. That measure shows that time is recognised, not as a primordial idea, but as a very complex conception involving motion, position and space.

Further, it seems utterly inconsistent with what is now known of the nature of force, to regard it as an elementary idea. If matter be really inert, the only rational use of the word force is to denote certain mechanical facts of motion. We may therefore for our present purposes regard space, matter, position and motion as the only elementary ideas in the physical world.

Heat consequently must be referred to these ideas or to combinations of them.

The experiments of Davy and Rumford demonstrated that heat cannot be matter, since they were able to extract an unlimited amount of heat from a limited quantity of matter, thus proving that the production of heat did not involve the consumption of matter. These experiments, together with an innumerable number of others of similar nature, show that the essential idea of heat lies in motion. But since to have motion matter must move, it is more correct to define Heat as a form of Energy than of Motion. From the fact that there is a mechanical equivalent of heat, it follows that the quantity of heat is proportional not to the quantity of motion, but to the quantity of energy. Thus Tyndall's brilliant work "Heat as a Mode of Motion," would have been more correctly and appropriately entitled, "Heat as a Form of Energy." Besides being more correct, this designation would have the important advantage of suggesting the remarkable connection of heat with light, magnetism, electricity, &c., by virtue of the Conservation of Energy, a principle, the discovery of which is perhaps the grandest reward of the scientific research of modern times.

Having then established that heat is a form of energy, it becomes necessary to consider the question—Are there two essentially different kinds of energy, kinetic and potential? If potential energy be defined (as it generally is) to be the energy of position, its existence is utterly inconsistent with the proposition that matter is inert, a proposition the truth of which lies at the foundation of Modern Physics.

Newton in one of his celebrated letters to Bentley, has justly said, "That one body may act upon another at a distance, through a vacuum without the mediation of anything else by and through which their action may be conveyed from one to another, is so great an absurdity, that no man, who has in philosophical matters, a competent faculty of thinking, can ever fall into it." From this it inevitably follows, that no body, or system of bodies can possess energy merely by virtue of its position, in other words by virtue of the distances of its parts from all other bodies. In this sense, therefore, potential energy involves a contradiction in terms.

But if we regard potential energy as a convenient name for those kinds of energy whose nature is not yet understood, the term is convenient and admissible, though liable to create considerable confusion. There are not therefore two distinct kinds of energy—energy of motion, and energy of position. The distinction can, in the nature of things, have no possible fundamental difference for its basis. But energy may be conveniently divided into two classes, namely, energy whose nature we in some measure understand—called kinetic—and energy—known on the other hand as potential—of whose nature we know comparatively little, but which we regard as dependent on position, not that this dependence is an ultimate physical fact, but because it is a secondary or conventional mark, which, in the absence of more definite knowledge, it is convenient to adopt.

Heat then, being beyond doubt, a form of energy. it is important to determine in what forms of matter the heat energy resides, whether for instance, in heated bodies, the vibrations, by virtue of which the bodies are said to be hot are vibrations of the atoms or of the molecules.

Notwithstanding the high authority of Tyndall to the contrary, there is good reason to suppose that heat properly so called. consists exclusively in molecular motion. To make out the probability of this apparently bold assertion, it is necessary to investigate the real nature of what is most erroneously called radiant heat, but which possesses no more of the characteristic qualities of heat than the motion of a hammer about to strike an anvil. Tyndall himself has conclusively proved, not only that radiant heat is not matter as is confusingly suggested by the origin of the phrase, but what is more to the point, that it is nothing more or nothing less than a wave motion of the luminiferous ether, which prevades not only all interstellar, but also intermolecular and interatomic space.

By the way, we may notice that the term luminiferous ether which is derived from its connection with the theory of light, and which does not at all suggest the varied functions which this mysterious medium is now supposed to fulfil is fast losing its appropriateness. In view of the recent advances in Molecular Science, energipherous would seem a much fitter term.

Though this name is suggested by the nature of radiant heat the coining of a new word is further justified by the views as to the nature of electricity, magnetism, &c., advanced by Maxwell, and now held by the leading investigators in that important field of knowledge.

Further, analysing light by the spectroscope, and remembering that on the undulatory theory of light, which is one of the most completely verified hypotheses of modern science, refrangibility is proportional to the wave-length, we can be certain that in any given section of the spectral band, whether in the doubtfully so-called thermal, luminous or actinic portions, we have vibrations of a determinate wave-length.

Now it is found by means of the thermopile that the luminous portion of the spectral hand has a heating effect, proving that luminous rays are also thermal rays, or that the identical rays, which falling on the optic nerve would excite the sensation of light, when allowed to strike the face of the thermopile produce the effects of heat.

This important identity is rendered probable by the fact that certain substances absorb light, the only explanation of the disappearance being that the substances are more or less heated. Leslie has shown experimentally that this heating does in fact take place.

Combining this conclusion with the property known as the transmutation of rays, a property discovered by Stokes, who succeeded in so diminishing the wave-lengths of the ultra-violet rays of the spectrum (by the interposition of thin plates of certain substances) as to render them visible, it follows that the fact of heat-producing chemical decomposition which can only be effected by an acceleration in the motions of the constituent atoms of the molecules, or in other words by interatomic forces, does not at all prove that heat consists in atomic as distinguished from molecular vibrations.

Even should Lockyer's hypothesis that in the enormously heated atmosphere of the sun the supposed elementary bodies are dissociated, and their existence, as such, rendered impossible be proved, the same reasoning goes to show that the necessity of supposing the seat of the heat vibrations to lie in the elementary constituents of the molecules would not follow.

Tyndall in one of his contributions to Molecular Physics argues that since the power of absorption of a vapor depends on that of the liquid from which it has been obtained, or since the state of aggregation does not alter the relative power of absorption of bodies, the seat of absorption must lie in the atoms—not in the molecules—the relative positions of the molecules being altered, and consequently the conditions of molecular motion. To this it may be replied that the change in the intermolecular relations involved in a change in the state of aggregation of a body does not necessitate any alteration in the periods of the molecular vibrations but may merely lengthen or shorten their amplitudes.

On the other hand were the atoms the seat of the heat vibrations, such undoubted facts as that water has such profoundly different physical properties from both hydrogen and oxygen, that ozone has many times the absorbing power of oxygen, and that ammonia has about 5000 times the absorbing power of either of its constituents, hydrogen or nitrogen, would be utterly incapable of explanation. On the whole these considerations, combined with the general law that heat for the most part produces physical and not chemical effects, though molecular motion may undoubtedly be transformed into atomic motion subject to the law of the conservation of energy, seem to point irresistibly to the conclusion that heat is not only a form of energy but more particularly that it consists in molecular motions. The relation of heat to light is shown clearly by the analysis of light by means of a prism, and lies in the fact that all the undulations of the energipherous medium, if transformed into the molecular motion of bodies, or if allowed to excite the tactile nerves manifest themselves in the form of heat, while only a limited portion when allowed to strike the eye excites the optic nerve and produces the sensation of sight. In a manner which we now propose briefly to describe similar, more or less intimate, connexions have been established between heat and the other forces of nature, so that heat, light, electricity, magnetism, sound, chemical affinity, potential and mechanical energy are now generally regarded as but different forms of an unchangeable amount of indestructible energy.

There can be now no doubt that the theoretical foundation for the modern doctrine of the conservation of energy, of which the equivalence of heat and work is a particular case, was distinctly and substantially laid by the genius of Newton in his wonderful scholium to his Third Law of Motion.

In this scholium and in the commentary on it Newton not only enunciates the law of conservation of energy, so far as the state of experimental science in his day would permit, but also clearly anticipated the so-called modern principle of Vis Viva and D'Alemhert's principle. No further advance of any moment seems to have been made till about 100 years later Davy and Rumford proved experimentallv the immateriality of heat. To Rumford is mainly due the credit of having rescued the question of the nature of heat from the domain of metaphysics, and of having devised several ingenious experiments, by means of which he arrived at a remarkably approximate value of the mechanical equivalent of heat. The next important names in connection with the history of the theory of heat are those of Fourier and Carnot. The calculations and conclusions of these profound mathematicians were expressed, it is true, in terms which to a certain extent involved the now exploded corpuscular theories of light and heat, but their reasoning and results were to such an extent independent of any particular theory that the elements involving the truth of these untenable hypotheses are capable of being almost entirely eliminated, leaving results which have proved of the greatest use in the development of the true theory of energy. Perhaps the most important of the many valuable contributions of Clausius to the theory of heat was his adaptation of the theorem of Carnot, so as to make it consistent with the principle of the equivalence of heat and work.

To Joule, the great English physicist, is undoubtedly due, as has been conclusively shown by Prof. Tait, the credit of having placed the grand law of the conservation of energy, of which the first main principle of the mechanical theory of heat is but a particular case, on a sure experimental foundation. By means of some of the most ingenious and refined experiments of modern times, Joule determined that 772 foot-pounds of work, if converted into heat, would raise 1 pound of water 1° F., or that to produce a quantity of heat sufficient to raise 1 kilogramme of water through 1° C. work must be consumed to the extent of 424 kilogrammetres, and thus placed the truth of the dynamical theory of heat beyond all manner of doubt. His results have been extended by Helmholtz, Mayer, Clausius, and Thomson, till the law of conservation has been shown to govern all natural forces.

Thomson demonstrated that Faraday's discovery of the rotation of the plane of polarization of a polarized ray of light, produced by media under the influence of a powerful magnet, involved the dependence of magnetism on motion.

The extension of the principles of the conservation and transformation of energy to physiological phenomena has been largely due to Helmholz and Carpenter.

There can be no doubt that Maxwell's electro-magnetic theory of light is destined to play no unimportant part in the development of the true theory of energy. From data supplied by Weber Maxwell, found that electro-magnetic disturbances were propagated with the same velocity as light. The explanation of this he held to be that electricity like light was due to the undulatory vibrations of the medium, which is beyond question necessary for the propagation of light. Should this hypothesis be found to be a valid one, a very clear insight will be obtained into the real connexion between electricity, light, and radiant heat.

From what has preceded, it will be seen that the mysterious, all-pervading ether plays an increasingly important part in the prevailing physical theories. To such an extent is this the case that Tyndall has justly remarked that its relations to the matter of the universe must mainly occupy the investigations of future scientists. In order to form a more definite idea of the properties of this highly attenuated substance, which is yet so elastic and incompressible, that Stallo has characterised it as an adamantine solid, it is now proposed to attempt a calculation of its probable density. To accomplish this object, it is necessary to know the amount of radiant energy emitted by the sun. This determined by careful observations with the pyrheliometer, and expressed by means of Joule's mechanical equivalent of heat, amounts to 5,500,000 foot-pounds per second from every square foot of the sun's surface.

Now, the velocity of light is 186,000 miles per second. Therefore the radiant energy sent forth by the sun during any given second of time will at the end of that second be contained between two spheres, the smaller 433,000 miles, or the semi-diameter of the sun for radius, and the larger 619,000, or 433,000 + 186,000 miles. The volume of this space is—

$$\frac{4\pi}{3}(5280)^3(10)^9\left\{(619)^3 - (433)^3\right\}\text{cub. ft.}$$

Also, the surface of the sun is $4\pi(433)^2(10)^6(5280)^2$ sq. ft. Therefore 1 cubic foot of ether is agitated by—

$$\frac{4\pi(433)^2(10)^6(5280)^2 \times 5500000}{\frac{4\pi}{3}(5280)^3(10)^9\left\{(619)^3 - (433)^3\right\}}$$

$$= \frac{5500000}{5280 \times 279000} \text{ foot-pounds of energy.}$$

Let $m$ represent the mass of each ether-particle, or the average mass if the ether-particles are not uniform, and $n$ the number of such particles in a cubic foot, so that $nm = M$ will be the number of pounds of ether in a cubic foot.

Using the ordinary equation of the harmonic curve—

$$y = a\sin\left(\frac{2\pi x}{\lambda} + a\right)$$

it will be seen by differentiating twice that the maximum velocity of any particle owing to any single wave is $\frac{2\pi a}{\lambda}V$, where $a$ is the amplitude, $\lambda$ the wave length and V the velocity of propagation. Hence the energy of a particle whose mass is $m$, under such circumstances is—

$$\frac{m}{g}\,\frac{2\pi^2 a^2}{\lambda^2}V^2 \text{ foot-pounds.}$$

Therefore the energy of a cubic foot of ether is—

$$\Sigma\frac{m}{g}\,\frac{2\pi^2 a^2 V^2}{\lambda^2} = \frac{M}{g}\,\frac{2\pi^2 a^2 V^2}{\lambda^2}$$

Equating these two expressions for the same quantity of energy we get as the mass of a cubic of ether

$$M = \frac{g\lambda^2}{2\pi^2 a^2}\,\frac{5500000}{(186000)^2(279000)(5{,}280)^3}\text{ lbs.}$$

It will be seen that the only assumption involved in this calculation is that the average velocity of the ether particles may be taken to be equal to the maximum velocity in consequence of a single wave motion.

In order to arrive at a numerical result we have to find the value of $\frac{\lambda}{a}$, and of these two quantities only one $\lambda$ has been experimentally determined.

However, remembering that on the undulatory theory of light $a$ diminishes with the distance from the centre of radiation we are certainly safe in supposing that even in the region of space we are considering $a$ cannot possibly be greater than $200\lambda$.

It is scarcely possible that the velocity of the ether-particles can exceed 233,626,000 miles per 1″, the stupendous rate necessitated by this supposition. Substituting for $\frac{\lambda}{a}$ $\frac{1}{200}$ and multiplying the result by $(5280)^3$ we conclude that the mass of a cubic mile of ether is not less than $\frac{1}{4}\left(\frac{1}{10}\right)^{13}$ of a pound. Now a cubic mile of air (at 0° 760mm) contains $(10)^{10}$ lbs. Therefore air is not more than $4(10)^{23}$ times denser than the ether.

Using this value for the density, a sphere whose radius is the same as that of Neptune's orbit, or 276,000,000 would contain $2(10)^{12}$ lbs. of ether or a sphere whose radius is 95,000,000 miles, the distance of the earth from the sun, would contain 4,400,000 tons.

If we suppose, as reasoning from acoustical analogies there is considerable reason for doing, that $a$ instead of being 200 times greater than $\lambda$ is 5 times less, a cubic mile of ether would contain $\frac{1}{4}\left(\frac{1}{10}\right)^7$ lbs., or a sphere of the same dimensions as the earth would contain about 6,500 lbs.

After having made the above calculations, and in the course of a vain search for further data as to the value of $\frac{\lambda}{a}$ we found that some years ago Sir W. Thomson had attempted a similar undertaking, and by means of a somewhat different method of investigation, had arrived at the conclusion that the probable density of the ether was 25 times less than that given above.

Considering the uncertainty of the assumption as to the ratio between the amplitude and wave-length of the ethereal vibrations, the coincidence is satisfactorily close.

Although, as has been pointed out, the quantity of energy in the universe is invariable and can neither be increased or diminished, yet by virtue of laws of which we have a particular case in Clausius' "Second Main Principle of the Mechanical Theory of Heat," the amount of what may be termed available energy is being constantly exhausted.

The truth of this, together with many very important consequences which follow from it, was first pointed out by Sir W. Thomson in a remarkably able paper on a "Universal Tendency in Nature to the Dissipation of Mechanical Energy." It is simply another method of saying that no known natural processes are perfectly reversible.

A few moments reflection will suffice to show that the main sources of energy available for man are (1) Food; (2) Fuel; (3) Water Power; (4) Wind. Of these food and fuel are of the same nature, food being utilized by means of animal machines, such as men, horses, &c., while fuel is converted into mechanical motion by means of engines of various kinds. The mechanical energy which is thus produced by means of food and fuel is evidently, for the most part, derived from the heat and light radiated from the sun. Water power and wind even more obviously obtain their energy from the same source. Solar radiation is therefore the grand source whence nearly all the energy available for man is derived.

Various theories have been advanced to account for the enormous amount of energy in the form of heat and light annually sent forth by the sun, and of which the earth intercepts a very small portion. It was, for instance, supposed by some that the sun's heat was produced by the combustion of its materials. A very few facts will show that this hypothesis is utterly untenable. The mass of the sun, estimated from the most reliable determinations of the solar parallax, has been found to be about $4(10)^{30}$ lbs. The consumption of a pound of coal is known to produce an amount of heat equivalent to 9,200,000 foot-pounds.

Combining these, we see that if the materials of the sun were supposed to be capable of producing by their combustion as much heat as equal masses of coal, an assumption eminently favorable to the hypothesis in question, the total mass of the sun would be consumed in producing a quantity of heat whose mechanical equivalent is $368(10)^{35}$ foot-pounds. In estimating the probable density of the ether, it was found that the quantity of energy radiated from the sun was $4\pi(433)^2 (10)^6 (5280)^2$ 5,500,000 foot-pounds per second, or $(10)^{34}$ foot-pounds per annum. It therefore follows that if the theory of the origin of solar heat under examination were the true one, the energy of the sun would be completely exhausted in 3,680 years, while we know that the quantity of heat radiated from the sun has been practically as great as at present for millions of years. The theory of combustion or chemical combination, therefore, falls to the ground, and it is now generally supposed that the perennial fountain whence flow the vast energies of the solar system, is the potential energy of gravitation which is converted into kinetic energy by its mass moving towards the centre of inertia of the solar system, and thence into heat by a mechanism indicated by the physical constitution of the fiery ruler of the day.

The following investigation will show that this now generally accepted hypothesis predicates a cause known to be a *vera causa* amply capable of producing the results it is supposed to explain, and that therefore it is not inconsistent with the axiom that the cause must be equal to the effect.

Let $\rho$ represent the density at distance $r$ from the centre of a spherical mass, supposed equally dense at equal distances from the centre. The elemental mass, therefore, between the spherical surfaces whose radii are $r$ and $r + dr$, is $\rho\, 4\pi r\, dr.$

Taking proper units of force, &c, and remembering the theorem that the attraction of a spherical shell on an internal particle vanishes, it follows that the force acting on this elemental mass is measured by the quantity—

$$\frac{4\pi\rho r\, dr \int_0^r 4\pi\rho r^2\, dr.}{r^2}$$

assuming of course the Newtonian law of gravitation. The work done by this elemental mass moving through an infinitesimal $dc$, will consequently be—

$$\frac{4\pi\rho r\, dr \int_0^r 4\pi\rho r\, dr\, dc.}{r^2}$$

Integrating with respect to $dr$ we get as the total work done—

$$\int \left\{ 4\pi\rho\, dr. \int_0^r 4\pi\rho r^2\, dr. \right\} dr.$$

a formula which will be found to be of considerable use in solving certain important classes of problems.

Supposing $\rho$ to be constantly uniform if the radius of the sphere be originally $a$ and become $a - da$, $dc$ will evidently be $\frac{r}{a}\, da$, and the total amount of work done on account of the contraction, will consequently be $\frac{3}{5} M^2 \frac{da}{a^2}$, where $M = \frac{4\pi}{3} \rho\, a^3$, the mass of the sphere.

Integrating this expression between the limits $a$ and $b$ we get as the amount of work done by a spherical mass M of radius $a$ (supposed uniform) contracting to a uniform sphere of radius $b$, $\frac{3}{5} M^2 \left(\frac{1}{b} - \frac{1}{a}\right)$.

Applying these formulæ to the case of the sun whose radius is 433,200 miles and whose mass is $4\,(10)^{30}$ lbs., the amount of work done, or in other words, the quantity of heat generated, by a contraction of 1 foot in the radius of the sun (supposed uniform) will be found to be represented by—

$$\frac{3}{5}\,\frac{16\,(10)^{60}}{(433200)^2\,(5280)^2}$$

The unit of force used here obviously is the attraction of unit mass on unit mass at unit distance; so that the attraction of the earth on unit mass at its surface would be represented by—

$$\frac{4}{33}\,(10)^{26}\,\frac{1}{(400)^2\,(5280)^2}$$

multiplied by the mass of the earth $= \frac{4}{33}\,(10)^{60}$ of these units.

Now this force will cause 1 lb. to move through $\frac{g}{2} = 16{\cdot}1$ ft. per second.

Therefore a contraction of 1 foot in the sun's radius will generate a quantity of heat equivalent to—

$$\frac{3}{5}\,\frac{16\,(10)^{60} \times 33 \times (4000)^2 \times (5280)^2 \times 16{\cdot}1}{(433200)^2 \times 4 \times (10)^{26}}$$

$= (10)^{33}$ foot-pounds.

If account were taken of the fact that the sun must become denser as its centre is approached, this quantity would be considerably larger.

Accordingly a yearly contraction of 10 feet in the sun's radius would be amply sufficient to sustain its heat at the present rate of radiation.

A decrease in the diameter of the sun of less than 20 miles would keep up the supply for over 5000 years. The most refined instruments would not be sufficiently precise to detect so small a variation.

If on the same hypothesis, the sun's radius were to become one-half what it now is, or the density of the sun eight times its present value, which would make its density about the same as that of lead, instead of—

$$\frac{3}{5} M^2 \frac{1}{(433200)^2 (5280)^2}$$

for a contraction of 1 foot, we should have

$$\frac{3}{5} M^2 \left( \frac{1}{\frac{1}{2} (433200) (5280)} - \frac{1}{(433200)\ 5280} \right)$$

*i.e.*, about $433200 \times 5280$ times as much heat would be generated.

This would be sufficient to sustain the present rate of radiation for 22,000,000 years. Similarly if the mass of the sun were equally diffused throughout a sphere having a radius of 276,000,000 miles, which is the distance of Neptune from the sun, and were to contract till it became uniformly as dense as lead, heat enough would be produced to meet the present demand for 44,000,000 years. Further, if the solar mass had the same specific heat as water, and were raised to a temperature of 28,000°, it would contain a store of heat 2,000,000 times as great as the present yearly expenditure.

These figures, curious and instructive in themselves, derive considerable importance from their bearing on the problems of geological time, when taken in connection with the vast æons considered necessary by most geologists for the formation of the different strata of rocks, and with the still vaster ages claimed by biologists for the evolution of the existing and extinct forms of animal life.

The palæontological evidence for the high development and wide dispersal of organisms, at least in later palæozoic times, is complete; and to the existence of a flora and a fauna, such as that indicated even in the Cambrian formations, a mild climate is absolutely essential. Now though climate is profoundly affected by the presence of mountains and large bodies of water, and even more by winds and ocean currents, and by the quantities of the variable elements in the atmosphere, yet to maintain a mild climate the heat-giving power of the sun must have been materially as great as at present.

The heat generated by the sun in assuming its present density and conformation can not be supposed to be greater than that produced by contraction from the limits of the solar system to a homogeneous sphere of one-half its present radius.

This would make 44,000,000 years, the limiting age which can be assigned to the Cambrian formations.

We shall conclude by applying the principle that the absorptive power of a vapour is determined by that of the liquid from which it is derived, to explain the empirical law (enunciated by Mr. McGee) that any increase in annual or diurnal range is accompanied by a diminution of mean temperature. The aqueous vapour of the atmosphere, being derived from water, which has a comparatively high absorptive power, must also possess considerable power of absorption, and Tyndall has conclusively shown experimentally that such is the case. Also, the power of radiation is strictly proportional to the power of absorption, as is known both from theory and experiment, so that the aqueous vapour of the atmosphere is both a good absorbent and radiant.

Now, when the temperature is raised, not only will the aqueous vapour of the atmosphere be heated, but a larger amount of it will be formed, and as gases expand when heated, this vapour will tend to rise to the higher regions of the atmosphere, and radiate its heat into space. On the other hand, in a comparatively cold season the relatively cooled vapour tends to descend, the heated vapour from the surface of the earth ascends, and imparts its heat to cold space.

Also the amount of heat received from the sun may for our present purpose be considered as invariable from year to year, so that the two actions above mentioned show that the radiant absorbent and expansive powers of aqueous vapour combine to lessen the relative amount of heat retained by the earth, during both exceptionally high and exceptionally low temperatures, *i. e.*, during a period of large thermometric range, and consequently to diminish the mean temperature.

There may be and probably are other con-causes of this effect, but the one we have assigned is certainly a real and efficient factor in producing the apparently anomalous result in question.

In the discussion which followed the reading of Mr. Clark's paper, Mr. Geo. E. Shaw, Mr. J. G. Mowat, Dr. Jos. Workman, and Mr. J. M. Buchan took part.

## SEVENTH ORDINARY MEETING.

The Seventh Ordinary Meeting of 1883-84 was held on Saturday, December 15th, the President in the chair.

The minutes of last meeting were read and confirmed.

The following gentlemen were admitted members:

Mr. R. W. Phipps, Mr. William Leslie Beale, Mr. Arthur J. Graham, John J. Cassidy, M. D.

List of donations and exchanges received since last meeting:—

1. Journal of the Franklin Institute for October, 1883.
2. Tillaeg til Aarboger for Norske.
3. Oldkyndighed og Historiae, Aargang, 1879.
   " " " 1880.
   Kjobenhavn, 1880-81.
4. Mémoires de la Société des Antiquaires du Nord, Nouvelle Série, 1881.
5. Bulletin of the Museum of Comparative Zoology at Harvard College, Vol. 11, Nos. 3 and 4.
6. Science, Vol. 2, No. 44, December 7th, 1883.
7. Appleton's Literary Bulletin, December, 1883.
8. Transactions of the Manitoba Historical and Scientific Society, Nos. 5 and 6.
   " " " " Nos. 1 and 2, 1883-4.
9. Proceedings of the Asiatic Society of Bengal, Nos. 1 to 8, January to September, 1883.
10. Journal of the Asiatic Society of Bengal, Vol. 52, Part 2, No. 1, 1883.
11. Scientific Proceedings of the Ohio Mechanics' Institute, Vol. 2, No. 3, September, 1883.
12. Waifs in Verse, by G. W. Wicksteed, Q. C., Law Clerk House of Commons of Canada, presented by the author.
13. Transactions of the Manchester Geological Society, Vol 17, Part 10, Sessions 1883-84.

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Mr. T. B. Browning, M. A., then read a paper entitled, "England's Oldest Colony."

Mr. Browning opened his paper by commenting upon the indifference with which the Provinces of British North America treat each other, and proceeded to discuss the rights which the French have in that part of Newfoundland called the French Shore under the treaties of Utrecht, Paris, and subsequent arrangements. He also alluded to the Banks fishery, and stated that the French employ about 700 ships in this and the shore fishery, about 28,000 seamen, and make an annual catch of a million quintals of codfish. The rights of the French seemed to him to be greatly detrimental to the interests of Newfoundland, made the richest part of the island practically a sealed book, and were a continual source of trouble to both England and France. He further referred to the rights which the Americans exercise under the Treaty of Washington, and showed that stringent regulations were become needful, in the interest of all, to prevent wanton destruction and depletion of the Newfoundland fisheries, upon which so great a part of the world depended for a great part of their food supply.

He next described the geographical position and geological formation of the island, its copper, coal, iron deposits, and made particular reference to currents along shore, which he stated to be the cause of the many shipwrecks which happen near Cape Race and St. Shotts. Having called attention to the city and harbour of St. Johns, the capital of the island and its principal attractions, he proceeded to discuss the foreign trade of Newfoundland, which, he said, is being drawn to the chief town more and more year by year, and which he placed at $16,000,000 annually. The land question next came under review in two branches; first, as regards the waterside premises of St. Johns which are built on leased lands, the leases of which expire in a year or two, and concerning which legislative action is contemplated in the coming session. Newfoundland has developed with her landlords a crisis similar to that with which Ontario had to deal in her clergy reserves, Quebec in her seignorial tenures, Prince Edward's Island in her proprietory rights.

Touching upon the larger question of land tenure Mr. Browning referred to the decrees of the Star Chamber 1630, to statute 10 and 11 Wm. III., and 15 Geo. III., ch. 31, as establishing communism in land. No man could own any acre of the soil, no reserves were given to the Protestant or any other church, and no power was granted to the governors to pass a title to land. This communism continued until 1820, and made the country a fishing preserve for the west country merchants. It enriched England and developed her maritime power, but impoverished the soil of Newfoundland. A geographical survey of the country into counties, townships, sections and lots is still to be made, and is needed for agricultural and lumbering purposes.

He then referred to certain manners and customs of the people, particularly to the gambols of Christmas-tide, which, long since dead in England, flourished in Newfoundland until about twenty years ago. He gave statistics showing the progress of total abstinence, and described the chief agencies in the movement as well as the lineage and religion of the inhabitants of the island. It seems that the first colony permanently settled in Newfoundland was that of John Guy, who acted as manager for a company in which Lord Bacon was a shareholder. Colonies were also formed by Lord Baltimore in 1623, and several by the French and Portuguese.

The main industries were described as the summer and spring fisheries; the first of cod, salmon and herring, the second of seals. The fish caught was valued at from ten to twelve million dollars, the number of seals reckoned at a yearly average of 600,000. The condition of the fishermen, which had been almost hopeless from the crushing weight upon them of the supply system, was improving. Education was doing something for them, facilities of communication more. Their great need was a home market, at least a market nearer than Brazil, Spain or Italy. Formerly Newfoundland's surplus wealth was drawn to the West of England, the shores of the Mersey and Clyde, but is now adorning her own capital and spreading a spirit of enterprise among her people. They look to Canada and the West rather than to Britain and the East. The question of Confederation, he said, is with Newfoundland one of terms, and may be expected to be answered in the affirmative in the near future.

In the discussion which followed Mr. J. M. Buchan, Mr. Fred. Phillips, Mr. James Bain, jun., Mr. Geo. E. Shaw, Mr. John Notman, and Mr. B. B. Hughes took part.

## EIGHTH ORDINARY MEETING.

The Eighth Ordinary Meeting of the Session 1883-'84 was held on Saturday, December 22nd, 1883, the President in the chair.

The minutes of last meeting were read and confirmed.

The following gentlemen were elected members of the Institute :—

H. H. Langton, B.A., Charles Miles, C.E., S. George Curry, Architect.

The following exchanges were announced :

1. Annual Report of the Museum of Comparative Zoology at Harvard College for 1882-'83.
2. Science, Vol. 2, No. 45, December 14, 1883.
3. Monthly Weather Review for November, 1883.
4. Report of the Superintendent of the United States Coast and Geodetic Survey for the year ending June, 1881.

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Mr. Alan Macdougall, C.E , F.R.S.E., read a paper entitled :—

## CANADIAN CATTLE TRADE AND ABATTOIRS.

The dependence of Britain on foreign or extraneous sources for much of its food supplies has led to the formation of numerous industries all over the world, and especially on the North American Continent. For its bread-stuffs it may be said to be wholly dependent on the United States, as the quantities sent over from there entirely dwarf the receipts from European countries. Out of the amount exported to Europe, Britain receives 75 per cent. of the wheat, and 90 per cent. of the flour and corn. The wheat crop in 1880 a failure in most of the European countries was a surprisingly abundant one in the States, and it is due to this that many of these countries were saved from starvation.

As the intercourse between Britain and her colonies has increased closer trade relations have been established, and with none have these relations grown to greater bulk than with our Dominion. Our export of bread-stuffs are assuming gratifying proportions, year by year they increase, and year by year the importance of our magnificent waterways grow in like magnitude. Our exports of bread-stuffs have increased to such proportions as to cause the St. Lawrence to be considered a formidable rival to the ports of the Eastern States. This route has opened up the way for the export of other agricultural products, among which is the important trade in cattle which has sprung up between this Province and Britain. The fattening of cattle for the British market has been carried on in our midst in such a quiet unobtrusive manner, few people are aware of the large volume of trade done in this line, or of its financial results to our Province and the Dominion.

From the last return of the Bureau of Industries for the Provinces of Ontario and Quebec, it is learned that our Province exported in the years 1871-'81 :—

| | |
|---|---|
| Eggs, to the value of | $ 4,114,040 |
| Butter " | 4,240,564 |
| Cheese " | 9,277,459 |

If the totals given for the two Provinces be taken the exports of

| | |
|---|---|
| Eggs were of the value of | $ 5,283,557 |
| Butter " | 29,625,762 |
| Cheese " | 37,243,351 |

It is not necessary for the present purpose to detail the amounts which went to Britain, the States and elsewhere.

The export of cattle and sheep has increased very much within the last six years, particularly to Europe. The figures to Europe, are :

| Year. | Cattle. | Sheep. |
|---|---|---|
| 1877 | 6,940 | 9,509 |
| 1878 | 18,655 | 41,225 |
| 1879 | 25,009 | 80,332 |
| 1880 | 50,905 | 81,843 |
| 1881 | 45,535 | 62,404 |
| 1882 | 35,738 | 75,905 |

The Shipments to Great Britain, were in

| | 1880. | | 1881. | | 1882. | |
|---|---|---|---|---|---|---|
| | Cattle. | Sheep. | Cattle. | Sheep. | Cattle. | Sheep. |
| Montreal | 35,416 | 67,943 | 32,722 | 39,218 | 28,183 | 65,183 |
| Quebec | 9,894 | 11,208 | 9,212 | 21,809 | | |
| Halifax | 5,595 | 2,692 | 3,601 | 1,374 | | |

The values of horned cattle and sheep exported in 1882, were for

HORNED CATTLE.

| Province. | To Britain. | To United States. | To All Countries. |
|---|---|---|---|
| Ontario.............. | $ 72,972 | $ 374,858 | $ 449,590 |
| Quebec.............. | 2,316,604 | 45,517 | 2,363,296 |
| Dominon............ | 2,706,051 | 423,807 | 3,256,330 |
| SHEEP. | | | |
| Ontario........ ..... | $ 20,976 | .............. | $ 491,640 |
| Quebec.......... .. | 446,755 | .............. | 606,050 |
| Dominion............ | 510,152 | .............. | 1,228,957 |

Beef to the value of $49,798 was exported from the Dominion in 1882, of which $25,095 went to Britain.

The falling-off in the numbers of cattle in 1882 is due to the increased number exported to the States, and also to the large shipments made in the prior three years, when all the marketable cattle were sent to Britain, and thousands of beasts left this Province which ought to have been kept here.

The total returns of cattle exports in 1882 are in excess of those of other years.

The improvement in quality is becoming more marked every year by the use of Shorthorn, Hereford and Angus bulls, which must in a few years greatly increase the value of Canadian cattle. Mr. Dyke, the Dominion Agent in Liverpool writes, that our cattle can compare favourably in points of breeding and quality with those bred in the best districts of Great Britain, and that this is specially noticeable in sheep.*

In all agricultural statistics relating to the Province of Ontario, the Province of Quebec has to be joined as the ports of shipment. Montreal and Quebec are in the latter, and exports are given from that Province far in excess of its legitimate trade, and belittling to our Province. The question is taken up in the last report of the Bureau of Industries, and ably treated by the energetic head of the department. He places the proportion for Ontario at 75 per cent. of the total exports. Prior to 1876 fully 80 per cent. of our exports went to the States, since that year the returns show a considerable increase in the shipments to Great Britain.

The total value of agricultural products sent to Great Britain from the two Provinces during the years 1871-'81 amount to the

* Sessional Papers Dom. Can. 1883, App. XIV., p. 199, *et seq.*

magnificent sum of $175,042,730, and to all countries to $325,-919,720.

In the dead meat trade the largest returns are made from the Province of Nova Scotia ; this may be due to shipments of dressed beef and mutton being made in winter when carcases are frozen by natural means, and are in a condition to bear a long railway journey and several handlings with impunity, whilst the shipment of live animals is confined to the warmer portions of the year when navigation is open.

The Dominion does not appear to have entered so largely into this branch as the States, from which the supply has decreased considerably in the last two or three years. It is affirmed by some authorities that there was not a sufficiently large margin to encourage a continuance, when Australian meat was being imported so sucessfully ; whilst others declare that home consumption has increased, chiefly in the west and north-west through the large immigration of the last two years, and consequently the demand was equalling the supply.

It may not be out of place to mention that in some British cities, Canadian dairy produce is much belittled, whatever is good in butter or cheese is called "American," and what is bad American is too often called "Canadian !" One city can be named in which a depot for Canadian produce was opened, and where ? in one of the poorest and lowest parts of the city ! "American" beef, mutton, butter and cheese can be obtained at numerous places, while "Canadian" is unknown.

The present cattle trade was commenced in 1876, and had its inception in this city. It was really an experiment. No one knew any thing of it. Shippers, ship-owners and harbor authorities were all in ignorance of the requirements of the trade. The first steamer chartered could only carry 150 head of cattle, and now the same ship carries 350. At the ports of debarkation no preparations had been made. It was difficult for the Liverpool harbour authorities to believe cattle could be brought across the ocean in large numbers free from infection or disease, when in spite of every care and attention outbreaks of pleuro-pneumonia and other diseases could not be checked in Britain.

In the earlier days of the trade heavy losses were incurred. The experience of to-day has indeed been dearly bought. Still it is highly satisfactory to learn that the losses are merely trifling.

| | Cattle. | Lost. | | Sheep. | Lost | |
|---|---|---|---|---|---|---|
| | | No. | P. C. | | No. | P. C. |
| The Dominion S.S. Line carried in 1882 | 6,057 | 41 | 0·67 | 20,241 | 522 | 2·57 |
| Do., 1883 | 7,963 | 54 | 0·70 | 21,553 | 989 | 4·60 |

| | Cattle. | Sheep. |
|---|---|---|
| Montreal exported in 1876 | 2,830 | 2,686 |
| " " 1883 | 50,365 | 102,835 |

It was not until the third season that the Liverpool authorities became alive to the importance of this trade. When they did so, with commendable promptitude they erected those handsome and commodious lairages, pens, slaughter-houses, &c., which now expedite the trade and allow of a ship-load of animals being slaughtered within 24 hours of debarkation.

In addition to all the vexations, losses, &c., incurred in the earlier days from the want of sufficient knowledge of the requirements of the trade, as well as having the opposition of the British farmer and cattle dealers to overcome, the provisions of the Contagious Diseases (animals) Acts had to be complied with. The depredations caused in Britain during the past 20 years by numerous diseases are unfortunately only too well known; in spite of the most stringent measures, the Government has failed to entirely stamp out these diseases, and valuable herds and animals are still daily lost by their ravages.

Recent statistics shew that there are in the United Kingdom 32,237,958 sheep and lambs, the loss due to diseases brought on by the recent wet seasons is estimated at 2,889,000, or nine per cent. The Canadian farmer may complain about the severity of the winter, but he has nothing to fear compared to his British brother.*

To guard against any spread of these diseases strict quarantine laws have been established applicable to all foreign countries, which necessitated the cattle being slaughtered within 24 hours of debarkation, and at the port of arrival. It must be a subject of much congratulation and pride to us all, that the Dominion of Canada is the only country which has never come under the clauses of the Act, or been

* Dyke—loc. cit.

"scheduled." Fortunate it is for us we are free from restrictions, and long may we continue to be so. It is only those persons who have had experience of the workings of that measure who can understand what a bane it is to a country, or how it interferes in its trade. Exhibitors of live stock have frequently failed to come up to their usual standard, and orders to slaughter cattle at home markets have interfered with their prices. Under the Act, every time an animal is put into a cattle car, the car has to be disinfected before it is allowed to be used again; the floor has to be washed out, all offal removed, and the car has to receive a coating of lime white-wash; every pen used for loading, unloading, or holding cattle, be the time ever so short, has to be white-washed. To move animals by road, permission has to be obtained from the Local Authorities, who have plenty of inspectors always on the look out for a breach of the law.

The best illustration of the care devoted to cattle in our province, is afforded in the large byres in this city for fattening cattle for the English market. There are at present 4,000 cattle distributed over six large feeding stables, or byres, each of which contains about 600 head; and there are also a large number of pigs. Each byre is one open space, there are no partitions, the cattle stand close together from 40 to 50 in a row; between each row are 2 troughs separated by a footway for the attendant to pass along, the troughs are sufficiently far apart to prevent the animals from horning each other. At the rear a similar arrangement receives the manure, urine, etc., these troughs are about 3 ft. wide, 3 ins. deep at the top, and 9 ins. at the outfall. A simply arranged system of sluices lets the distillery wash flow into the troughs. Overhead is a large loft for hay, having openings directly over each line of troughs, through these the hay is dropped down directly to the animals. The "wash" is supplied directly from the distillery which is about 1,100 yards distant; it comes boiling hot, and is received in large vats holding 30,000 gallons each; it does not cool very much and is fed to the animals hot; each animal receives 20 gallons on the average, per diem. The stalls are carefully scraped out three times a day, all manure and urine is drawn into the troughs outside the buildings, from which it is run off twice a day. The atmosphere of the byres is wonderfully sweet.

After the manure has been drawn into the outer troughs it is allowed to settle, and all solid matter is pitchforked on to a planked roadway, the liquid is further screened by being passed through gratings one inch wide, after which it is carried down into the lake at Ashbridge's Bay. The byres and outfall troughs are all well flushed with fresh water every day. The solid manure is carted away, daily, by market gardeners and farmers in the neighbourhood of this city ; they get it free, each contractor receives the manure of two rows, and there has never been any trouble nor has the manure been allowed to lie for more than twenty-four hours.

The animals come in during the month of October and go out in June, during that time they make from 1,500 to 1,800 lbs. in weight. In addition to the 20 gallons of "wash" each animal receives daily, it gets about a ton of hay during the season; this is fed to allow it to chew its cud and keep its bowels in order.

There is a great deal of difference of opinion among Sanitarians on the propriety of feeding animals on "distillery wash" or "dregs." Numerous investigations have been made into its qualities which have led to its being prohibited, as far as milch cows are concerned, in many cities and towns in the States and Britain. The question is still an open one, however.

## ABATTOIRS.

No special care or arrangements appear to have been made in the early years of this century to regulate slaughter-houses, as we read that even in such large cities as Paris, London, and Edinburgh these buildings were in the densely populated parts of these cities ; that no care was bestowed on them, and that the effluvium arising from them was overwhelming. Napoleon I. passed an edict regulating the abattoirs of Paris, in 1810, which fixed their sites, and on these sites they remain at present. The leading British cities did not bestir themselves in this matter till about thirty years ago.

The arrangements of the Paris abattoirs have been very generally followed, the buildings are placed in rectangular order and consist of the

> *Echaudoir*, or particular division allotted for knocking down the animal.
> *Bouverie*, the spaces, or sheds, where the animals are kept after a journey to rest and cool till the body gets to a normal condition.
> *Fondeurs*, or boiling down houses, for meat unfit for human use, &c.
> *Triperies*, the places used for cleaning the tripe of bullocks, and the fat, heads, and tripe of sheep and calves.

In addition there have been lately added a blood house, where all the blood is coagulated, or treated for the albumen, which is used in calico printing. In Edinburgh, the blood which was at one time wasted is now sold and brings from £800 to £1,200 sterling per annum.

One of the first requisites for a place intended for the slaughtering of cattle is absolute cleanliness, it becomes an essential to have all appliances connected with abattoirs of the cleanest and most simple and easily-cleaned nature. Vermin must also be excluded from them. In Edinburgh the houses are built of dressed stone, the floors are laid on a layer of Portland cement concrete, twelve inches deep, the surface being paved with large close jointed flagstones; the roadways between the buildings are also laid on cement concrete, the stone blocks being laid in close sets well jointed. All abattoirs are at all times open to the inspection of city health officers, and are supplied with plenty of water for flushing purposes. One of the best substances for abattoir floors is cement concrete, which can be prepared to any degree of surface roughness, to prevent slipping; being homogeneous and of almost indestructible consistence, it will stand any amount of wear and tear, and it is very easily washed and kept clean.

Few of our Canadian cities are well placed regarding abattoir arrangements, there are too many abattoirs mixed up among dwelling-houses, and health-inspectors have not yet the compulsory powers they must have before they can abate these nuisances. The author has learned, with much surprise, that offal is still fed to hogs at many abattoirs, and that there is a decided demand and preference for pork so fed. This reprehensible and dangerous custom cannot be too strongly censured.

The systems adopted in England for slaughtering and handling the carcases, are shewn by the drawings on the wall, and are an enlargement of the arrangements now in use at several pork packing and other factories; this system saves all handling of the meat and preserves it better than in those cases where it has to be carried on men's shoulders to carts, and upon carts to the butcher stalls.*

It is to be hoped that in any new abattoirs to be built in any of our cities, care will be taken to arrange everything with a view to absolute cleanliness, and that a plentiful supply of water will be laid on. Proper buildings can easily be erected for the destruction of all waste

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* The abattoir machinery referred to is known as Meiklejon's Patent Abattoir Machinery and Fittings. Further information on this matter can be obtained from the author.

matter, or the conversion of it into chemical manure for which a market can readily be found; by these means what is now a foul nuisance and decided evil can be remedied at a moderate cost, the health of the municipality guaranteed, and much valuable matter now being lost turned into a source of revenue.

In the discussion that followed, Dr. Oldright stated that 50,000 gallons of liquid manure mingled with solid particles are daily carried into Ashbridge's Bay to the detriment of the health of those residing in the vicinity. The slaughter-houses are abominable, and that on the Don is a worse nuisance than Mr. Gooderham's byres. He thought that anything that made life less enjoyable, should, if possible, be done away with, even though it might not be practicable to show that there was a direct connexion between this particular nuisance, and the prevalence of any given disease or class of diseases. He asked the assistance of the Institute to enable the Board of Health to carry certain changes in the law in the general interest of the public.

Mr. George Murray spoke as to the advisability of devising laws for the prevention of such nuisances.

Mr. George Acheson raised the question as to the wholesomeness of meat in which the blood has been allowed to remain.

Mr. Alan Macdougall thought that to feed pigs on animal offal increased their liability to become infested with *cestoidea*, chiefly the *trichina spiralis*.

# HYPNOTISM AND ITS PHENOMENA.

BY P. H. BRYCE, M. A., M. B., L. R. C. P. & S. Edin.

*(Read before the Institute on the 11th March, 1882.)*

In choosing this subject upon which to base some remarks, I feel how imperfectly anything I may say can serve to convey to you any adequate idea of the strange series of phenomena attendant upon the hypnotic state. My excuse, however, for choosing it must be given in the fact that some months ago a patient came under my charge, after having passed through the hands of several physicians, who had given different opinions as to the real nature of her malady. Seeing her for the first time, I was at once struck by the similarity of her condition and appearance to certain patients I had been accustomed to see in Professor Charcot's wards in the Hospice de Salpétrière in Paris.

Her lower limbs were found in a condition of tonic rigidity, while various clonic contractures were taking place in various other sets of muscles. With the ophthalmoscope I endeavored to make out the vascular state of the retina, but was through her movements unable to do so. To perfect, however, my diagnosis I tried the hypnotizing experiment, and in a short time she had passed into a profound slumber. After she had so passed into a slumber I raised an eyelid, thus allowing light to strike upon the eye, when I found that a state of complete cataleptic rigidity had seized upon that side of the body. My diagnosis was finally made beyond doubt when I found that the slightest pressure over the ovaries, after she was again awake, proved their state of extreme hyperæsthesia by inducing an hystero-epileptic attack which was checked by continued firm pressure upon them. Before me was, in very truth, a case of Hystero-epilepsy, precisely similar to those seen in Prof. Charcot's wards, and which have excited the wonder of all scientific men, who have ever had the good fortune, while in Paris, to visit the wards of Salpétrière.

From the nature of the case it will be impossible for us to study the phenomena of hypnotism without to some extent introducing other phenomena always present in hypnotic subjects (especially in hystero-epileptics) ; and since my experience of such is limited only to those persons, who have come under the charge of physicians, I shall leave to the apostles of animal-magnetism to explain the spiritual relations which they ostentatiously assume to exist between themselves and those to whom they communicate the *fluidic* force from their over-charged and hypermagnetic souls.

I have chosen Dr. Braid's word, Hypnotism, in preference to somnabulism as expressing more exactly the condition, and nothing more, which we wish to consider ; and further prefer it to Charcot's word of "lethargy," applied to the state, since in our language this word has a meaning hardly applicable to what we wish to express.

Perhaps there is no subject about which have hung more awe-inspiring ideas and morbid curiosity than about this of hypnotism—or if we would rather somnabulism, mesmerism, *aut alter* ; and there is no scientific subject at the present time which presents more physiological difficulties or pathological interest than the hypnotic phenomena, attendant upon certain—to use the mildest term—*functional* maladies. It would be foreign to the purpose of this paper for me to enter into any lengthy historical account of the many fanciful ideas, which have grown up around our subject ; nor would it be very edifying to re-count the confused mass of credulity, charlatanry, and science, which has in the past, and in many quarters does still form part of the conception associated with the term hypnotism. Still it may be interesting to note that I have found in an edition of Galen that magnets, incantations, &c., are spoken of as therapeutic agents in mental affections ; and I may further remark that Charcot has become so convinced that the New Testament demoniacs were persons afflicted with no other than epileptic and hystero-epileptic maladies, that, having witnessed so frequently amongst his own patients paroxysms similar to the recorded ones, he has actually had sketches made illustrative of these scriptural demoniacs. But within the present century we see an outgrowth from these pathological conditions, which have hypnotism as a phenomenon, in that pseudo-science termed variously animal-magnetism, biology, mesmerism, &c. It would seem as if there have been too many persons so filled with love for the extraordinary that when they encounter certain facts apparently inexplicable, instead of endeavouring calmly to search out causes prefer to rest in supernatural explanations. With such then animal-magnetism has taken its origin. According to them some mysterious, imponderable, yet potent fluid passes from person to person: the manipulator of spirits has, doubtless at first honestly, and then afterward with conscious deception, thought his power over the passive subject of his will to be due to some peculiar magnetic virtue in his own constitution. In such persons has the hydra-headed monster of Spiritualism been conceived and reared; and only recently have scientific men been found brave enough to face credulity and ignorant prejudice, and deal with certain undoubted facts, endeavouring to explain them upon the true basis of physical and psychical science. We shall not trouble ourselves with the empiric consultations and diagnostications of Teste and Deleuze, finding thereby diseases that have never had an existence; nor how Vasseur-Lombard cured cancer by magnetism, nor yet of how diseased plants have been stimulated by its mysterious power to a more vigorous growth; but we shall endeavour, in at most a very imperfect way, to study some of the phenomena of this neurosis, produced, it may be, artificially or by pathological causes.

Defining then our subject, we would say that there are certain persons, mostly females, of such constitution, that they, by certain manipulations, simple or more or less complicated, may be brought into such a neurotic condition as that they may be made to pass into a deep sleep in which they may be kept at will for an almost indefinite number of hours. Such then is the apparently simple fact of hypnotism; but this apparently simple fact, I think we shall see as we proceed, will become one both of very great interest and of much difficulty as regards its explanation.

And first it becomes necessary for us to consider whether in this condition of hypnotism the physical system is in exactly the same condition as in natural sleep. As we all know the factors which enter into the causation of the unconscious state known as sleep are so varied that it is most natural that many explanations have been given of the state. Sömmer, as we know, supported by Pettenköfer and others, believed that sleep means exhaustion of the oxygen of the blood and tissues, which has taken place during the day, and that, when this is again stored up at night in sufficient quantity waking follows. While in all probability the fact of there being a greater consumption of oxygen during the day than at night is probably true, yet we are hardly prepared to accept the theory of sleep founded on one isolated though comprehensive fact. Dr. Cappie's theory is one which seems to comprise many more of the factors entering into the causation of sleep. Briefly, he says: (1) there is with the growing exhaustion, towards evening, of all the tissues a lessened molecular activity of the cerebral cells, and (2) coincidently therewith a change in the capillary circulation of the brain so that less blood is supplied to the brain, and hence the volume of the brain is less. But (3) this situated within the immobile capsule of the cranium must have the hitherto occupied space, now again filled; hence, as Arthur Durham remarks, the result is that the blood in the venous sinuses is increased. But further, Mr. J. Hilton, F.R.C.S., remarks that the cerebro-spinal arachnoid fluid always equipoises the haemic condition of the brain, and especially of the parts surrounding the ventricles—thus resting the brain; and not only so, but also the relation between this fluid and the blood is always one of unstable equilibrium. But, once more, Dr. Hughlings Jackson has shown that the ophthalmoscopic disc is in sleep always in an anaemic condition. Now all this seems simple enough, yet I doubt not that many abnormal states may arise which will be found difficult to coapt with this theory. However, this theory would further seem to be supported by what we find present in many pathological conditions. Thus we know that in active delirium, dependent upon an hyperaemia and inflammation of the brain, sleeplessness is a common symptom, *e. g.*, acute mania and the early stages of acute meningitis, while again in the later stages of both there is unconsciousness and more or less complete coma arising from venous stasis and effusion of lymph into the cerebral tissues. This in an organ with such an enormous capillary circulation—the encephalon containing, according to Haller, $\frac{1}{5}$ of the total blood of the body—must produce the most disastrous effects upon its functional activity as has been experimentally shown in many ways. Thus pressure upon a portion of brain exposed by a fractured cranium has immediately produced a suspension of its functional activity, thereby inducing unconsciousness. That it is anaemia which has produced this state is evident from the fact that a removal of the pressure brings back immediately functional activity of the part.

Before we endeavour to draw a parallel between the physical conditions of natural sleep and induced hypnotism, we shall try and explain how the anaemia of natural sleep is produced.

First, then, we think it now conceded by all that there is a natural law by which all organic life unconsciously seeks rest, in order as it were to store up energy for the renewal of active functions. As far as we know all animals follow this law : we know as well that plants do. How this takes place in plants we know in the fact that the actinic rays of the sun, aiding the decomposition of carbonic acid by the plant and the assimilation by it of carbon, thereby become the exact idex of this functional activity. Nothing then seems more certain than that man's physical, and likewise intellectual, nature seeks in sleep that rest which enables the various organs to *revitalize* themselves by both lessening the physical waste, and the storing up of new energy. But this process, inherent in the natural constitution of man, must of course be carried on by means of natural processes. What are these? Following out embryogenic changes we must necessarily place nutrition of blood and its renovation first. But since nerve force is that which evolutionary progress has carried to its highest point of development in man, we feel that in adult man it should almost be placed first, so potent a regulator has it become of the processes of nutrition. We may say then that nerve force exists through all the degrees from extreme nerve tension to that of complete nerve relaxation, the various degrees depending upon the ability to assimilate nourishment, derived from the blood and external warmth, light, exercise, &c. Now in trying to explain physical phenomena and the part played by nerve matter in them, it is necessary to proceed with the greatest caution, since we frequently find popular expressions and scientific expressions diameterically opposed to one another. Thus the popular expression for nerve anaemia or nerve debility is nervousness, which in reality ought to mean the very opposite, viz., nerve force; and so a whole series of misused expressions originating in wrong pathological ideas might be given.

Starting then somewhere in the complex circle of cause and effect let us suppose that nerve force is given. Now it seems generally accepted that the ganglionic system of nerves, which especially subserves the functions of organic life, is that too which, by giving nerve supply to the muscular tissue of the blood vessels, regulates the blood supply of a part, either by contraction of the walls lessening the blood supply, or relaxation causing a temporary hyperaemia. (It should be noticed here that the hyperaemia attendant upon inflammation seems to some extent at least dependent upon some morbid condition of the blood, affecting the vitality of the walls of the vessels; but more probably it is largely due to sensory reflex action of the nerves.) That this latter seems the commoner mode of action would seem to be shown from the fact that emotional influences of joy and pleasure with their opposites of sorrow and anger, produce their regular effects of heightened circulation in the capillaries in the one case, and pallor from spasmodic contraction of the same vessels in the other. We must here add to this the important factor of sympathetic nervous influence directly exerted upon the heart, probably from the vaso-motor centre in the medulla oblongata upon the accelerator ganglion in the one instance, and the depressor ganglion in the other, both of which have their supposed centres in its muscular tissues.

We now would seem to have sufficient data wherewith to proceed in our endeavour to explain the phenomena of hypnotism. We have explained the supposed physical conditions tending to produce sleep. Have we the same present in induced hypnotism? It seems to me that in a large degree we have. It is perfectly well known that the hypnotic state cannot be produced at will in all persons, and in others only with various degrees of ease. It is true, moreover, that persons in whom hypnotism can be produced are almost invariably those of an emotional tendency, or those in whom the equilibrium which in health exists between the cerebral and spinal systems is most readily destroyed—certainly those in whom the sympathetic nervous system is most readily acted upon. Nothing can express our views upon this point more exactly than the quotation of M. Jaccoud's remarks concerning hysteria. He says: "The physiological characteristics of Hysteria depend upon the importance of the opposing relations which exist between voluntary or cerebral innervation, and the involuntary or spinal. The performance of the regular functions of the nervous apparatus depends upon the natural and innate subordination of spinal activity to that of the cerebrum; this established hierarchy (which demonstrates among other things the experimental study of reflex motility) is the absolute condition of the normal harmony of the nervous functions. Now in hysteria this harmonic equilibrium is always broken and always in favour of the spinal cord; thus is produced a disorder which bears fatally upon the collective functions of innervation—a veritable cerebro-spinal ataxia which constitutes and characterizes the decay of cerebral action, and the predominance of spinal action." He further remarks that the physiologist may produce the same condition in three ways: (1) by exaggerating the excitability of the spinal system by irritation of the centripetal nerves; 2) by exaggerating directly the action of the cord itself; and (3) by suppressing the functions of the brain.

These three conditions have each their pathological analogies, and they contain in themselves the totality of the pathogenic conditions of hysteria. Whatever has been the causation of this malady, he further says, we have always these two fundamental elements united, viz.: (1) the weakening of cerebral action, especially that of the will, and (2) the exaggeration of the automatic or spinal action (hyperkinesie spinale).

Thus we see that in these hysterical patients we have emotional subjects who are readily impressed by whatever may affect the sympathetic system, in other words, who are ruled too frequently by the emotions and too seldom by the will,—or as M. Jaccoud so well expresses it: "There is at least temporarily present a cerebral paresis." Now physiologically what does this mean? It must mean, if we adhere rigidly to the belief that the more or less complete abeyance of functional activity in a part is necessarily dependent upon a corresponding temporary absence of force-producing materials in the part, and, so far as we know, this means arterialized blood. For instance, pallor is an anaemia of the capillaries of the skin; while we have, unfortunately, too many examples showing that the functional activity of an arm or leg depends directly upon its nutrition. Moreover, our best authors give among the causes of hysteria, loss of blood, prolonged lactation, &c. The first of these shows that other than purely female disorders may be causes of this malady, *i. e.*, hysteria may occur in delicate and impressionable males as well as in females.

In claiming the anaemia theory as explaining these states I am perfectly well aware that there are some authorities, notably Brown-Sequard, who are opposed to it as being in many cases a sufficient explanation of either hysteria or epilepsy. I find in notes taken from his lectures on the peripheral irritation of nerves, that his explanation of these pathological conditions is not on the supposition of any slow or sudden unequal distribution of blood to the brain, but that he considers the attacks essentially due to reflex action from peripheral sensations creating impressions upon the brain centres. Then follows a citation of cases where peripheral irritation induced epileptic attacks. No doubt these cases are facts, but I am inclined to the belief that most, if not all, of them can be explained on the anaemia theory. Let us select one example from many. He cites a case where disease of the supra-renal capsules induced epileptic attacks. Now, here it would seem as if we had present much the same sort of peripheral irritation of the nerves, which we have in ovarian hyperaesthesia, &c.; and each is followed by an attack or paroxysm, due, we have reason to believe, to the irritation to the ganglionic nervous system inducing contraction of the brain, capillaries, &c. But, to proceed, assuming that since the hypnotic state is induced principally in persons of natural or induced emotional tendencies, and that in such there is present more or less of a cerebro-spinal ataxia, *i. e.*, a temporary suppression of will power or cerebral force, we necessarily have present a condition of cerebral anaemia, or the very same physiological condition which Cappie, Durham, Jackson, Schiff, &c., agree, is present in normal sleep.

Let us now refer to some of the conditions which exist in hypnotic individuals. You will remember the hypnotizing experiment used as a diagnostic aid in the case already referred to. The method, as remarked by Prof. Charcot, made use of for inducing the hypnotic state is for the most part immaterial, the subjective state of the patient being apparently the necessary condition. What, however, in most cases seems necessary is a fixity of gaze, or at least some impression made upon the visual organs, which we may consider in the light of an irritant. Thus the patient looking fixedly for a few seconds at a single point, placed a few inches in front, and a little above the level of the eyes, is seen to have the pupils first contract and then soon dilate, with this the eyelids are seen to droop, and the patient simultaneously shows signs of muscular relaxation; the head falls to one side or forward, stridulous breathing supervenes for a few moments, then the patient passes into a profound sleep. Other means, such as looking at a bright piece of silver, the Drummond light, or even closure of the eyelid with slight pressure on the eyeball, have all been used, producing the same results. We are now brought to the exceedingly difficult question of the physiological changes which have here taken place. To physiology, rather than pathology, must we look for our answer. First, then, we recognize the fact that the impression made by light or by pressure is made upon the retina, thence the optic nerve. Thus, with the light we have the special irritant applied to this nerve of a special sense; and, as proved anatomically as well as by physiological experiments, this nerve reflects its impression along the *third* (3rd) nerve to the iris, through the ophthalmic ganglion, and, as we know, instantaneous iris contraction is the result. But the impression reflected upon this ganglion has for us the highest interest. In it are ganglion cells with fibres connecting with other sympathetic ganglia. Now, however great or little may be the optic sensibility here, we are certain of one thing in these cases, and that is of an extreme hyperaesthesia of the ganglionic nervous system. Since externally in the changes of the iris, we can see the proof of the above supposition, it seems logical for us to assume that the sensation reflected from the optic nerve creates upon the ganglionic system such an impression that it is communicated to the vaso-motor centre—seated in the medulla oblongata—of the cerebral arteries; and that thence is communicated an irritation which causes an instantaneous contraction of the cerebral arteries, (possibly also by the irritation supplied to the depressor ganglion of the heart,) thus creating an anaemia, an abeyance of cerebral functions, and as a consequence the hypnotic state. This hypothesis seems quite the same as the one by which Ferrier accounts for related cases, where from emotional states, as anger, &c., spasm of some of the cerebral arteries has taken place, producing temporary blindness, deafness or aphasia, or which were relieved by the use of the magnet overcoming the spasm. We must not forget to note as a factor in this hypnotizing process, that in all such subjects the will-power has been passing into abeyance, since we have already seen that in proportion, as this is absent the spinal, and certainly the sympathetic, hyper-excitability is increased.

Here again let me quote from M. Jaccoud on "Cerebro-Spinal Irritation," words appropriately describing the condition here present. He says:—"The abnormal excitation of the cerebro-spinal system, causes its first effects to be felt upon the vaso-motor system, whose impressibility is so readily shown by the instantaneous production of pallor and of blushing, whence an anaemia or rather secondary ischaemia, both of brain and cord, which increases the disorder of excitability and transforms it into a persistent condition of irritable feebleness. Both clinical facts as shown by Ferrier and the experiments of Van der Becke, Callenfels, Nathnagel, and Krishaber have placed these hypotheses in the region of verified facts." How inconceivably impressible is the nerve system to influences, seems to be further substantiated from recent experiments by Jaeger, so wholly new, and, if true, so remarkable that I cannot refrain from a brief reference. To use his own words concerning his experiments with the chronoscope, he says, with reference to neural analysis:—"My discovery relates chiefly to the *gemeingefühl* (collective-feeling, emotions), which by physiologists is distinctly separated from the perception by the senses (the philological difference between soul and mind corresponds exactly to this physiological difference). The essential peculiarity of the *emotions* is that the accompanying functional changes are not limited only to a few anatomical parts of the body, but concern all parts of its muscles, nerves, glands, &c. In other words emotion is a condition of the whole body. Hence it follows that not only the sensory nerves undergo a change, but also the muscular or (*i. e.*, motor) nerves. That which is changed is the nervous excitability, and that which produces these changes are soluble substances which enter into the liquids of the body, and amongst which the volatile ones (odorous) produce the greatest effects. The changes of excitability are indicated by the motor nerves as a quantitative index of the conductibility of these nerves for perceptions. Thus we are enabled graphically to illustrate the peculiarity of the emotions by registering an involuntary movement, viz., that of the heart, since every such substance entering the system affects the rhythm of heart and pulse, and may be measured by the sphygmograph. Thus what the nerve of smell, smells, nerve of taste, tastes, and nerve of sight, sees, are all registered by the muscle nerve. He then gives diagrams of sphygmographic tracings of curves of joy (Jargonelle pears), of anger (rancid butter), of nausea (bad drinking water, &c.). Now, allowing that there is a basis of fact underlying what to many may seem fanciful theorizing, we further see how impressible is the nervous system, as shown time and again by Charcot's method for ending the hypnotic state by simply a puff of breath upon the face of the patient.

From these extended remarks, then, it would seem as if we have something like a definite explanation possible of the causation of the hypnotic state, which we may describe as at least a functional pathological state, having its near analogue physiologically in sleep, but with several additional phenomena superadded; and of all these the most prominent is a remarkable condition of general hyperaesthesia of the spinal system of nerves. But we must beware of making this a too distinctive phenomenon of hypnotism, since we know that not only are different individuals very differently susceptible to external influences while asleep, but also that the same person at different times sleeps with varying degrees of sensibility to external impressions.

We have now to notice the condition into which the system is thrown during the somnabulistic state. Necessarily it is one in which cerebral force is wholly in abeyance. A most interesting illustration of this is seen in some of M. Charcot's experiments. For instance, a patient whom we may call Marie, is hypnotized; her eyes are opened by the operator, and she is told to look carefully at the bystander, that he is Ernestine, a friend of hers. Her eyes are again closed and her friend Ernestine is brought forward, and in the same manner Marie is told that Ernestine is the bystander. The operator now puffs upon her face and Marie awakes and treats the bystander as Ernestine, and Ernestine as the bystander. This delusion persists a long time unless she is again hypnotized, and the hallucination resolved. As we know, destruction of the cerebrum in frogs not only does not destroy, but seems to augment reflex spinal movements; and since, as we have seen, a hyperaesthesia is more or less constantly present in, at least, *plaques* or parts of the bodies of hypnotic patients, we naturally expect them while asleep to be peculiarly susceptible of external influences. Others again exhibit, what may be deemed truly wonderful, sensibility even while awake to external impressions. A Dr. Cowan, relates in the London *Lancet*, that a patient of his was so sensitive to external impressions, that the flying of a bird past a window with drawn curtains, and with the bed-curtains also drawn, produced in her a sudden jerking of the spinal muscles, extending, if violent, to the hands and legs, and all this without any conscious mental emotion. The same person heard, and was affected by sounds not appreciable to other persons, these sounds producing similar reflex movements to those of sight. Besides such examples we have many other examples of reflex spinal acts, as nausea and vomiting from bad sights or odours, quite apart it may be from any mental emotion. What, however, is most to be remarked in all these cases of undue reflex spinal acts, in these functional maladies at anyrate, is that their force is exactly in proportion as cerebral influence is in abeyance ; and further we notice that the longer this state exists so much the more difficult is it to regain cerebral control over reflex spinal movements. Many instances of this latter fact have been witnessed in the hystero-epileptic patient already alluded to. Thus while examining the eye with the ophthalmoscope I have asked her to look down, up, &c. At times this has been done with ease, while at others no apparent efforts on her part could overcome the ataxia due to the lack of cerebral force over reflex spinal action. Again the hyper-excitability of afferent sensory nerves induced by this condition is in its effects readily appreciated. Let us suppose a patient hypnotized and sleeping quietly, the whole muscular system being apparently relaxed. Here we find that the sensibility is so great that very slight friction along the course of any nerve causes tonic contractures of the corresponding muscles supplied by its branches to take place. This I have frequently witnessed in sets of muscles in all parts of the body. What the pathological condition is, inducing this state is in some instances difficult to explain ; but a curious experiment which I had the good fortune to witness in M. Charcot's laboratory would seem to throw some light upon the subject. There was present a patient, very healthy-looking, well developed, of fair complexion, and of sanguine temperament, but one of peculiarly emotional tendencies. The experiment upon her was as follows : She, having been first hypnotized, was sleeping peacefully while sitting in her chair. An assistant now bandaged the right arm, and having tied it above the bandage showed it to be anaemic. Now by slight pressure upon the ulnar nerve at the elbow the form of contracture *en griffe* was set up in the corresponding fingers of that side. A large magnet was then placed in contact with the left arm when, wonderful to relate, there followed a slight muscular tremor in the muscles of the left arm, and thereafter the same contractures took place in the muscles of that hand, the contractures on the right side being correspondingly relaxed at the same time, but by irritation were again induced, there being contractures thus present in both at once. I did not hear M. Charcot's theory as to the causation of this phenomenon, but it seems to me that we have a right to assume that :—(1) anaemia of the right arm made it very irritable and sensible of impressions ; (2) when the cerebrum was even slightly impressed it set up motor reflex action and contractions took place ; (3) and in the third, and strangest of all, that of the magnet's influence, we must assume that it, like the static electricity of the plate electric machine produces with its high tension a state of extreme hyperaesthesia, or impressibility, so that the impression made upon the sensory centres from the right arm irritation, is now great enough to excite through the commissural fibres the same reflex action on the left side. But further, it was found that on removing the tourniquet from the right arm the contractures of the left gradually relaxed, and the contractures came back again in the right arm, but slowly and not very completely.

We must confess that we have present what seem to be at first two contradictory phenomena: (*a*) anaemia producing hyper-excitability in one arm, (*b*) while in the other tonic magnetic influence has produced, at least as far as effects go, a similar state of great sensibility.

But though we may fail in fully explaining this peculiar condition, yet I think we can gain at least one step in advance by noticing an explanation given by Dr. Broadbent concerning some of the causes of paralysis from hemorrhage into the *corpora striata* and *thalami optici.* He thinks it can be shown that where the muscles of corresponding parts of the body constantly act in concert the nerve nuclei of these muscles are so connected by commissural fibres as to be *pro tanto* a single nucleus. Now supposing that the magnetic influence has greatly increased the impressibility of the left side we may fairly infer that the reflex action setting forth from the sensorial nucleus which was impressed by the irritation on the right side, and which caused the tonic contraction of muscles in the right arm (being of a certain quantity which we may call $x$), has been transferred to that muscle having the greater temporary conductibility. Thus we have now relaxation in the muscles of the right arm, and the phenomenon of tonic contraction in those of the left. Let us now remove the temporary stimulus of the magnet and we have the original impression made upon the nucleus, again transferred to the right arm but in a greatly diminished degree, since this side has again become that of greatest excitability.

Before closing there is another condition induced in patients whilst in the hypnotic state so strange—we might say marvellous—and unusual that it demands some few remarks. I refer to the remark already made that, when the one eye of a hypnotized patient is opened, the impression produced, we must assume, by light induces some new condition by which that side of the body of the patient is thrown into a cataleptic state. Now before inquiring what this change is, it may be well for us to try and explain the pathological condition present in a catalepsy which may attack persons without their first passing into the hypnotized state. At the outset we must confess to the unsatisfactory information which most of our authors give us on the subject. All that even Bristow says is, "that in cataleptics we have a class of cases difficult to classify. and difficult to attach to specific lesions or specific conditions of the nervous system." We do find, however, in M. Jaccoud already quoted from something which really does aid us.

He says :—" Catalepsy is a spasmodic paroxysm and is constituted of two elements : (1) the suspension of cerebral operations, or their external manifestations ; (2) the increase of the spontaneous and reflex tonicity (innervation de stabilité) in the muscles of animal life. The abolition of cerebral action presents itself under two forms (rather degrees) which imply different organic localizations : in one (*a*) there is total loss of consciousness, viz., of sensation, perception, ideaism and its consecutive acts, and this can be interpreted only by the inertia of the grey substance of the hemispheres ; in the other (*b*) consciousness is not suspended, perception and ideasim are complete, but lack the last link of the chain, *i. e.*, the motor intuition cannot be communicated to the motor apparatus. Here it is clear the cortical substance is normal, but the inertia is in the conductive fibres which bind together the organizing apparatus and the performing apparatus. Nevertheless the result is the same ; tonic spasm is present, keeping various sets of muscles in whatever position placed. And this tonic spasm (spasmes du tonics) is a lasting tension. Here we have a most noticeable fact in the marked increase in the innervation of of stability. The tension keeping up this stable condition of the muscles must be looked upon as a reflex phenomenon, provoked by the molecular change (elongation or shortening) which the communicative movements cause the muscles to undergo. It is this molecular change which is the centripetal excitation necessary to all reflex movements ; and this stimulus repeats itself every time that the muscle is moved. One difficulty exists in the constant relation which binds the quantity of tension to that of passive movement in such a way that the reflex spasm produced by this latter is always rigidly adequate to it, and arrests the muscles exactly in the position which one gives to them. Benedikt notes, concerning this point, that according to the researches of Volkmann the contractile capacity of muscle augments or diminishes according as it is shortened or elongated by traction." Evidently, we think, M. Jaccoud has thrown much light on the pathology of the symptoms of catalepsy; but as he says, the causation of the malady is yet obscure;—or, how are produced those opposed states of the cerebral and spinal centres, and why are the symptoms limited to the muscles of animal life?

Referring again to the cataleptic condition associated with the hypnotic state, we ask what changes take place in the system, which by the simple raising of an eyelid effect the change into what M. Jaccoud says is one of increased spontaneous and reflex tonicity?

First, then, in hypnotism the first of Jaccoud's cataleptic postulates is present, viz., the suspension of cerebral operations and their external manifestations. How has it been possible for light to produce all these changes? We have already noted the hyper-excitability of the muscular nerves present in hypnotism, causing muscular contractions when subject to the slightest irritation. We have further supposed that light has been the excitant or irritant inducing sleep with cerebral force in abeyance. Again we must remember the muscular relaxation taking place when hypnotism is induced. Evidently then our assumed nerve spasm has here passed off. But on opening the eye of the patient the excitant is again present with cerebral operations wholly in abeyance; hence we may suppose that the irritant affecting the optic nerve not only renews the spasm previously present and setting out from the sympathetic nerve cells residing in the medulla oblongata, thereby not only making the cerebro-spinal ataxia more complete, but also as a consequence leaving the spinal cord perfectly separated from cerebral influence; and, moreover, having an irritant in the form of light constantly producing a central influence upon it, we have it held in a state accurately defined by M. Jaccoud as *innervation de stabilité.*

But, gentlemen, our already too long paper must be brought to a close. These hypotheses and suggestions are only made by us as possible explanations of a series of phenomena both strange and unusual. It will indeed afford us a real pleasure when advancing medical science will have rescued many of these questions from the mists still enveloping them, and when the pure light of day will be seen illuminating them as it now does the many common maladies which we daily encounter. Most truly would we express the fervent prayer of Tennyson :

> "Let knowledge grow from more to more,"

for to no other as much as to the true physician does this desire come that thereby the sum of human ills may be lessened, and the saddened face of a suffering humanity be illumined, let us hope, with spontaneous gratitude towards a profession which, with all its imperfections, is yet most earnest in the promotion of man's highest mental as well as physical well-being.

Many are the points concerning these neurotic puzzles which we have left untouched ; but it is hoped that other more experienced minds, and pens, wielded by other more facile hands, will take these up, adding thereby to the sum total of that medical knowledge, one of the many glories of the future for, as our Laureate sings,

> "And the thoughts of men are widened with the process of the sun."

TO THE BINDER.

Where necessary in Vol. I., place the Plates with the Papers which they illustrate.

JULY, 1884.

VOL. II. FASCICULUS No. 2.

# PROCEEDINGS

OF

# THE CANADIAN INSTITUTE,

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## CONTENTS:



*(For continuation of Contents, see second page of cover).*

TORONTO:

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1884.

## CONTENTS—(*Continued*).

VOL. II. OCTOBER, 1884. FASCICULUS No. 3.

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[*Read before the Canadian Institute, March 3rd, 1883*].

# PRINCIPLES

OF THE

# SOLUTION OF EQUATIONS OF THE HIGHER DEGREES,

WITH APPLICATIONS.

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BY GEORGE PAXTON YOUNG,

*Toronto, Canada.*

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## CONTENTS.

$$r_1 = \frac{1}{m}\left(g + \Delta_1^{\frac{1}{m}} + a_1\Delta_1^{\frac{2}{m}} + b_1\Delta_1^{\frac{3}{m}} + \ldots + e_1\Delta_1^{\frac{m-2}{m}} + h_1\Delta_1^{\frac{m-1}{m}}\right);$$

where $g$ is rational, and $a_1$, $b_1$, etc., involve only surds subordinate to $\Delta_1^{\frac{1}{m}}$. §38, 47.

7. The equation $F(x) = 0$ has an auxiliary equation of the $(m - 1)^{\text{th}}$ degree. §35, 52.

8. If the roots of the auxiliary be $\Delta_1, \delta_2, \delta_3, \ldots, \delta_{m-1}$, the $m - 1$ expressions in each of the groups

$$\Delta_1^{\frac{1}{m}}\delta_{m-1}^{\frac{1}{m}},\quad \delta_2^{\frac{1}{m}}\delta_{m-2}^{\frac{1}{m}},\ldots,\quad \delta_{m-1}^{\frac{1}{m}}\Delta_1^{\frac{1}{m}},$$

$$\Delta_1^{\frac{2}{m}}\delta_{m-2}^{\frac{1}{m}},\quad \delta_2^{\frac{2}{m}}\delta_{m-4}^{\frac{1}{m}},\ldots,\quad \delta_{m-1}^{\frac{2}{m}}\delta_2^{\frac{1}{m}},$$

$$\Delta_1^{\frac{3}{m}}\delta_{m-3}^{\frac{1}{m}},\quad \delta_2^{\frac{3}{m}}\delta_{m-6}^{\frac{1}{m}},\ldots,\quad \delta_{m-1}^{\frac{3}{m}}\delta_3^{\frac{1}{m}},$$

and so on, are the roots of a rational equation of the $(m-1)^{\text{th}}$ degree. The $\frac{m-1}{2}$ terms

$$\Delta_1^{\frac{1}{m}}\delta_{m-1}^{\frac{1}{m}},\quad \delta_2^{\frac{1}{m}}\delta_{m-2}^{\frac{1}{m}},\ldots,\quad \delta_{\frac{m-1}{2}}^{\frac{1}{m}}\delta_{\frac{m+1}{2}}^{\frac{1}{m}},$$

are the roots of a rational equation of the $\left(\frac{m-1}{2}\right)^{\text{th}}$ degree. §39, 44, 55.

9. Wider generalization. §45, 57.

10. When the equation $F(x) = 0$ is of the first class, the auxiliary equation of the $(m - 1)^{\text{th}}$ degree is irreducible. §35. Also the roots of the auxiliary are rational functions of the primitive $m^{\text{th}}$ root of unity. §36. And, in the particular case when the equation $F(x) = 0$ is the reducing Gaussian equation of the $m^{\text{th}}$ degree to the equation $x^n - 1 = 0$, each of the $\frac{m-1}{2}$ expressions,

$$\Delta_1^{\frac{1}{m}}\delta_{m-1}^{\frac{1}{m}},\quad \delta_2^{\frac{1}{m}}\delta_{m-2}^{\frac{1}{m}},\ \&c.,$$

has the rational value $n$. §41. Numerical verification. §42.

11. Solution of the Gaussian. §43.

12. Analysis of solvable irreducible equations of the fifth degree. The auxiliary biquadratic either is irreducible, or has an irreducible sub-auxiliary of the second degree, or has all its roots rational. The three cases considered separately. Deduction of Abel's expression for the roots of a solvable quintic. §58-74.

## PRINCIPLES.

§1. It will be understood that the surds appearing in the present paper have *prime numbers* for the denominators of their indices, unless where the contrary is expressly stated. Thus, $2^{\frac{1}{15}}$ may be regarded as $h^{\frac{1}{5}}$, a surd with the index $\frac{1}{5}$, $h$ being $2^{\frac{1}{3}}$. It will be understood also that no surd appears in the denominator of a fraction. For instance, instead of $\frac{2}{1 + \sqrt{-3}}$ we should write $\frac{1 - \sqrt{-3}}{2}$. When a surd is spoken of as occurring in an algebraical expression, it may be present in more than one of its powers, and need not be present in the first.

§2. In such an expression as $\sqrt{2} + (1 + \sqrt{2})^{\frac{1}{3}}$, $\sqrt{2}$ is *subordinate* to the *principal* surd $(1 + \sqrt{2})^{\frac{1}{3}}$, the latter being the only principal surd in the expression.

§3. A surd that has no other surd subordinate to it may be said to be *of the first rank*; and the surd $h^{\frac{1}{c}}$, where $h$ involves a surd of the $(a - 1)^{\text{th}}$ rank, but none of a higher rank, may be said to be *of the $a^{\text{th}}$ rank.* In estimating the rank of a surd, the denominators of the indices of the surds concerned are always supposed to be prime numbers. Thus, $3^{\frac{1}{6}}$ is a surd of the second rank.

§4. An algebraical expression in which $\Delta_1^{\frac{1}{m}}$ is a principal (see §2) surd may be arranged according to the powers of $\Delta_1^{\frac{1}{m}}$ lower than the $m^{\text{th}}$, thus,

$$\frac{1}{m}\left(g_1 + k_1 \Delta_1^{\frac{1}{m}} + a_1 \Delta_1^{\frac{2}{m}} + b_1 \Delta_1^{\frac{3}{m}} + \ldots + e_1 \Delta_1^{\frac{m-2}{m}} + h_1 \Delta_1^{\frac{m-1}{m}}\right) \quad (1)$$

where $g_1$, $k_1$, $a_1$, etc., are clear of $\Delta_1^{\frac{1}{m}}$.

§5. If an algebrical expression $r_1$, arranged as in (1), be zero, while the coefficients $g_1$, $k_1$, etc., are not all zero, an equation

$$\omega \Delta_1^{\frac{1}{m}} = l_1 \tag{2}$$

must subsist; where $\omega$ is an $m^{\text{th}}$ root of unity; and $l_1$ is an expression involving only such surds exclusive of $\Delta_1^{\frac{1}{m}}$ as occur in $r_1$. For, let the first of the coefficients $h_1$, $e_1$, etc., proceeding in the order of the descending powers of $\Delta_1^{\frac{1}{m}}$, that is not zero, be $n_1$, the coefficient of $\Delta_1^{\frac{s}{m}}$. Then we may put

$$mr_1 = n_1 \{ f ( \Delta_1^{\frac{1}{m}} ) \} = n_1 \Delta_1^{\frac{s}{m}} + \text{etc.} = 0.$$

Because $\Delta_1^{\frac{1}{m}}$ is a root of each of the equations $f(x) = 0$ and $x^m - \Delta_1 = 0$, $f(x)$ and $x^m - \Delta_1$ have a common measure. Let their H. C. M., involving only such surds as occur in $f(x)$ and $x^m - \Delta_1$, be $\varphi(x)$. Then, because $\varphi(x)$ is a measure of $x^m - \Delta_1$, the roots of the equation

$$\varphi(x) = x^c + p_1 x^{c-1} + p_2 x^{c-2} + \text{etc.} = 0$$

are $\Delta_1^{\frac{1}{m}}$, $\omega_1 \Delta_1^{\frac{1}{m}}$, $\omega_2 \Delta_1^{\frac{1}{m}}$, ...., $\omega_{c-1} \Delta_1^{\frac{1}{m}}$; where $\omega_1$, $\omega_2$, etc., are distinct primitive $m^{\text{th}}$ roots of unity. Therefore,

$$\Delta_1^{\frac{c}{m}} (\omega_1 \omega_2 ..) (-1)^c = p_c.$$

Now $c$ is a whole number less than $m$ but not zero; and, by §1, $m$ is prime. Therefore there are whole numbers $n$ and $h$ such that

$$\Delta_1^{\frac{cn}{m}} (\omega_1 \omega_2 ..)^n (-1)^{cn} = \Delta_1^{\frac{1}{m}} \Delta_1^h (\omega_1 \omega_2 ..)^n (-1)^{cn} = p_c^n.$$

Therefore, if $(\omega_1 \omega_2 ..)^n = \omega$, and $l_1 \Delta_1^h (-1)^{cn} = p_c^n$, $\omega \Delta_1^{\frac{1}{m}} = l_1$.

§6. Let $r_1$ be an algebraical expression in which no root of unity having a rational value occurs in the surd form $1^{\frac{1}{m}}$. Also let there be in $r_1$ no surd $\Delta_1^{\frac{1}{m}}$ not a root of unity, such that

$$\Delta_1^{\frac{1}{m}} = e_1 , \qquad (3)$$

where $e_1$ is an expression involving no surds of so high a rank as $\Delta_1^{\frac{1}{m}}$ except such as either are roots of unity, or occur in $r_1$ being at the same time distinct from $\Delta_1^{\frac{1}{m}}$. The expression $r_1$ may then be said to have been *simplified* or to be *in a simple state.*

§7. Some illustrations of the definition in §6 may be given. The root $8^{\frac{1}{3}}$ cannot occur in a simplified expression $r_1$ ; for its value is $2\omega$, $\omega$ being a third root of unity ; but the equation $8^{\frac{1}{3}} = 2\omega$ is of the inadmissible type (3). Again, the root $\surd 5$ cannot occur in a simplified expression ; for, $\omega_1$ being a primitive fifth root of unity, $\surd 5 = 2 (\omega_1 + \omega_1^4) + 1$ ; an equation of the type (3). Once more, a root of the cubic equation $x^3 - 3x - 4 = 0$, in the form $(2 + \surd 3)^{\frac{1}{3}} + (2 - \surd 3)^{\frac{1}{3}}$, is not in a simple state, because $(2 - \surd 3)^{\frac{1}{3}} = (2 - \surd 3) (2 + \surd 3)^{\frac{2}{3}}$.

§8. Let
$$p_1 \Delta_1^{\frac{m-1}{m}} + p_2 \Delta_1^{\frac{m-1}{m}} + \,.\,. + p_m = 0 ; \qquad (4)$$
where $\Delta_1^{\frac{1}{m}}$ is a surd occurring in a simplified expression $r_1$ ; and $p_1$, $p_2$, etc., involve no surds of so high a rank as $\Delta_1^{\frac{1}{m}}$, except such as either are roots of unity, or occur in $r_1$ being at the same time distinct from $\Delta_1^{\frac{1}{m}}$. The coefficients $p_1$, $p_2$, etc., must be zero separately. For, by §5, if they were not, we should have $\omega \Delta_1^{\frac{1}{m}} = l_1$, $\omega$ being an $m^{\text{th}}$ root of unity, and $l_1$ involving only surds in (4) distinct from $\Delta_1^{\frac{1}{m}}$ ; an equation of the inadmissible type (3).

§9. The expression $r_1$ being in a simple state, we may use $R$ as a generic symbol to include the various particular expressions, say $r_1$, $r_2$, $r_3$, etc., obtained by assigning all their possible values to the surds involved in $r_1$, with the restriction that, where the base of a surd is unity, the rational value of the surd is not to be taken into account. These particular expressions, not necessarily all unequal, may be called *the particular cognate forms of R.* For instance, if $r_1 = 1^{\frac{1}{3}}$, $R$ has two particular cognate forms, the rational value of the third root of unity not being counted. If $r_1 = (1 + \surd 2)^{\frac{1}{3}}$, $R$ has six particular cognate forms all unequal. Should $r_1 = (2 + \surd 3)^{\frac{1}{3}} + (2 - \surd 3)(2 + \surd 3)^{\frac{2}{3}}$, $R$ has six particular cognate forms, but only three unequal, each of the unequal forms occurring twice.

§10. Proposition I. An algebraical expression $r_1$ can always be brought to a simple state.

For $r_1$ may be cleared of all surds such as $1^{\frac{1}{m}}$ having a rational value. Suppose that $r_1$ then involves a surd $\Delta_1^{\frac{1}{m}}$, not a root of unity, by means of which an equation such as (3) can be formed. Substitute for $\Delta_1^{\frac{1}{m}}$ in $r_1$ its value $e_1$ as thus given. The result will be to eliminate $\Delta_1^{\frac{1}{m}}$ from $r_1$ without introducing into the expression any *new* surd as high in rank as $\Delta_1^{\frac{1}{m}}$, and at the same time not a root of unity. By continuing to make all the eliminations of this kind that are possible, we at last reach a point where no equation of the type (3) can any longer be formed. Then because, by the course that has been pursued, no roots of the form $1^{\frac{1}{m}}$ having a rational value have been left in $r_1$, $r_1$ is in a simple state.

§11. It is known that, if $N$ be any whole number, the equation whose roots are the primitive $N^{\text{th}}$ roots of unity is rational and irreducible.

§12. Let $N$ be the continued product of the distinct prime numbers $n$, $a$, $b$, etc. Let $\omega_1$ be a primitive $n^{\text{th}}$ root of unity, $\theta_1$ a primitive $a^{\text{th}}$ root of unity, and so on. Let $\omega$ represent any one indifferently of the primitive $n^{\text{th}}$ roots of unity, $\theta$ any one indifferently of the primitive $a^{\text{th}}$ roots of unity, and so on. Let $f(\omega_1, \theta_1, \text{etc.,})$ be a rational function of $\omega_1$, $\theta_1$, etc. Then a corollary from §11 is, that if $f(\omega_1, \theta_1, \text{etc.}) = 0$, $f(\omega, \theta, \text{etc.}) = 0$. For $t_1$ being a primitive $N^{\text{th}}$ root of unity, and $t$ representing any one indifferently of the primitive $N^{\text{th}}$ roots of unity, we may put

$$f(\omega_1, \theta_1, \text{etc.}) = a_1 t_1^{N-1} + a_2 t_1^{N-2} + \text{etc.} = 0,$$

$$\text{and } f(\omega, \theta, \text{etc.}) = a_1 t^{N-1} + a_2 t^{N-2} + \text{etc.};$$

where the coefficients $a_1$, $a_2$, etc., are rational. Should these coefficients be all zero, $f(\omega, \theta, \text{etc.}) = 0$. Should they not be all zero, let $a_r$ be the first that is not zero. Then we may put

$$f(\omega_1, \theta_1, \text{etc.}) = a_r \{ \phi(t_1) \} = a_r t_1^{N-r} + \text{etc.} = 0.$$

Therefore, $t_1$ is a root of the rational equation $\varphi(x) = 0$, being at the same time a root of the rational (see §11) equation $\psi(x) = 0$, whose roots are the primitive $N^{th}$ roots of unity. Hence $\psi(x)$ and $\varphi(x)$ have a common measure. But by §11, $\psi(x)$ is irreducible. Therefore it is a measure of $\varphi(x)$; and the roots of the equation $\psi(x) = 0$ are roots of the equation $\varphi(x) = 0$. Therefore,

$$f(\omega, \theta, \text{etc.}) = a_r \left\{ \varphi(t) \right\} = 0.$$

§13. Another corollary is, that if

$$f(\omega_1, \theta_1, \text{etc.}) = h_1 \omega_1^{n-1} + h_2 \omega_1^{n-2} + \ldots + h_n = 0,$$

where $h_1$, $h_2$, etc., are clear of $\omega_1$, the coefficients $h_1$, $h_2$, etc., are all equal to one another. For, by §12, because $f(\omega_1, \theta_1, \text{etc.}) = 0$, $f(\omega, \theta_1, \text{etc.}) = 0$. Therefore $\omega \left\{ f(\omega, \theta_1, \text{etc.}) \right\} = 0$. In $\omega \left\{ f(\omega, \theta_1, \text{etc.}) \right\}$ give $\omega$ successively its $n - 1$ different values. Then, in addition,

$nh_1 = h_1 + h_2 + \ldots + h_n$. Similarly, $nh_2 = h_1 + h_2 + \ldots + h_n \therefore h_1 = h_2$. In like manner all the terms $h_1$, $h_2$, etc., are equal to one another.

§14. Proposition II. If the simplified expression $r_1$, one of the particular cognate forms of $R$, be a root of the rational equation $F(x) = 0$, all the particular cognate forms of $R$ are roots of that equation.

For, let $r_2$ be a particular cognate form of $R$. By §12, the law to be established holds when there are no surds in $r_1$ that are not roots of unity. It will be kept in view that, according to §1, when roots of unity are spoken of, such roots are meant as $1^{\frac{1}{m}}$, $m$ being a prime number. Assume the law to have been found good for all expressions that do not involve more than $n - 1$ distinct surds that are not roots of unity; then, making the hypothesis that $r_1$ involves not more than $n$ distinct surds that are not roots of unity, the law can be shown still to hold; in which case it must hold universally. For, let $\Delta_1^{\frac{1}{m}}$, not a root of unity, be a surd of the highest rank (see §3) in $r_1$. Then $F(r_1)$ may be taken to be the expression (1), and $F(r_2)$ to be the expression formed from (1) by selecting particular values of the surds involved under the restriction specified in §9. In passing from $r_1$ to $r_2$, let $\Delta_1^{\frac{1}{m}}$, $a_1$, etc., become respectively $\Delta_2^{\frac{1}{m}}$, $a_2$, etc. Then

$$m\left\{F(r_1)\right\} = h_1 \Delta_1^{\frac{m-1}{m}} + e_1 \Delta_1^{\frac{m-2}{m}} + \text{etc.} = 0,$$

$$\text{and } m\left\{F(r_1)\right\} = h_2 \Delta_2^{\frac{m-1}{m}} + e_2 \Delta_2^{\frac{m-2}{m}} + \text{etc.}$$

By §8, because $r_1$ is in a simple state, and $F(r_1) = 0$, the coefficients $h_1$, $e_1$, etc., are zero separately. But $h_1$ is clear of the surd $\Delta_1^{\frac{1}{m}}$. It therefore does not involve more than $n - 1$ distinct surds that are not roots of unity. Therefore, on the assumption on which we are proceeding, because $h_1 = 0$, $h_2 = 0$. In like manner, $e_2 = 0$, and so on. Therefore $F(r_2) = 0$.

§15. *Cor.* Let the simplified expression $r_1$ be the root of an equation $F(x) = 0$ whose coefficients involve certain surds $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc., that have the same determinate values in $r_1$ as in $F(x)$. Then, if $r_2$ be a particular cognate form of $R$ in which the surds $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc., retain the determinate values belonging to them in $r_1$, $r_2$ is a root of the equation $F(x) = 0$. For, $F(r_1) = 0$. Therefore, by the Proposition, $F(R) = 0$. Let $R$, restricted by the condition that the surds $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc., retain the determinate values belonging to them in $r_1$, be $R'$. Then $F(R') = 0$. A particular case of this is $F(r_2) = 0$. The corollary established simply means that the surds $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc., may be taken to be rational for the purpose in hand.

§16. The simplified expression $r_1$ being one of the particular cognate forms of $R$, let

$$r_1, r_a, \text{ etc.} \tag{5}$$

be the entire series of the particular cognate forms of $R$, not necessarily unequal to one another. Then, if the equation whose roots are the terms in (5) be $X = 0$, $X$ is rational. In like manner, if those particular cognate forms of $R$, not necessarily unequal, that are obtained when certain surds $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc., retain the determinate values belonging to them in $r_1$, be

$$r_1, r_c, \text{ etc.} \tag{6}$$

and if the equation whose roots are the terms in (6) be $X' = 0$, $X'$ involves only surds found in the series $z_1^{\frac{1}{n}}, u_1^{\frac{1}{s}}$, etc. This is substantially proved by Legendre in his Théorie des Nombres, §487, third edition.

§17. Proposition III. The unequal particular cognate forms of $R$, the generic expression under which the simplified expression $r_1$ falls, are the roots of a rational irreducible equation; and each of the unequal particular cognate forms occurs the same number of times in the series of the cognate forms.

As in §16, let the entire series of the particular cognate forms of $R$ be the terms in (5), the equation that has these terms for its roots being $X = 0$. By §16, $X$ is rational. Should $X$ not be irreducible, it has a rational irreducible factor, say $F(x)$, such that $r_1$ is a root of the equation $F(x) = 0$. By Prop. II., because $r_1$ is in a simple state, all the terms in (5) are roots of the equation $F(x) = 0$, while at the same time, because $F(x)$ is a factor of $X$, all the roots of the equation are terms in (5). And the equation $F(x) = 0$, being irreducible, has no equal roots. Therefore its roots are the unequal terms in (5). Should $F(x)$ not be identical with $X$, put

$$X = \{F(x)\}\ \{\varphi(x)\}.$$

Because $X$ and $F(x)$ are rational, $\varphi(x)$ is rational. Then, since $\varphi(x)$ is a measure of $X$, and the equation $F(x) = 0$ has for its its roots the unequal roots of the equation $X = 0$, the equations $F(x) = 0$ and $\varphi(x) = 0$ have a root in common. Consequently, since $F(x)$ is irreducible, it is a measure of $\varphi(x)$. Therefore $\{F(x)\}^2$ is a measure of $X$. Going on in this way we ultimately get $X = \{F(x)\}^N$; which means that each of the particular cognate forms of $R$ has its value repeated $N$ times in the series of the particular cognate forms.

§18. *Cor.* 1. The series (6) consisting of those particular cognate forms of $R$ in which certain surds $z_1^{\frac{1}{n}}$, $u_1^{\frac{1}{s}}$, etc., retain the determinate values belonging to them in $r_1$, each of the unequal terms in (6) occurs the same number of times in (6); and the unequal terms in (6) are the roots of an irreducible equation whose coefficients involve only surds found in the series $z_1^{\frac{1}{n}}$, $u_1^{\frac{1}{s}}$, etc. Should $X'$ not be irreducible, by which in such a case is meant incapable of being broken into lower factors involving only surds occurring in $X'$, let it have the irreducible factor $X''$. That is to say, $X''$ involves only surds occurring in $X'$, and has itself no lower factor involving only surds that occur in $X''$. We may take $r_1$ to be a root of the equation $X'' = 0$. Then, by Cor. Prop. II., all the terms in (6) are roots of that equation, all the roots of the equation being at the same time terms in (6). And the equation $X'' = 0$ being irreducible, has no equal roots. Therefore its roots are the unequal terms in (6). Put

$X' = (X'')(X''')$. Then, by the line of reasoning followed in the Proposition, $X'''$ has a measure identical with $X''$. And so on. Ultimately $X' = (X'')^N$.

§19. *Cor.* 2. If $r_2$, one of the particular cognate forms of $R$, be zero, all the particular cognate forms of $R$ are zero. For, by the proposition, the particular cognate forms of $R$ are the roots of a rational irreducible equation $F(x) = 0$. And $r_2$, one of the roots of that equation, is zero, but the only rational irreducible equation that has zero for a root is $x = 0$. Therefore $F(x) = x = 0$. In fact, in the case supposed, the simplified expression $r_1$ is zero, and $R$ has no particular cognate forms distinct from $r_1$.

§20. Proposition IV. Let $N$ be the continued product of the distinct prime numbers $n$, $a$, etc. Let $\omega_1$ be a primitive $n^{\text{th}}$ root of unity, $\theta_1$ a primitive $a^{\text{th}}$ root of unity, and so on. Then if the equation

$$F(x) = x^d + b_1 x^{d-1} + b_2 x^{d-2} + \text{etc.} = 0$$

be one in which the coefficients $b_1$, $b_2$, etc., are rational functions of $\omega_1$, $\theta_1$, etc., and if all the primitive $n^{\text{th}}$ roots of unity, which, when substituted for $\omega_1$ in $F(x)$, leave $F(x)$ unaltered, be

$$\omega_1, \omega_2, \ldots, \omega_s, \tag{7}$$

the series (7) either consists of a single term or it is made up of a cycle of primitive $n^{\text{th}}$ roots of unity,

$$\omega_1, \omega_1^{\lambda}, \omega_1^{\lambda^2}, \ldots, \omega_1^{\lambda^{s-1}}; \tag{18}$$

that is to say, no term in (8) after the first is equal to the first, but $\omega_1^{\lambda^s} = \omega_1$. Also, if (let it be kept in view that $n$ is prime) the cycle that contains all the primitive $n^{\text{th}}$ roots of unity be

$$\omega_1, \omega_1^{\beta}, \omega_1^{\beta^2}, \ldots, \omega_1^{\beta^{n-2}}, \tag{9}$$

and if $C_1$ be the sum of the terms in the cycle (8), the form of $F(x)$ is

$$F(x) = x^d - (p_1C_1 + p_2C_2 + \ldots + p_mC_m)\,x^{d-1} + (q_1C_1 + q_2C_2 + \text{etc.})\,x^{d-2} + \text{etc.} \tag{10}$$

where each of the expressions in the series $C_1$, $C_2$, $C_3$, etc., is what the immediately preceding term becomes by changing $\omega_1$ into $\omega_1^{\beta}$, $C_m$ through this change becoming $C_1$; and $p_1$, $p_2$, $q_1$, etc., are clear of $\omega_1$.

For, assuming that there is a term $\omega_2$ in (7) additional to $\omega_1$, we may take $\omega_2$ to be the first term in (9) after $\omega_1$ that occurs in (7); and it may be considered to be $\omega_1^{\beta^m}$, which may be otherwise written $\omega_1^{\lambda}$. Then, if $F(x)$ be written $\varphi(\omega_1)$, we have by hypothesis

$\varphi(\omega_1) = \varphi(\omega_1^{\lambda})$. Therefore, by §12, changing $\omega_1$ into $\omega_1^{\lambda}$, $\varphi(\omega_1^{\lambda}) = \varphi(\omega_1^{\lambda^2})$. Therefore $\varphi(\omega_1) = \varphi(\omega_1^{\lambda^2})$. And thus ultimately $\varphi(\omega_1) = \varphi(\omega_1^{\lambda^z})$, or $\varphi(\omega_1) = \varphi(\omega_1^{\beta^{mz}})$, $z$ being any whole number positive or negative. But $\omega_1^{\lambda^z}$ includes all the terms in (8). Therefore each of these terms is a term in (7). Suppose if possible that there is a term in (7), say $\omega_1^{\beta^h}$, which does not occur in (8). Then, just as we deduced $\varphi(\omega_1) = \varphi(\omega_1^{\beta^{mz}})$ from the equation $\varphi(\omega_1) = \varphi(\omega_1^{\beta^m})$, we can, because still farther $\varphi(\omega_1) = \varphi(\omega_1^{\beta^h})$, deduce $\varphi(\omega_1) = \varphi(\omega_1^{\beta^{mz+hu}})$. Because $\omega_1^{\beta^h}$ lies outside the cycle (8), $h$ is not a multiple of $m$. And it is not less than $m$, because $\omega_1^{\beta^m}$ is the first term in (9) after $\omega_1$, which, when substituted for $\omega_1$ in $\varphi(\omega_1)$, leaves $\varphi(\omega_1)$ unaltered. Therefore $h = qm + v$, where $q$ and $v$ are whole numbers, and $v$ is less than $m$ but not zero. Put

$$z = -(h+q), \text{ and } u = m+1 \therefore mz+hu = v \therefore \varphi(\omega_1) = \varphi(\omega_1^{\beta^v});$$

which, because $v$ is less than $m$ but not zero, and $\omega_1^{\beta^m}$ is the first term in (9) after $\omega_1$ which, when substituted for $\omega_1$ in $\varphi(\omega_1)$, leaves $\varphi(\omega_1)$ unaltered, is impossible. Hence, no term in (7) lies outside the cycle (8), while it has also been shown that all the terms in (8) are terms in (7). Therefore the terms in (7) are identical with those constituting the cycle (8). We have now to determine the form of $F(x)$. The expressions, $C_1$, $C_2$, etc., taken together, are the sum of the terms in (9). Therefore $C_1 + C_2 + \ldots . + C_m = -1$. (11)
Because (9) contains all the primitive $n^{\text{th}}$ roots of unity, we may put

$$F(x) = x^d - \{p + (p+p_1)\omega_1 + (p+p_2)\omega_1^{\beta} + \text{etc.}\}x^{d-1} + \text{etc.}; \quad (12)$$

where $p$, $p_1$, etc., are clear of $\omega_1$. But $F(x)$ remains unaltered when $\omega_1$ is changed into $\omega_1^{\beta^m}$. Therefore

$$F(x) = x^d - \{p + (p+p_1)\omega_1^{\beta^m} + \text{etc.}\}x^{d-1} + \text{etc.} \quad (13)$$

Therefore, equating the coefficients of $x^{d-1}$ in (12) and (13),

$$(p - p_1) + \ldots . + (p_{m+1} - p_1)\omega_1^{\beta^m} + \text{etc.} = 0.$$

Here, by §13, the coefficients of the different powers of $\omega_1$ have all the same value. And one of them, $p - p_1$, is zero. Therefore

$p_{m+1} = p_1$. That is to say, the coefficient of $\omega_1^{\beta^m}$ or $\omega_1^{\lambda}$ is the same as that of $\omega_1$. In like manner the coefficients of all the terms in (8) are the same. Therefore one group of the terms that together make up the coefficient of $x^{d-1}$ in (12) is properly represented by $-(p+p_1)C_1$. In the same way another group is properly represented by $-(p+p_2)C_2$, and so on. Hence

$$F(x) = x^d - \{p + (p+p_1)\,C_1 + (p+p_2)\,C_2 + \text{etc.}\}x^{d-1} + \text{etc.}$$

And by (11) this is equivalent to (10). The form of $F(x)$ has been deduced on the assumption that the series (7) contains more than one term; but, should the series (7) consist of a single term, the result obtained would still hold good, only in that case each of the expressions $C_1$, $C_2$, etc., would be a primitive $n^{\text{th}}$ root of unity.

§21. A simplified expression will not cease to be in a simple state, if we suppose that any surd that can be eliminated from it, without the introduction of any new surd, has been eliminated.

§22. Proposition V. In the simplified expression $r_1$, one of the particular cognate forms of $R$, modified according to §21, let the surd $\Delta_1^{\frac{1}{m}}$ of the highest rank be not a root (see §1) of unity. Then, if the particular cognate forms of $R$ obtained by changing $\Delta_1^{\frac{1}{m}}$ in $r_1$ successively into the different $m^{\text{th}}$ roots of the determinate base $\Delta_1$, be

$$r_1\,,\, r_2\,,\, \ldots\,,\, r_m, \tag{14}$$

these terms are all unequal.

For the terms in (14) are all the particular cognate forms of $R$ obtained when we allow all the surds in $r_1$ except $\Delta_1^{\frac{1}{m}}$ to retain the determinate values belonging to them in $r_1$. Therefore, by Cor. 1, Prop. III., each of the unequal terms in (14) has its value repeated the same number of times in that series. Let $u$ be the number of the unequal terms in (14), and let each occur $c$ times. Then $uc = m$. Suppose if possible that $u = 1$. This means that all the terms in (14) are equal. Therefore, $r_1$ being the expression (1),

$$mr_1 = r_1 + r_2 + \ldots + \text{etc.} = g_1.$$

Therefore the surd $\Delta_1^{\frac{1}{m}}$ can be eliminated from $r_1$ without the introduction of any new surd; which, by §21, is impossible. Therefore $u$ is not unity. But, by §1, $m$ is a prime number. And $m = uc$. Therefore $c = 1$ and $u = m$. This means that all the terms in (14) are unequal.

§23. *Cor.* 1. Let $r_{a+1}$ be any one of the particular cognate forms of $R$; and let $\Delta_{a+1}^{\frac{1}{m}}$, $h_{a+1}$, etc., be respectively what $\Delta_1^{\frac{1}{m}}$, $h_1$, etc., become in passing from $r_1$ to $r_{a+1}$. Also let the $m$ particular cognate forms of $R$, obtained by changing $\Delta_{a+1}^{\frac{1}{m}}$ in $r_{a+1}$ successively into the different $m^{th}$ roots of $\Delta_{a+1}$, be

$$r_{a+1}\,,\; r_{a+2}\,,\; \ldots\ldots\,,\; r_{a+m}\,. \qquad (15)$$

These terms are all unequal. For, because $\Delta_1^{\frac{1}{m}}$ is a principal surd in $r_1$, and $r_2$ is what $r_1$ becomes when $\Delta_1^{\frac{1}{m}}$ is changed into a surd whose value is $\omega_1\Delta_1^{\frac{1}{m}}$, $\omega_1$ being a primitive $m^{th}$ root of unity. the view may be taken that $r_2$ involves no surds additional to those found in $r_1$, except the primitive $m^{th}$ root of unity $\omega_1$. Therefore $r_1 - r_2$ involves no surds distinct from primitive $m^{th}$ roots of unity that are not found in the simplified expression $r_1$. Therefore $r_1 - r_2$ is in a simple state. Let $r_{a+2}$ be what $r_{a+1}$ becomes by changing $\Delta_{a+1}^{\frac{1}{m}}$ into $\omega_1\Delta_{a+1}^{\frac{1}{m}}$. Then $r_{a+1} - r_{a+2}$ is a particular cognate form of the generic expression under which the simplified expression $r_1 - r_2$ falls. Therefore $r_{a+1} - r_{a+2}$ cannot be zero; for, if it were, $r_1 - r_2$ would, by Cor. 2, Prop. III., be zero; which, by the proposition, is impossible. Hence, the first two terms in (15) are unequal. In like manner all the terms in (15) are unequal.

§24. *Cor.* 2. Let $X_1 = 0$ be the equation whose roots are the terms in (14). When $X_1$ is modified according to §21, it is, by §16, clear of the surd $\Delta_1^{\frac{1}{m}}$. Should it involve any surds that are not roots of unity, take $z_1^{\frac{1}{c}}$ a surd of the highest rank not a root of unity in $X_1$; and, when $z_1^{\frac{1}{c}}$ is changed successively into the different $c^{th}$ roots of the determinate base $z_1$, let

$$X_1\,,\; X_1'\,,\; X_1''\,,\; \ldots\ldots\,,\; X_1^{(c-1)}\,, \qquad (16)$$

be respectively what $X_1$ becomes. Any term in (16), as $X_1'$, being selected, the $m$ roots of the equation $X_1' = 0$ are unequal particular cognate forms of $R$. For, $z_2^{\frac{1}{c}}$ being a $c^{\text{th}}$ root of $z_1$ distinct from $z_1^{\frac{1}{c}}$, let $r_{a+1}$ be what $r_1$ becomes when $z_1^{\frac{1}{c}}$ becomes $z_2^{\frac{1}{c}}$; the expressions $\Delta_1^{\frac{1}{m}}$, $h_1$, etc., at the same time becoming $\Delta_{a+1}^{\frac{1}{m}}$, $h_{a+1}$, etc. Then we may put

$$X_1 = x^m + (bz_1^{\frac{c-1}{c}} + dz_1^{\frac{c-2}{c}} + \text{etc.})\, x^{m-1} + \text{etc.}; \qquad (17)$$

where $b$, $d$, etc., are clear of $z_1^{\frac{1}{c}}$. Therefore, because $r_1$ is a root of the equation $X_1 = 0$,

$$\left\{ \frac{1}{m} (h_1 \Delta_1^{\frac{m-1}{m}} + \text{etc.}) \right\}^m$$
$$+ (bz_1^{\frac{c-1}{c}} + dz_1^{\frac{c-2}{c}} + \text{etc.}) \left\{ \frac{1}{m} (h_1 \Delta_1^{\frac{m-1}{m}} + \text{etc.}) \right\}^{m-1} + \text{etc.} = 0.$$

All the surds in this equation occur in the simplified expression $r_1$. Therefore, by Prop. II.,

$$\left\{ \frac{1}{m} (h^{a+1} \Delta_{a+1}^{\frac{m-1}{m}} + \text{etc.}) \right\}^m$$
$$+ (bz_2^{\frac{c-1}{c}} + dz_2^{\frac{c-2}{c}} + \text{etc}) \left\{ \frac{1}{m} (h_{a+1} \Delta_{a+1}^{\frac{m-1}{m}} + \text{etc.}) \right\}^{m-1} + \text{etc.} = 0.$$

Therefore $\frac{1}{m} (h_{a+1} \Delta_{a+1}^{\frac{m-1}{m}} + \text{etc.})$ or $r_{a+1}$ is a root of the equation

$$X_1' = x^m + (bz_2^{\frac{c-1}{c}} + \text{etc.})\, x^{m-1} + \text{etc.} = 0. \qquad (18)$$

Therefore also, by Cor. Prop. II., all the terms in (15) are roots of that equation. And, by Cor. 1, the terms in (15) are all unequal. Therefore the equation $X_1' = 0$ has $m$ unequal particular cognate forms of $R$ for its roots.

§25. *Cor.* 3. No two of the expressions in (16), as $x_1$ and $X_1'$, are identical with one another. For, in order that $X_1$ and $X_1'$ might be identical, the coefficients of the several powers of $x$ in $X_1$ would need to be equal to those of the corresponding powers of $x$ in $X_1'$; but, if one of the coefficients of $X_1$ be selected in which $z_1^{\frac{1}{c}}$ is present, this coefficient can be shown to be unequal to the corresponding coefficient in $X_1'$ in the same way in which the terms in (15) were proved to be all unequal.

§26. *Cor.* 4. Any two of the terms in (16), as $X_1$ and $X_1'$, being selected, the equations $X_1 = 0$ and $X_1' = 0$ have no root in common. For, suppose, if possible, that these equations have a root in common. Taking the forms of $X_1$ and $X_1'$ in (17) and (18), since $r_1$ is a root of the equation $X_1' = 0$,

$$r_1^m + (bz_2^{\frac{c-1}{c}} + \text{etc.})\, r_1^{m-1} + \text{etc.} = 0. \qquad (19)$$

All the surds in this equation except $z_2^{\frac{1}{c}}$ occur in $r_1$. It is impossible that $z_2^{\frac{1}{c}}$ can occur in $r_1$; for, $z_1^{\frac{1}{c}}$ occurs in $r_1$; and $z_2^{\frac{1}{c}} = \theta_1 z_1^{\frac{1}{c}}$, $\theta_1$ being a primitive $c^{\text{th}}$ root of unity; but this equation, if both $z_1^{\frac{1}{c}}$ and $z_2^{\frac{1}{c}}$ occurred in $r_1$, would be of the inadmissible type (3). Since $z_2^{\frac{1}{c}}$ does not occur in $r_1$, it is a principal (see §2) surd in (19). We may, therefore, keeping in view that $r_1$ is the expression (1) in which $\Delta_1^{\frac{1}{m}}$ is a principal surd, arrange (19) thus,

$$\varphi\,(\Delta_1^{\frac{1}{m}}) = \Delta_1^{\frac{m-1}{m}}\,(p_1 z_2^{\frac{c-1}{c}} + p_2 z_2^{\frac{c-2}{c}} + \text{etc.})$$

$$+ \Delta_1^{\frac{m-2}{m}}\,(q_1 z_2^{\frac{c-1}{c}} + q_2 z_2^{\frac{c-2}{c}} + \text{etc.}) + \text{etc.} = 0\,; \qquad (20)$$

where $p_1$, $q_1$, etc., are clear of $z_2^{\frac{1}{c}}$. Then, $\omega_1$ being a primitive $m^{\text{th}}$ root of unity such that, by changing $\Delta_1^{\frac{1}{m}}$ into the $m^{\text{th}}$ root of $\Delta_1$ whose value is $\omega_1 \Delta_1^{\frac{1}{m}}$, $r_1$ becomes $r_2$,

$$\varphi\left(\omega_1 \Delta_1^{\frac{1}{m}}\right) = \omega_1^{m-1} \Delta_1^{\frac{m-1}{m}} \left(p_1 z_2^{\frac{c-1}{c}} + \text{etc.}\right)$$

$$+ \omega_1^{m-2} \Delta_1^{\frac{m-1}{m}} \left(q_1 z_2^{\frac{c-1}{c}} + \text{etc.}\right) + \text{etc.} \tag{21}$$

The coefficients of the several powers of $\Delta_1^{\frac{1}{m}}$ in $\varphi\left(\Delta_1^{\frac{1}{m}}\right)$ cannot be all zero; for, if they were, we should have, from (21), $\varphi\left(\omega_1 \Delta_1^{\frac{1}{m}}\right) = 0$. This means that $r_2$ is a root of the equation $X_1' = 0$. But in like manner all the terms in (14) would be roots of that equation, and $X_1'$ would be identical with $X$; which, by Cor. 3, is impossible. Since the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ in $\varphi\left(\Delta_1^{\frac{1}{m}}\right)$ are not all zero, the equation (20) gives us, by §5, $\omega \Delta_1^{\frac{1}{m}} = l_1$, $\omega$ being an $m^{\text{th}}$ root of unity, and $l_1$ involving only surds in $\varphi\left(\Delta_1^{\frac{1}{m}}\right)$exclusive of $\Delta_1^{\frac{1}{m}}$. In $l_1$ we may conceive $z_2^{\frac{1}{c}}$ changed into $\theta_1 z_1^{\frac{1}{c}}$. Then $l_1$ involves only surds distinct from $\Delta_1^{\frac{1}{m}}$, all of them except the primitive $c^{\text{th}}$ root of unity $\theta_1$ being surds that occur in $r_1$. This makes the equation $\omega \Delta_1^{\frac{1}{m}} = l_1$ of the inadmissible type (3). Hence the equations $X_1 = 0$ and $X_1' = 0$ have no root in common.

§27. *Cor.* 5. Let $X_2$ be the continued product of the terms in (16). Then $X_2$, modified according to §21, is clear of $z_1^{\frac{1}{c}}$, in the same way in which $X_1$ is clear of $\Delta_1^{\frac{1}{m}}$. Also since, by Cor. 2, each of the equations $X_1 = 0$, $X_1' = 0$, etc., has $m$ unequal particular cognate forms of $R$ for its roots, and since, by Cor. 4, no two of these equations have a root in common, the $mc$ roots of the equation $X_2 = 0$ are unequal particular cognate forms of $R$.

§28. PROPOSITION VI. Let the simplified expression $r_1$, modified according to §21, be a root of the rational irreducible equation of the $N^{\text{th}}$ degree, $F(x) = 0$. Then if $\Delta_1^{\frac{1}{m}}$, not a root of unity, be a surd of the highest rank in $r_1$, $N$ is a multiple of $m$. But if $r_1$ involve only surds that are roots of unity, one of them being the primitive $n^{\text{th}}$ root of unity, $N$ is a multiple of a measure of $n - 1$.

First, let $\Delta_1^{\frac{1}{m}}$, not a root of unity, be a surd of the highest rank in $r_1$. Taking the expression (1) to be $r_1$, let $X_1$ be formed as in §24, and let it be modified according to §21. It is clear of the surd $\Delta_1^{\frac{1}{m}}$. Should it involve a surd that is not a root of unity, let $X_2$ be formed as in §27. Setting out from $r_1$ we arrived by one step at $X_1$, an expression clear of $\Delta_1^{\frac{1}{m}}$, and such that the roots of the equation $X_1 = 0$ are unequal particular cognate forms of $R$. A second step brought us to $X_2$, an expression clear of the additional surd $z_1^{\frac{1}{c}}$, and such that the $mc$ roots of the equation $X_2 = 0$ are unequal particular cognate forms of $R$. Thus we can go on till, in the series $X_1$, $X_2$, etc., we reach a term $X_e$ into which no surds enter that are not roots of unity, the $mc \ldots\ldots l$ roots of the equation $X_e = 0$ being unequal particular cognate forms of $R$. Should $X_e$ modified according to §21, not be rational, its form, by Prop. IV., putting $d$ for $mc \ldots\ldots l$, is

$$X_e = x_d - (p_1C_1 + \ldots\ldots + p_mC_m)x^{d-1} + (q_1C_1 + \ldots\ldots + q_mC_m)x^{d-2} + \text{etc.};$$

where, one of the roots occurring in $X_e$ being the primitive $n^{\text{th}}$ root of unity $\omega_1$, the coefficients $p_1$, $q_1$, etc., are clear of $\omega_1$; and $C_1$ is the sum of the cycle of primitive $n^{\text{th}}$ roots of unity (8) containing $s$ or $\frac{n-1}{m}$ terms; and, the cycle (9) containing all the primitive $n^{\text{th}}$ roots of unity, the change of $\omega_1$ into $\omega_1^{\beta}$ causes $C_1$ to become $C_2$, and $C_2$ to become $C_3$, and so on, $C_m$ becoming $C_1$. As was explained at the close of §20, the cycle (8) may be reduced to a single term, which is then identical with $C_1$. It will also not be forgotten that the roots of unity such as the $n^{\text{th}}$ here spoken of are, according to §1, subject to the condition that the numbers such as $n$ are prime. When $C_1$ in $X_e$ is changed successively into $C_1$, $C_2$, etc., let $X_e$ become

$$X_e\,,\ X_e'\,,\ X_e''\,,\ \ldots\ldots,\ X_e^{(m-1)} \tag{22}$$

If $X_{e+1}$ be the continued product of the terms in (22), the $dm$ roots of the equation $X_{e+1} = 0$ can be shown to be unequal particular cognate forms of $R$. For, no two terms in (22) as $X_e$ and $X_e'$ are identical; because, if they were, $X_e$ would remain unaltered by the change of $\omega_1$ into $\omega_1^{\beta}$; which, by Prop. IV., because $\omega_1^{\beta}$ is not a term in the cycle (8), is impossible. It follows that no two of the equations $X_e = 0$, $X_e' = 0$, etc., have a root in common. For, if the equations $X_e = 0$, and $X_e' = 0$ had a root in common, since $X_e$ and $X_e'$ are not identical, $X_e$ would have a lower measure involving only surds found in $X_e$, because the surds in $X_e'$ are the same with those in $X_e$. Let $\varphi(x)$ be this lower measure of $X_e$, and let $r_1$ be a root of the equation $\varphi(x) = 0$. Then, by Cor. Prop. II., all the $d$ roots of the equation $X_e = 0$ are roots of the equation $\varphi(x) = 0$; which is impossible. In the same way it can be proved that no equation in the series $X_e = 0$, $X_e' = 0$, etc., has equal roots. Since no one of these equations has equal roots, and no two of them have a root in common, the $dm$ roots of the equation $X_{e+1} = 0$ are unequal particular cognate forms of $R$. Also $X_{e+1}$, modified according to §21, is clear of the primitive $n^{\text{th}}$ roots of unity. Should $X_{e+1}$ not be rational, we can deal with it as we did with $X_e$. Going on in this way, we ultimately reach a *rational* expression $X_z$ such that the $dm \ldots. g$ roots of the equation $X_z = 0$ are unequal particular cognate forms of $R$. This equation must be identical with the equation $F(x) = 0$ of which $r_1$ is a root. For, by Prop. III., the equation $F(x) = 0$ has for its roots the unequal particular cognate forms of $R$. Therefore, because the roots of the equation $X_z = 0$ are all unequal and are at the same time particular cognate forms of $R$, $X_z$ must be either a lower measure of $F(x)$ or identical with $F(x)$. But $F(x)$, being irreducible, has no lower measure. Therefore $X_z$ is identical with $F(x)$. Therefore, the equation $F(x) = 0$ being the $N^{\text{th}}$ degree, $N = mc \ldots. lm \ldots. g$. Hence $N$ is a multiple of $m$. This is the result arrived at when $r_1$ involves a surd of the highest rank $\Delta_1^{\frac{1}{m}}$ not a root of unity. Should $r_1$ involve no surds except roots (see §1) of unity, we should then have set out from $X_e$ regarded as identical with $x - r_1$. The result would have been $N = m \ldots. g$. Therefore $N$ is a multiple of $m$; and, because $m$ is here the number of cycles of $s$ terms each, that make up the series of the primitive $n^{\text{th}}$ roots of unity, $ms = n - 1$. Therefore $N$ is a multiple of a measure of $n - 1$.

§29. *Cor.* Let $N$ be a prime number. Then, if $r_1$ involve a surd of the highest rank $\Delta_1^{\frac{1}{m}}$ not a root (see §1) of unity, $N = m$; for, the series of integers $m$, $c$, etc., of which $N$ is the continued product, is reduced to its first term. If $r_1$ involve only surds that are roots of unity, $n - 1$ is a multiple of $N$; for $N = m \ldots . g$; therefore, because $N$ is prime, it is equal to $m$; but $ms = n - 1$; therefore $n - 1 = sN$.

## The Solvable Irreducible Equation of the $m^{\text{th}}$ Degree, $m$ Prime.

§30. The principles that have been established may be illustrated by an examination of the solvable irreducible rational equation of the $m^{\text{th}}$ degree $F(x) = 0$, $m$ being prime. Two cases may be distinguished, though it will be found that the roots can in the two cases be brought under a common form; the one case being that in which the simplified root $r_1$ is, and the other that in which it is not, a rational function of roots of unity, that is, according to §1, of roots of unity having the denominators of their indices prime numbers. The equation $F(x) = 0$ may be said to be in the former case *of the first class*, and in the latter *of the second class.*

## The Equation $F(x) = 0$ of the First Class.

§31. In this case, by Cor. Prop. VI., $r_1$ being modified according to §21, if one of the roots involved in $r_1$ be the primitive $n^{\text{th}}$ root of unity $\omega_1$, $n - 1$ is a multiple of $m$. Also the expression written $X_e$ in Prop. VI. is reduced to $x - r_1$, so that

$$r_1 = p_1 C_1 + p_2 C_2 + \ldots . + p_m C_m .$$

The $m$ roots of the equation $F(x) = 0$ being $r_1$, $r_2$, etc, we must have

$$\left.\begin{array}{l} r_1 = p_1 C_1 + p_2 C_2 + \ldots . + p_m C_m , \\ r_2 = p_m C_1 + p_1 C_2 + \ldots . + p_{m-1} C_m , \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ r_m = p_2 C_1 + p_3 C_2 + \ldots . + p_1 C_m . \end{array}\right\} \quad (23)$$

For, by Prop. II., because $r_1$ is a root of the equation $F(x) = 0$, all the expressions on the right of the equations (23) are roots of that equation. And no two of these expressions are equal to one another. For, take the first two. If these were equal, we should have $(p_m - p_1) C_1 + (p_1 - p_2) C_2 +$ etc. $= 0$. Therefore, by §13, each of the terms $p_m - p_1$, $p_1 - p_2$, etc., is zero. This makes $p_1$, $p_2$, etc., all equal to one another. Therefore $r_1 = - p_1$; so that the primitive $n^{\text{th}}$ root of unity is eliminated from $r_1$; which, by §21, is impossible. Hence the values of the $m$ roots of the equation $F(x) = 0$ are those given in (23).

§32. Let $r_1'$ be one of the particular cognate forms of the generic expression $R$ under which the simplified expression $r_1$ falls. Then, because, by Prop. II., all the particular cognate forms of $R$ are roots of the equation $F(x) = 0$, $r_1'$ is equal to one of the $m$ terms $r_1$, $r_2$, etc., say to $r_z$. I will now show that the changes of the surds involved that cause $r_1$ to become $r_1'$, whose value is $r_z$, cause $r_2$ to receive the value $r_{z+1}$, and $r_3$ to receive the value $r_{z+2}$, and so on. This may appear obvious on the face of the equations (23); but, to prevent misunderstanding, the steps of the deduction are given. Any changes made in $r_1$ must transform $C_1$ into $C_s$, one of the $m$ terms $C_1$, $C_2$, etc. In passing from $r_1$ to $r_1'$, while $C_1$ becomes $C_s$, let $r_2$ become $r_2'$, and $p_1$ become $p_1'$, and $p_2$ become $p_2'$, and so on. The change that causes $C_1$ to become $C_s$ transforms $C_2$ into $C_{s+1}$, and $C_3$ into $C_{s+2}$, and so on. Therefore, it being understood that $p_{m+1}$, $C_{m+1}$, etc., are the same as $p_1$, $C_1$, etc., respectively,

$$r_1' = p_1' C_s + p_2' C_{s+1} + \text{etc.},$$

$$\text{and } r_2' = p_m' C_s + p_1' C_{s+1} + \text{etc.};$$

which may be otherwise written

$$\left.\begin{aligned} r_1' &= p'_{m+2-s}\, C_1 + p'_{m+3-s}\, C_2 + \text{etc.}, \\ r_2' &= p'_{m+1-s}\, C_1 + p'_{m+2-s}\, C_2 + \text{etc.} \end{aligned}\right\} \quad (24)$$

Therefore, form (24) and (23),

$$C_1(p_{m+2-z} - p'_{m+2-z}) + C_2(p_{m+3-z} - p'_{m+3-s}) + \text{etc.} = 0.$$

Therefore, by §13, $p'_{m+2-s} = p_{m+2-z}$, $p'_{m+3-s} = p_{m+3-z}$, etc.

Hence the second of the equations (24) becomes

$$r_2' = p_{m+1-z}\, C_1 + p_{m+2-z}\, C_2 + \text{etc.} = r_{z+1}.$$

Thus $r_2$ is transformed into $r_{z+1}$. In like manner $r_3$ receives the value $r_{z+2}$, and so on.

§33. By Cor. Prop. VI., the primitive $n^{\text{th}}$ root of unity being one of those involved in $r_1$, $n - 1$ is a multiple of $m$. In like manner, if the primitive $a^{\text{th}}$ root of unity be involved in $r_1$, $a - 1$ is a multiple of $m$, and so on. Therefore, if $t_1$ be the primitive $m^{\text{th}}$ root of unity, $t_1$ is distinct from all the roots involved in $r_1$.

§34. From this it follows that, if the circle of roots $r_1, r_2, \ldots,$ $r_m$, be arranged, beginning with $r_c$, in the order $r_c, r_{c+1}, r_{c+2}$, etc., and again, beginning with $r_s$, in the order $r_s, r_{s+1}, r_{s+2}$, etc., and if, $t_1^a$ being one of the primitive $m^{\text{th}}$ roots of unity,

$$r_c + r_{c+1}t_1 + r_{c+2}t_1^2 + \text{etc.} = r_s + r_{s+1}t_1^a + r_{s+2}t_1^{2a} + \text{etc.} \quad (25)$$

$r_c = r_s$. It is understood that in the series $r_c, r_{c+1}$, etc., when $r_m$ is reached, the next in order is $r_1$, so that $r_{m+1}$ is the same as $r_1$, and so on. In like manner $r_{s+1}$ is the same as $r_1$, and so on. Since $r_1, r_2$, etc., do not involve the primitive $m^{\text{th}}$ root of unity $t_1$, we can, by §12, substitute for $t_1$ in (25) successively the different primitive $m^{\text{th}}$ roots of unity. Let this be done. Then, by addition,

$mr_c - (r_1 + r_2 + \text{etc.}) = mr_s - (r_1 + r_2 + \text{etc.})$. Therefore $r_c = r_s$.

§35. Proposition VII. Putting

$$\left.\begin{aligned} \Delta_1^{\frac{1}{m}} &= r_1 + t_1 r_2 + t_1^2 r_3 + \ldots + t_1^{m-1} r_m, \\ \Delta_2^{\frac{1}{m}} &= r_1 + t_1^2 r_2 + t_1^4 r_3 + \ldots + t_1^{2(m-1)} r_m, \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \Delta_{m-1}^{\frac{1}{m}} &= r_1 + t_1^{-1} r_2 + t_1^{-2} r_3 + \ldots + t_1 r_m, \end{aligned}\right\} \quad (26)$$

the terms, $\qquad \Delta_1, \Delta_2, \Delta_3, \ldots, \Delta_{m-1}, \qquad (27)$

are the roots of a rational irreducible equation of the $(m - 1)^{\text{th}}$ degree $\varphi(x) = 0$, which may be said to be *auxiliary* to the equation $F(x) = 0$.

For, let $\Delta$ be the generic expression of which $\Delta_1$ is a particular cognate form; and let $\Delta'$ denote any one indifferently of the $m - 1$ particular cognate forms of $\Delta$ in (27). Because, by §33, the primitive $m^{\text{th}}$ root of unity does not enter into $r_1, r_2$, etc., no changes made in $r_1, r_2$, etc., affect $t_1$. Also, by §32, if $r_1$ becomes $r_z$, $r_2$ becomes $r_{z+1}$, $r_3$ becomes $r_{z+2}$, and so on. Therefore the expression

$$(r_z + tr_{z+1} + t^2 r_{z+2} + \text{etc.})^m,$$

contains all the particular cognate forms of $\Delta$; where $z$ may be any number in the series $1, 2, \ldots, m - 1$; and $t$ denotes any one indifferently of the primitive $m^{\text{th}}$ roots of unity. But this is equal to

$$\left\{ t^{1-z}(r_1 + tr_2 + t^2 r_3 + \text{etc.}) \right\}^m \text{ or } \Delta'.$$

The conclusion established means that all the differences of value that can present themselves in the particular cognate forms of $\Delta$ must arise from the different values of $t$ that are taken in $\Delta'$, while the expressions $r_1$, $r_2$, etc., remain unaltered. And $t$ has not more than $m-1$ values. Hence there are not more than $m-1$ unequal particular cognate forms of $\Delta$. But the $m-1$ forms obtained by taking the different values of $t$ in $\Delta'$ are all unequal. For, selecting $t_1$ and $t_1^a$, two distinct values of $t$, suppose if possible that

$$(r_1 + t_1 r_2 + \text{etc.})^m = (r_1 + t_1^a r_2 + \text{etc.})^m$$

$$\therefore t_1^s (r_1 + t_1 r_2 + \text{etc.}) = r_1 + t_1^a r_2 + \text{etc.},$$

$s$ being a whole number. This may be written

$$r_{m+1-s} + r_{m+2-s}\, t_1 + \text{etc.} = r_1 + t_1^a r_2 + \text{etc.} \qquad (28)$$

Therefore, by §34, $r_{m+1-s} = r_1$. This means, since all the $m$ terms $r_1$, $r_2$, etc., are unequal, that $s = 0$. Hence (28) becomes

$$r_1 + r_2 t_1 + \text{etc.} = r_1 + r_2 t_1^a + \text{etc.}$$

Therefore

$$r_2 + r_3 t_1^a + \text{etc.} = r_2 t_1^{1-a} + r_3 t_1^{2-a} + \text{etc.}$$

$$= r_{a+1} + r_{a+2} t_1 + \text{etc.}$$

Therefore, by §35, $r_2 = r_{a+1}$. Therefore, because all the $m$ terms $r_1$, $r_2$, etc., are unequal, $a = 1$; which, because $t_1$ and $t_1^a$ were supposed to be distinct primitive $m^{\text{th}}$ roots of unity, is impossible. Therefore no two of the terms in (27) are equal to one another. And it has been proved that there is no particular cognate form of $\Delta$ which is not equal to a term in (27). Therefore the terms in (27) are the unequal particular cognate forms of $\Delta$. Therefore, by Prop. III., they are the roots of a rational irreducible equation.

§36. Proposition VIII. The roots of the equation $\varphi(x) = 0$ auxiliary (see §35) to $F(x) = 0$ are rational functions of the primitive $m^{\text{th}}$ root of unity.

For, let the value of $\Delta_1$, obtained from (26), and modified according to §21, be

$$\Delta_1 = k_1 + k_2 t_1 + k_3 t_1^2 + \dots + k_m t_1^{m-1},$$

where $k_1$, $k_2$, etc., are clear of $t_1$. Suppose if possible that $k_1$, $k_2$, etc., are not rational. We may take the primitive $n^{\text{th}}$ root of unity $\omega_1$ to be present in these coefficients. But $\omega_1$ occurs in $r_1$, $r_2$, etc., and therefore also in $\Delta_1$, only in the expressions $C_1$, $C_2$, etc. Therefore $\Delta_1 = d_1 C_1 + \dots + d_m C_m$; where $d_1$, etc., are clear of $\omega_1$. The coefficients $d_1$, $d_2$, etc., cannot all be equal; for this would make $\Delta_1 = -d_1$; which, by §21, is impossible. Hence $m$ unequal values of the generic expression $\Delta$ are obtained by changing $C_1$ successively into $C_1$, $C_2$, etc., namely,

$$d_1 C_1 + d_2 C_2 + \dots + d_m C_m,$$
$$d_m C_1 + d_1 C_2 + \dots + d_{m-1} C_m,$$
$$\dots\dots\dots\dots\dots\dots\dots\dots$$
$$d_2 C_1 + d_3 C_2 + \dots + d_1 C_m.$$

To show that these expressions are all unequal, take the first two. If these were equal, we should have

$$(d_m - d_1) C_1 + (d_1 - d_2) C_2 + \text{etc.} = 0.$$

Therefore, by §13, $d_m - d_1 = 0$, $d_1 - d_2 = 0$, and so on; which, because $d_1$, $d_2$, etc., are not all equal to one another, is impossible. Since then $\Delta$ has at least $m$ unequal particular cognate forms, $\Delta_1$ is, by Prop. III., the root of a rational irreducible equation of a degree not lower than the $m^{\text{th}}$; which, by Prop. VII., is impossible. Therefore $k_1$, $k_2$, etc., are rational. Hence each of the expressions in (27) is a rational function of $t_1$.

§37. *Cor.* Any expression of the type $k_1 + k_2 t_1 + k_3 t_1^2 + \text{etc.}$, which is such that all the unequal particular cognate forms of the generic expression under which it falls are obtained by substituting for $t_1$ successively the different primitive $m^{\text{th}}$ roots of unity, while $k_1$, $k_2$, etc., remain unaltered, is a rational function of $t_1$. For, in the Proposition, $\Delta_1$ or $k_1 + k_2 t_1 + \text{etc.}$ was shown to be a rational function of $t_1$, the conclusion being based on the circumstance that $\Delta_1$ satisfies the condition specified.

§38. Proposition IX. If $g$ be the sum of the roots of the equation $F(x) = 0$,

$$r_2 = \frac{1}{m}\left(g + \Delta_1^{\frac{1}{m}} + a_1 \Delta_1^{\frac{2}{m}} + b_1 \Delta_1^{\frac{3}{m}} + \dots + e_1 \Delta_1^{\frac{m-2}{m}} + h_1 \Delta_1^{\frac{m-1}{m}}\right); \quad (29)$$

For, $z$ being one of the whole numbers, 1, 2, ...., $m - 1$, put

$$p_z = (r_1 + t_1^z r_2 + t_1^{2z} r_3 + \text{etc.}) (r_1 + t_1 r_2 + t_1^2 r_3 + \text{etc.})^{-z}. \quad (30)$$

Multiply the first of its factors by $t_1^{-z}$ and the second by $t_1^z$. Then

$$p_z = (r_2 + t_1^z r_3 + t_1^{2z} r_4 + \text{etc.}) (r_2 + t_1 r_3 + t_1^2 r_4 + \text{etc.})^{-z}. \quad (31)$$

Hence $p_z$ does not alter its value when we change $r_1$ into $r_2$, $r_2$ into $r_3$, and so on. In like manner it does not alter its value when we change $r_1$ into $r_a$, $r_2$ into $r_{a+1}$, and so on. Therefore, by §33, $p_z$ is not changed by any alterations that may be made in $r_1$, $r_2$, etc., while $t_1$ remains unaltered. Consequently, if $p_z$ be a particular cognate form of $P$, all the unequal particular cognate forms of $P$ are obtained by substituting for $t_1$ successively in $p_z$ the different primitive $m^{th}$ roots of unity, while $r_1$, $r_2$, etc., remain unaltered. Therefore, by Cor., Prop. VIII., $p_z$ is a rational function of $t_1$. When $z = 2$, let $p_z = a_1$; when $z = 3$, let $p_z = b_1$, and so on. Then, from (26) and (30), $\Delta_2^{\frac{1}{m}} = a_1 \Delta_1^{\frac{2}{m}}$, $\Delta_3^{\frac{1}{m}} = b_1 \Delta_1^{\frac{3}{m}}$ and so on. But, from (27), since $g$ is the sum of the roots of the equation $F(x) = 0$,

$$r_1 = \frac{1}{m}\left(g + \Delta_1^{\frac{1}{m}} + \Delta_2^{\frac{1}{m}} + \ldots + \Delta_{m-1}^{\frac{1}{m}}\right).$$

By putting $a_1 \Delta_1^{\frac{2}{m}}$ for $\Delta_2^{\frac{1}{m}}$, $b_1 \Delta_1^{\frac{3}{m}}$ for $\Delta_3^{\frac{1}{m}}$ and so on, this becomes (29). Because $a_1$, $b_1$, etc., are rational functions of $t_1$, while $\Delta_1$, the root of a rational irreducible equation of the $(m - 1)^{th}$ degree, is also a rational function of $t_1$, the coefficients $a_1$, $b_1$, etc., involve no surd that is not subordinate to $\Delta_1^{\frac{1}{m}}$.

§39. PROPOSITION X. If the prime number $m$ be odd, the expressions

$$\Delta_1^{\frac{1}{m}} \Delta_{m-1}^{\frac{1}{m}},\ \Delta_2^{\frac{1}{m}} \Delta_{m-2}^{\frac{1}{m}},\ \ldots,\ \Delta_{\frac{m-1}{2}}^{\frac{1}{m}} \Delta_{\frac{m+2}{m}}^{\frac{1}{m}}, \tag{32}$$

are the roots of a rational equation of the $\left(\frac{m-1}{2}\right)^{th}$ degree.

By §32, when $r_1$, is charged into $r_z$, $r_2$ becomes $r_{z+1}$, $r_3$ becomes $r_{z+2}$, and so on. Hence the terms $r_1 r_2$, $r_2 r_3$, .... $r_m r_1$, form a cycle, the sum of the terms in which may be denoted by the symbol $\Sigma_2^1$. In like manner the sum of the terms in the cycle $r_1 r_3$, $r_2 r_4$, ...., $r_m r_2$, may be written $\Sigma_3^1$. And so on. In harmony with this notation, the sum of the $m$ terms $r_1^2$, $r_2^2$, etc., may be written $\Sigma_1^1$. Now $r_1$ can only be changed into one of the terms $r_1$, $r_2$, etc.; and we have seen that, when it becomes $r_z$, $r_2$ becomes $r_{z+1}$, and so on. Such changes leave the cycle $r_1 r_2$, $r_2 r_3$, etc., as a whole unaltered.

Therefore, by Prop. III., $\Sigma_2^1$ is the root of a simple equation, or has a rational value. In like manner each of the expressions

$$\Sigma_1^1,\ \Sigma_2^1,\ \Sigma_3^1,\ \ldots,\ \Sigma_m^2, \tag{33}$$

has a rational value. From (26), by actual multiplication,

$$\Delta_1^{\frac{1}{m}}\,\Delta_{m-1}^{\frac{1}{m}} = \Sigma_1^1 + (\Sigma_2^1)\,t_1 + (\Sigma_3^1)\,t_1^2 + \text{etc.}$$

But $\Sigma_2^1$, $\Sigma_3^1$, etc., are respectively identical with $\Sigma_m^1$, $\Sigma_{m-1}^1$, etc. Therefore

$$\Delta_1^{\frac{1}{m}}\,\Delta_{m-1}^{\frac{1}{m}} = \Sigma_1^1 + (\Sigma_2^1)\,(t_1 + t_1^{-1}) + (\Sigma_3^1)(t_1^2 + t_1^{-2}) + \text{etc.} \tag{34}$$

Hence, since the terms in (33) are all rational, and since the terms in (32) are respectively what $\Delta_1^{\frac{1}{m}}\ \Delta_{m-1}^{\frac{1}{m}}$ becomes by changing $t_1$ successively into the $\frac{m-1}{2}$ terms $t_1$, $t_1^2$, etc., the terms in (32) are the roots of a rational equation of the $\left(\frac{m-1}{2}\right)^{\text{th}}$ degree.

§40. For the solution of the equation $x^n - 1 = 0$, $n$ being a prime number such that $m$ is a prime measure of $n - 1$, it is necessary to obtain the solution of the equation of the $m^{\text{th}}$ degree which has for one of its roots the sum of the $\frac{n-1}{m}$ terms in a cycle of primitive $n^{\text{th}}$ roots of unity. This latter equation will be referred to as the *reducing Gaussian equation* of the $m^{\text{th}}$ degree to the equation

$$x^n - 1 = 0\,.$$

§41. Proposition XI. When the equation $F(x) = 0$ is the reducing Gaussian (see §40) of the $m^{\text{th}}$ degree to the equation $x^n - 1 = 0$, each of the $\frac{m-1}{2}$ expressions in (32) is equal to $n$.

Let the sum of the primitive $n^{\text{th}}$ roots of unity forming the cycle (8), which sum has in preceding sections been indicated by the symbol $C_1$, be the root $r_1$ of the equation $F(x) = 0$. This implies, since $s$ is the number of the terms in (8), that $ms = n - 1$. Let us reason first on the assumption that the cycle (8) is made up of pairs of reciprocal roots $\omega_1$ and $\omega_1^{-1}$, and so on. Then, because the cycle consists of $\frac{s}{2}$ pairs of reciprocal roots, $C_1^2$ or $r_1^2$ is the sum of

$s^2$ terms, each an $n^{\text{th}}$ root of unity. Among these unity occurs $s$ times. Let $\omega_1$ occur $h_1$ times; and let $\omega_1^{\lambda}$ the second term in (8), occur $h'$ times. Since $\omega_1^{\lambda}$ may be made the first term in the cycle (8), it must, under the new arrangement, present itself in the value of $r_1^2$, precisely where $\omega_1$ previously appeared. That is to say, $h' = h_1$. In like manner each of the terms in (8) occurs exactly $h_1$ times in the expression for $r_1^2$. The cycle (9) being that which contains all the primitive $n^{\text{th}}$ roots of unity, let us, adhering to the notation of previous sections, suppose that, when $\omega_1$ is changed into $\omega_1^{\beta}$, $C_1$ or $r_1$ becomes $C_2$ or $r_2$, $C_2$ or $r_2$ becomes $C_3$ or $r_3$, and so on. On the same grounds on which every term in (8) occurs the same number of times in the value of $r_1^2$, each term in the cycle of terms whose sum is $C_2$ occurs the same number of times; and so on. Therefore

$$r_1^2 = s + h_1 C_1 + h_2 C_2 + \ldots\ldots + h_m C_m.$$

$$r_2^2 = s + h_m C_1 + h_1 C_2 + \ldots\ldots + h_{m-1} C_m,$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$r_m^2 = s + h_2 C_1 + h_3 C_2 + \ldots\ldots + h_1 C_m.$$

Therefore, keeping in view (11), $\Sigma_1^1 = ms - (h_1 + h_2 + \ldots\ldots + h_m)$. But $s^2 - s$ is the number of the terms in the value of $r_1^2$ which are primitive $n^{\text{th}}$ roots of unity. And this must be equal to

$$s\,(h_1 + \ldots\ldots + h_m).$$

Therefore

$$h_1 + h_2 + \ldots\ldots + h_m = s - 1 \;\therefore\; \Sigma_1^1 = ms + 1 - s = n - s.$$

Again, because $r_1$ is made up of pairs of reciprocal roots, and because therefore unity does not occur among the $s^2$ terms of which $r_1\,r_2$ is the sum,

$$r_1\,r_2 = k_1 C_1 + k_2 C_2 + \ldots\ldots + k_m C_m,$$

$$r_2\,r_3 = k_m C_1 + k_1 C_2 + \ldots\ldots + k_{m-1} C_m,$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$r_m\,r_1 = k_2 C_1 + k_3 C_2 + \ldots\ldots + k_1 C_m;$$

where $k_1$, $k_2$, etc., are whole numbers whose sum is $s$. Therefore $\Sigma_2^1 = -s$. In like manner each of the terms in (33) except the first is equal to $-s$. Therefore (34) becomes

$$\Delta_1^{\frac{1}{m}}\,\Delta_{m-1}^{\frac{1}{m}} = (n - s) - s\,(t_1 + t_1^2 + \text{etc.}) = n.$$

Let us reasnn now on the assumption that the cycle (8) is not made up of pairs of reciprocal roots. It contains in that case no reciprocal roots. By the same reasoning as above we get $\Sigma^1_1 = -s$. As regards the terms in (33) after the first, one of the terms $C_1$, $C_2$, etc., say $C_z$, must be such that the $n^{\text{th}}$ roots of unity of which it is the sum are reciprocals of those of which $C_1$ is the sum. In passing from $C_1$ to $C_z$, we change $r_1$ into $r_z$. In fact, $C_1$ being $r_1$, $C_z$ is $r_z$. This being kept in view, we get, by the same reasoning as above, $\Sigma^1_z = n - s$. But, if any of the expressions $C_1$, $C_2$, etc., except $C_z$ be selected, say $C_a$, none of the roots in (8) are reciprocals of any of those of which $C_a$ is the sum. Therefore $\Sigma^1_a = -s$. Therefore, from (34)

$$\Delta_1^{\frac{1}{m}} \Delta_{m-1}^{\frac{1}{m}} = -s + (n-s)\, t_1^{z-1}$$

$$-s \left\{ (t_1 + t_1^2 + \ldots + t_1^{m-1}) - t_1^{z-1} \right\} = n.$$

In like manner every one of the expressions in (34) can be shown to have the value $n$.

§42. Two numerical illustrations of the law established in the preceding section may be given. The reducing Gaussian equation of the third degree to the equation $x^{19} - 1 = 0$ is $x^3 - x^2 - 6x - 7 = 0$; which gives

$$r_1 = \tfrac{1}{3}(-1 + \Delta_1^{\frac{1}{3}} + \Delta_2^{\frac{1}{3}}),$$
$$2\Delta_1 = 19\,(7 + 3\surd 3),$$
$$2\Delta_2 = 19\,(7 - 3\surd 3),$$
$$\Delta_1^{\frac{1}{3}} \Delta_2^{\frac{1}{3}} = 19.$$

The next example is taken from Lagrange's Theory of Algebraical Equations, Note XIV., §30. The Gaussian of the fifth degree to the equation $x^{11} - 1 = 0$ is $x^5 + x^4 - 4x^3 - 3x^2 + 3x + 1 = 0$; which gives

$$r_1 = \tfrac{1}{5}(-1 + \Delta_1^{\frac{1}{5}} + \Delta_2^{\frac{1}{5}} + \Delta_3^{\frac{1}{5}} + \Delta_4^{\frac{1}{5}});$$
$$4\,\Delta_1 = 11\,(-89 - 25\surd 5 + 5p - 45q),$$
$$4\,\Delta_2 = 11\,(-89 + 25\surd 5 - 45p - 5q),$$
$$4\,\Delta_4 = 11\,(-89 - 25\surd 5 - 5p + 45q),$$
$$4\,\Delta_3 = 11\,(-89 + 25\surd 5 + 45p + 5q),$$
$$p = \surd(-5 - 2\surd 5),$$
$$q - \surd(-5 + 2\surd 5),$$
$$pq = -\surd 5 \;\therefore\; \Delta_1 \Delta_4 = 11^5.$$

§43. Proposition XII. To solve the Gaussian.

The path we have been following leads directly, assuming the primitive $m^{\text{th}}$ root of unity $t_1$ to be known, to the solution of the reducing Gaussian equation of the $m^{\text{th}}$ degree to the equation $x^n - 1 = 0$. For, as in §41, the roots of the Gaussian are $C_1$, $C_2$, etc. Therefore $g$, the sum of the roots, is $-1$. Therefore

$$r_1 = \frac{1}{m}\left(-1 + \Delta_1^{\frac{1}{m}} + \Delta_2^{\frac{1}{m}} + \dots + \Delta_{m-1}^{\frac{1}{m}}\right). \tag{35}$$

By Prop. VIII., $\Delta_1$, $\Delta_2$, etc., are rational functions of $t_1$. Therefore

$$\left.\begin{array}{l} \Delta_1 = k_1 + k_2 t_1 + k_3 t_1^2 + \dots + k_m t_1^{m-1} \\ \Delta_2 = k_1 + k_2 t_1^2 + k_3 t_1^4 + \dots + k_m t_1^{2(m-1)} \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \Delta_{m-1} = k_1 + k_2 t_1^{-1} + k_3 t_1^{-2} + \dots + k_m t_1 ; \end{array}\right\} \tag{36}$$

where $k_1$, $k_2$, etc., are rational. From the first of equations (26), putting $C_1$ for $r_1$, $C_2$ for $r_2$, and so on,

$$\Delta_1 = (C_1 + t_1 C_2 + \text{etc.})^m.$$

By actual involution this gives us $k_1$, $k_2$, etc., as determinate functions of $C_1$, $C_2$, etc., and therefore as known rational quantities. For instance take $k_1$. Being a determinate function of $C_1$, $C_2$, etc., we have

$$k_1 = q_1 + q_2 C_1 + q_3 C_2 + \dots + q_m C_{m-1} ;$$

where $q_1$, $q_2$, etc., are known rational quantities. But, by §13, the rational coefficients $q_1 - k_1$, $q_2$, etc., are all equal to one another. Therefore $k_1 = q_1 - q_2$. In like manner $k_2$, $k_3$, etc., are known. Therefore, from (36), $\Delta_1$, $\Delta_2$, etc., are known. Therefore, from (35), $r_1$ is known.

§44. Proposition XIII. The law established in Prop. X falls under the following more general law. The $m - 1$ expressions in each of the groups

$$\left.\begin{array}{l} \left(\Delta_1^{\frac{1}{m}} \Delta_{m-1}^{\frac{1}{m}}, \ \Delta_2^{\frac{1}{m}} \Delta_{m-2}^{\frac{1}{m}}, \dots, \Delta_{m-1}^{\frac{1}{m}} \Delta_1^{\frac{1}{m}},\right) \\ \left(\Delta_1^{\frac{2}{m}} \Delta_{m-2}^{\frac{1}{m}}, \ \Delta_2^{\frac{2}{m}} \Delta_{m-4}^{\frac{1}{m}}, \dots, \Delta_{m-1}^{\frac{2}{m}} \Delta_2^{\frac{1}{m}},\right) \\ \left(\Delta_1^{\frac{3}{m}} \Delta_{m-3}^{\frac{1}{m}}, \ \Delta_2^{\frac{3}{m}} \Delta_{m-6}^{\frac{1}{m}}, \dots, \Delta_{m-1}^{\frac{3}{m}} \Delta_3^{\frac{1}{m}} ;\right) \end{array}\right\} \tag{37}$$

and so on, are the roots of a rational equation of the $(m - 1)^{\text{th}}$ degree.

The $m - 1$ terms in the first of the groups (37) are the $\frac{m-1}{2}$ terms in (32) each taken twice. Therefore, by Prop. X., the law enunciated in the present Proposition is established so far as this groupe is concerned. The general proof is as follows. By (30) in §38, taken in connection with (26), $p_{m-z} \Delta_1^{\frac{m-z}{m}} = \Delta_{m-z}^{\frac{1}{m}}$. Therefore $\Delta_1^{\frac{z}{m}} \Delta_{m-z}^{\frac{1}{m}} = p_{m-z} \Delta_1$. But, by §38, $p_{m-z}$ is a rational function of $t_1$; and, by Prop. VIII., $\Delta_1$ is a rational function of $t_1$. Therefore $\Delta_1^{\frac{z}{m}} \Delta_{m-z}^{\frac{1}{m}}$ is a rational function of $t_1$. Also from the manner in which $p_{m-z}$ is formed, when $t_1$ in $p_{m-2} \Delta_1$ is changed sucessively into $t_1\ t_1^2, \ldots, t_1^{m-1}$, the expression $\Delta_1^{\frac{z}{m}} \Delta_{m-z}^{\frac{1}{m}}$ is changed successively into the $m - 1$ terms of that one of the groups (37) whose first term is $\Delta_1^{\frac{z}{m}} \Delta_{m-z}^{\frac{1}{m}}$. Therefore the terms in that group are the roots of a rational equation.

§45. *Cor.* The law established in the Proposition may be brought under a yet wider generalization. The expression

$$\Delta_1^{\frac{a}{m}} \Delta_2^{\frac{b}{m}} \Delta_3^{\frac{c}{m}} \ldots \Delta_{m-1}^{\frac{s}{m}} \tag{38}$$

is the root of a rational equation of the $(m - 1)^{\text{th}}$ degree, if

$$a + 2b + 3c + \ldots + (m - 1)s = Wm,$$

$W$ being a whole number. For, by (30) in connection with (26), $\Delta_2^{\frac{1}{m}} = p_2 \Delta_1^{\frac{2}{m}}$, $\Delta_3^{\frac{1}{m}} = p_3 \Delta_3^{\frac{1}{m}}$, and so on. Therefore (38) has the value

$$(p_2^b p_3^c \ldots) \Delta_1^{\frac{a + 2b + 3c + \ldots + (m-1)s}{m}}, \text{ or } (p_2^b p_3^c \ldots) \Delta_1^W.$$

This is a rational function of $t_1$, and therefore the root of a rational equation of the $(m - 1)^{\text{th}}$ degree.

## THE EQUATION $F(x) = 0$ OF THE SECOND CLASS.

§46. We now suppose that the simplified root $r_1$ of the rational irreducible equation $F(x) = 0$ of the $m^{\text{th}}$ degree, $m$ prime, involves, when modified according to §21, a principal surd not a root of unity. It must not be forgotten that, when we thus speak of roots of unity, we mean, according to §1, roots which have prime numbers for the denominators of their indices. In this case conclusions can be established similar to those reached in the case that has been considered. The root $r_1$ is still of the form (29). The equation $F(x) = 0$ has still an auxiliary of the $(m - 1)^{\text{th}}$ degree, whose roots are the $m^{\text{th}}$ powers of the expressions

$$\Delta_1^{\frac{1}{m}},\ a_1 \Delta_1^{\frac{2}{m}},\ b_1 \Delta_1^{\frac{3}{m}},\ \ldots,\ e_1 \Delta_1^{\frac{m-2}{m}},\ h_1 \Delta_1^{\frac{m-1}{m}}, \tag{39}$$

though the auxiliary here is not necessarily irreducible. Also, substituting the expressions in (39) for $\Delta_1^{\frac{1}{m}}$ $\Delta_2^{\frac{1}{m}}$, etc., in (37), the law of Proposition XIII. still holds, together with corollary in §45.

§47. By Cor. Prop. VI., the denominator of the index of a surd of the highest rank in $r_1$ is $m$. Let $\Delta_1^{\frac{1}{m}}$ be such a surd. By §21, the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ in $r_1$ cannot be all zero. We may take the coefficient of the first power to be distinct from zero and to be $\frac{1}{m}$ for, if it were $\frac{k_1}{m}$, we might substitute $s^{\frac{1}{m}}$ for $k_1\Delta_1^{\frac{1}{m}}$, and so eliminate $\Delta_1^{\frac{1}{m}}$ from $r_1$, introducing in its room the new surd $s^{\frac{1}{m}}$ with $\frac{1}{m}$ for the coefficient of its first power. We may then put

$$r_1 = \frac{1}{m}\left(g + \Delta_1^{\frac{1}{m}} + a_1 \Delta_1^{\frac{3}{m}} + \ldots + e_1 \Delta_1^{\frac{m-2}{m}} + h_1 \Delta_1^{\frac{m-1}{m}}\right); \tag{40}$$

where $g$, $a_1$, etc., are clear of $\Delta_1^{\frac{1}{m}}$. When $\Delta_1^{\frac{1}{m}}$ is changed successively into $\Delta_1^{\frac{1}{m}}$, $t_1^{-1} \Delta_1^{\frac{1}{m}}$, $t_1^{-2} \Delta_1^{\frac{1}{m}}$, etc., let

$$r_1,\ r_2,\ \ldots\ r_m, \tag{41}$$

be respectively what $r_1$ becomes, $t_1$ being a primitive $m^{\text{th}}$ root of unity. By Prop. VI., the terms in (41) are the roots of the equation $F(x) = 0$. Taking $r_n$, any one of the particular cognate forms of $R$, let $\varDelta_n^{\frac{1}{m}}$, $a_n$, etc., be respectively what $\varDelta_1^{\frac{1}{m}}$, $a_1$, etc., become in passing from $r_1$ to $r_n$; and when $\varDelta_n^{\frac{1}{m}}$ is changed successively into the different $m^{\text{th}}$ roots of the determinate base $\varDelta_n$, let $r_n$ become

$$r_n, r_n', r_n'', \ldots, r_n^{(m-1)}. \tag{42}$$

By Prop. II., the terms in (42) are roots of the equation $F(x) = 0$; and, by §23, they are all unequal. Therefore they are identical, in some order, with the terms in (41). Also, the sum of the terms in (41) is $g$. Therefore $g$ is rational.

§48. Proposition XIV. In $r_1$, as expressed in (40), $\varDelta_1^{\frac{1}{m}}$ is the only principal (see §2) surd.

Suppose, if possible, that there is in $r_1$ a principal surd $z_1^{\frac{1}{c}}$ distinct from $\varDelta_1^{\frac{1}{m}}$. And first, let $z_1^{\frac{1}{c}}$ be not a root of unity. (It will be kept in view that when, in such a case, we speak of roots of unity, the denominators of their indices are understood, according §1, to be prime numbers.) When $z_1^{\frac{1}{c}}$ is changed into $z_2^{\frac{1}{c}}$, one of the other $c^{\text{th}}$ roots of $z_1$, let $r_1$, $a_1$, etc., become respectively $r_1'$, $a_1'$, etc. Then

$$mr_1', = g + \varDelta_1^{\frac{1}{m}} + a_1' \varDelta_1^{\frac{2}{m}} + \text{etc} \tag{43}$$

By Prop. II., $r_1'$ is equal to a term in (41), say to $r_n$. And, by §48, putting $t_{n-1}$ for $t_1^{1-n}$,

$$mr_n = g + t_{n-1} \varDelta_1^{\frac{1}{m}} + t_{n-1}^2 a_1 \varDelta_1^{\frac{2}{m}} + \text{etc.} \tag{44}$$

Therefore,

$$\varDelta_1^{\frac{1}{m}} (1 - t_{n-1}) + \varDelta_1^{\frac{2}{m}} (a'_1 - a_1 t_{n-1}^2) + \text{etc.} = 0. \tag{45}$$

This equation involves no surds except those found in the simplified expression $r_1$, together with the primitive $m^{\text{th}}$ root of unity. Therefore the expression on the left of (45) is in a simple state. Therefore, by §8, the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ are separately zero. Therefore $t_{n-1} = 1$, $a'_1 = a_1$, $b'_1 = b_1$, and so on. But, as was shown in Prop. V., $z_1^{\frac{1}{c}}$ being a principal surd not a root of unity in the simplified expression $a_1$, $a_1$ cannot be equal to $a'_1$ unless $z_1^{\frac{1}{c}}$ can be eliminated from $a_1$ without the introduction of any new surd. In like manner $b_1$ cannot be equal to $b'_1$ unless $z_1^{\frac{1}{c}}$ can be eliminated from $b_1$. And so on. Therefore, because $a_1 = a'_1$, and $b_1 = b'_1$, and so on, $z_1^{\frac{1}{c}}$ admits of being eliminated from $r_1$ without the introduction of any new surd, which, by §21, is impossible. Next, let $z_1^{\frac{1}{c}}$ be a root (see §1) of unity, which may be otherwise written $\theta_1$. Let the different primitive $c^{\text{th}}$ roots of unity be $\theta_1$, $\theta_2$, etc.; and, when $\theta_1$ is changed successively into $\theta_1$, $\theta_2$, etc., let $r_1$ become successively $r_1$, $r'_1$, etc. Suppose if possible that the $c - 1$ terms $r_1$, $r'_1$, etc., are all equal. Since $z_1^{\frac{1}{c}}$ is a principal surd in $r_1$, we may put $r_1 = h\theta_1^{c-1} + k\theta_1^{c-2} + \ldots . + l$; where $h$, $k$, etc., are clear of $\theta_1$. Therefore $(c - 1)\, r_1 = cl - (h + k + \text{etc.})$ Thus $z_1^{\frac{1}{c}}$ may be eliminated from $r_1$ without the introduction of any new surd; which by §21 is impossible. Since then the terms $r_1$, $r'_1$, etc., are not all equal, let $r_1$ and $r'_1$ be unequal. Then $r'_1$ is equal to a term in (41) distinct from $r_1$, say to $r_n$. Expressing $mr_1$ and $mr_n$ as in (43) and (44), we deduce (45); which, as above, is impossible.

§49. Proposition XV. Taking $r_1$, $r_n$, $\Delta_n^{\frac{1}{m}}$, etc., as in §47, an equation

$$t\,\Delta_n^{\frac{1}{m}} = p\,\Delta_1^{\frac{c}{m}} \qquad (46)$$

can be formed; where $t$ is an $m^{th}$ root of unity, and $c$ is a whole number less than $m$ but not zero, and $p$ involves only surds subordinate (see §3) to $\Delta_1^{\frac{1}{m}}$ or $\Delta_n^{\frac{1}{m}}$

By §47, one of the terms in (42) is equal to $r_1$. For our argument it is immaterial which be selected. Let $r_n = r_1$. Therefore

$$
\begin{aligned}
&(h_n \Delta_n^{\frac{m-1}{m}} + e_n \Delta_n^{\frac{m-2}{m}} + \dots + \Delta_n^{\frac{1}{m}}) \\
&- (h_1 \Delta_1^{\frac{m-1}{m}} + e_1 \Delta_1^{\frac{m-2}{m}} + \dots + \Delta_1^{\frac{1}{m}}) = 0. \qquad (47)
\end{aligned}
$$

The coefficients of the different powers of $\Delta_n^{\frac{1}{m}}$ here are not all zero, for the coefficient of the first power is unity. Therefore by §5, an equation $t\Delta_n^{\frac{1}{m}} = l_1$ subsists, $t$ being an $m^{th}$ root of unity, and $l_1$ involving only surds exclusive of $\Delta_n^{\frac{1}{m}}$ that occur in (47). By Prop. XIV., $\Delta_1^{\frac{1}{m}}$ is a surd of a higher rank (see §3) than any surd in (47) except $\Delta_n^{\frac{1}{m}}$. Therefore we may put

$$l_1 = d + d_1 \Delta_1^{\frac{1}{m}} + d_2 \Delta_1^{\frac{2}{m}} + \dots + d_{m-1} \Delta_1^{\frac{m-1}{m}};$$

where $d$, $d_1$, etc., involve only surds lower in rank than $\Delta_1^{\frac{1}{m}}$. Then

$$
\begin{aligned}
\Delta_n = l_1^m &= (d + d_1 \Delta_1^{\frac{1}{m}} + \text{etc.})^m \\
&= d' + d_1' \Delta_1^{\frac{1}{m}} + d_2' \Delta_1^{\frac{2}{m}} + \text{etc.};
\end{aligned}
$$

where $d'$, $d_1'$, etc., involve only surds lower in rank than $\Delta_1^{\frac{1}{m}}$. By §8, since $\Delta_1^{\frac{1}{m}}$ is a surd in the simplified expressions $r_1$, the coefficients $d' - \Delta_n$, $d_1'$, etc., in the equation

$$(d' - \Delta_n) + d'_1 \Delta_1^{\frac{1}{m}} + d'_2 \Delta_1^{\frac{1}{m}} + \text{etc.} = 0 \qquad (48)$$

are separately zero. Therefore $(d + d_1 \Delta_1^{\frac{1}{m}} + \text{etc.})^m = d'$. And, $t_1$ being a primitive $m^{\text{th}}$ root of unity,

$$(d + d_1 t_1 \Delta_1^{\frac{1}{m}} + \text{etc.})^m = d' + d' t_1 \Delta_1^{\frac{1}{m}} + \text{etc.} = d'.$$

Therefore,

$$(d + d_1 t_1 \Delta_1^{\frac{1}{m}} + \text{etc.}) = t_1^a (d + d_1 \Delta_1^{\frac{1}{m}} + d_2 \Delta_1^{\frac{2}{m}} + \text{etc.}),$$

$t_1^a$ being one of the $m^{\text{th}}$ roots of unity. In the same way in which the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ in (48) are separately zero, each of the expressions $d\,(1 - t_1^a)$, $d_1\,(t_1 - t_1^a)$, etc., must be zero. But not more than one of the $m - 1$ factors, $t_1 - t_1^a$, $t_1^2 - t_1^a$, etc., can be zero. Therefore not more than one of the $m - 1$ terms $d_1$, $d_2$, etc., is distinct from zero. Suppose if possible that all these terms are zero. Then $t\,\Delta_n^{\frac{1}{m}} = d$. Therefore the different powers of $\Delta_n^{\frac{1}{m}}$ can be expressed in terms of the surds involved in $d$ and of the $m^{\text{th}}$ root of unity. Substitute for $\Delta_n^{\frac{1}{m}}$, $\Delta_n^{\frac{2}{m}}$ etc., in (47), their values thus obtained. Then (47) becomes

$$Q - (h_1 \Delta_1^{\frac{m-1}{m}} + \dots + \Delta_1^{\frac{1}{m}}) = 0; \qquad (49)$$

where $Q$ involves no surds, distinct from the primitive $m^{\text{th}}$ root of unity, that are not lower in rank than $\Delta_1^{\frac{1}{m}}$; which, because the coefficient of the first power of $\Delta_1^{\frac{1}{m}}$ in (49) is not zero, is, by §8, impossible. Hence there must be one, while at the same there can be only one of the $m - 1$ terms, $d_1$, $d_2$, etc., distinct from zero. Let

$d_c$ be the term that is not zero. Then $t_1^c - t_1^a = 0$. Therefore $1 - t_1^{\bar{}}$ is not zero. Therefore $d = 0$. Therefore, putting $p$ for $d_c$,

$$t\,\varDelta_n^{\frac{1}{m}} = p\,\varDelta_1^{\frac{c}{m}}.$$

§50. *Cor.* By the proposition, values of the different powers of $\varDelta_n^{\frac{1}{m}}$ can be obtained as follows;

$$t\varDelta_n^{\frac{1}{m}} = p\,\varDelta_1^{\frac{c}{m}},\ t^2\,\varDelta_n^{\frac{2}{m}} = q\,\varDelta_1^{\frac{s}{m}},\ t^3\,\varDelta_n^{\frac{3}{m}} = k\,\varDelta_1^{\frac{z}{m}},\ \text{etc.}; \qquad (50)$$

where $p$, $q$, etc., involve only surds that occur in $\varDelta_1$ or $\varDelta_n$; and $c$, $s$, $z$, etc., are whole numbers in the series $1, 2, \ldots\ldots m-1$. No two of the numbers $c$, $s$, etc., can be the same; for they are the products, with multiples of the prime number $m$ left out, of the terms in the series $1, 2, \ldots\ldots, m-1$, by the whole number $c$ which is less than $m$. Therefore the series $c$, $s$, $z$, etc., is the series $1, 2, \ldots\ldots, m-1$, in a certain order.

§51. Proposition XVI. If $r_n$ be one of the particular cognate forms of $R$, the expressions

$$t\varDelta_n^{\frac{1}{m}},\ t^2\,a_n\,\varDelta_n^{\frac{2}{m}},\ \ldots\ldots,\ t^{m-2}\,e_n\,\varDelta_n^{\frac{m-2}{m}},\ t^{m-1}\,h_n\,\varDelta_n^{\frac{m-1}{m}}, \qquad (51)$$

are severally equal, in some order, to those in (39), $t$ being one of the $m^{\text{th}}$ roots of unity.

By §47, one of the terms in (42) is equal to $r_1$. For our argument it is immaterial which be chosen. Let $r_n = r_1$. By Cor. Prop. XV., the equations (50) subsist. Substitute in (47) the values of the different powers of $\varDelta_n^{\frac{1}{m}}$ so obtained. Then

$$\therefore\ (t^{-1}\,p\,\varDelta_1^{\frac{c}{m}} + t^{-2}\,qa_n\,\varDelta_1^{\frac{s}{m}} + \text{etc.})$$
$$-\ (\varDelta_1^{\frac{1}{m}} + a_1\,\varDelta_1^{\frac{2}{m}} + \text{etc.}) = 0. \qquad (52)$$

By Cor. Prop. XV., the series $\varDelta_1^{\frac{c}{m}}$, $\varDelta_1^{\frac{s}{m}}$, etc., is identical, in some order, with the series $\varDelta_1^{\frac{1}{m}}$, $\varDelta_1^{\frac{2}{m}}$, etc. Also, by §8, since $\varDelta_1^{\frac{1}{m}}$ is a surd occurring in the simplified expression $r_1$, and since besides $\Delta_1^{\frac{1}{m}}$ there are in (52) no surds, distinct from the primitive $m^{\text{th}}$ root of unity, that are not lower in rank than $\Delta_1^{\frac{1}{m}}$, if the equation (52) were arranged according to the powers of $\Delta_1^{\frac{1}{m}}$ lower than the $m^{\text{th}}$, the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ would be separately zero. Hence $\Delta_1^{\frac{1}{m}}$ is equal to that one of the expressions,

$$t^{-1}\, p\, \Delta_1^{\frac{c}{m}},\ t^{-2}\, q a_n\, \Delta_1^{\frac{s}{m}},\ \text{etc.} \tag{53}$$

in which $\Delta_1^{\frac{1}{m}}$ is a factor. In like manner $a_1\, \Delta_1^{\frac{2}{m}}$ is equal to that one of the expressions (53) in which $\Delta_1^{\frac{2}{m}}$ is a factor. And so on. Therefore the terms $\Delta_1^{\frac{1}{m}}$, $a_1\, \Delta_1^{\frac{2}{m}}$, etc., forming the series (39), are severally equal, in some order, to the terms in (53), which are those forming the series (51.)

§52. Proposition XVII. The equation $F(x) = 0$ has a rational *auxiliary* (Compare Prop. VII.) equation $\varphi(x) = 0$, whose roots are the $m^{\text{th}}$ powers of the terms in (39).

Let the unequal particular cognate forms of the generic expression $\Delta$ under which the simplified expression $\Delta_1$ falls be

$$\Delta_1,\ \Delta_2,\ \ldots\ldots,\ \Delta_c. \tag{54}$$

By Prop. XVI., there is a value $t$ of the $m^{\text{th}}$ root of unity for which the expressions

$$t\, \Delta_2^{\frac{1}{m}},\ t^2 a_2\, \Delta_2^{\frac{2}{m}},\ \ldots\ldots,\ t^{m-2}\, e_2\, \Delta_2^{\frac{m-2}{m}},\ t^{m-1}\, h_2\, \Delta_2^{\frac{m-1}{m}} \tag{55}$$

are severally equal, in some order, to those in (39). Therefore $\Delta_2$ is equal to one of the terms

$$\Delta_1,\ a_1^m\, \Delta_1^2, \ldots\ldots, e_1^m\, \Delta_1^{m-2},\ h_1^m\, \Delta_1^{m-1}. \tag{56}$$

In like manner each of the terms in (54) is equal to a term in (56). And, because the terms in (54) are unequal, they are severally equal to different terms in (56). By Prop. III., the terms in (54) are the roots of a rational irreducible equation, say $\psi_1(x) = 0$. Rejecting from the series (56) the roots of the equation $\psi_1(x) = 0$, certain of the remaining terms must in the same way be the roots of a rational irreducible equation $\psi_2(x) = 0$. And so on. Ultimately, if $\varphi(x)$ be the continued product of the expressions $\psi_1(x)$, $\psi_2(x)$, etc., the terms in (56) are the roots of the rational equation $\varphi(x) = 0$.

§53. The equations $\psi_1(x) = 0$, $\psi_2(x) = 0$, etc., formed by means of the expressions $\psi_1(x)$, $\psi_2(x)$, etc., may be said to be *sub-auxiliary* to the equation $F(x) = 0$. It will be observed that the sub-auxiliaries are all irreducible.

§54. Proposition XVIII. In passing from $r_1$ to $r_n$, while $\Delta_1$ becomes $\Delta_n$, the expressions $a_1$, $b_1$, which, by Prop. XIV., involve only surds occurring in $\Delta_1$, must severally receive determinate values, $a_n$, $b_n$, etc. In other words, $a_1$ being a particular cognate form of $A$, there cannot, for the same value of $\Delta_n$, be two particular cognate forms of $A$, as $a_n$ and $a_N$, unequal to one another. And so in the case of $b_1$, $e_1$, etc.

For, just as each of the terms in (42) is equal to a term in (41), there are primitive $m^{\text{th}}$ roots of unity $\tau$ and $T$ such that the expressions

$$\tau \Delta_n^{\frac{1}{m}} + \tau^2 a_n \Delta_n^{\frac{2}{m}} + \text{etc.},\quad T \Delta_N^{\frac{1}{m}} + T^2 a_N \Delta_N^{\frac{1}{m}} + \text{etc.},$$

are equal to one another. Therefore, if $\Delta_N = \Delta_n$, in which case, by assigning suitable values to $\tau$ and $T$, $\Delta_N^{\frac{1}{m}}$ may be taken to be equal to $\Delta_n^{\frac{1}{m}}$,

$$\Delta_n^{\frac{1}{m}}(\tau - T) + \Delta_n^{\frac{2}{m}}(a_n \tau^2 - a_N T^2) + \text{etc.} = 0. \qquad (57)$$

Suppose if possible that the coefficients of the different powers of $\Delta_1^{\frac{1}{m}}$ in (57) are not all zero. Then, by §5, $t\,\Delta_n^{\frac{1}{m}} = l_1$; $t$ being an $m^{\text{th}}$ root of unity; and $l_1$ involving only surds of lower ranks than $\Delta_1^{\frac{1}{m}}$. Hence, by Prop. XV. and Cor. Prop. XV., $\Delta_1^{\frac{1}{m}}$ is a rational function of surds of lower ranks than $\Delta_1^{\frac{1}{m}}$ and of the primitive $m^{\text{th}}$ root of unity; which, by the definition in §6, is impossible. Since then the coefficients of the different powers of $\Delta_n^{\frac{1}{m}}$ in (57) are separately zero, $\tau = T$, $a_n \tau^2 = a_N T^2$, therefore $a_n = a_N$.

§55. Proposition XIX. Let the terms in (39) be written respectively

$$\Delta_1^{\frac{1}{m}}, \delta_2^{\frac{1}{m}}, \delta_3^{\frac{1}{m}}, \ldots, \delta_{m-1}^{\frac{1}{m}}. \tag{58}$$

The symbols $\Delta_1$, $\delta_2$, $\delta_3$, etc., are employed instead of $\Delta_1$, $\Delta_2$, $\Delta_3$, etc., because this latter notation might suggest, what is not necessarily true, that the terms in (56) are all of them particular cognate forms of the generic expression under which $\Delta_1$ falls. Then (compare Prop. XIII.) the $m - 1$ expressions in each of the groups

$$\left.\begin{array}{l}
(\Delta_1^{\frac{1}{m}} \delta_{m-1}^{\frac{1}{m}}, \delta_2^{\frac{1}{m}} \delta_{m-2}^{\frac{1}{m}}, \delta_3^{\frac{1}{m}} \delta_{m-3}^{\frac{1}{m}}, \ldots, \delta_{m-1}^{\frac{1}{m}} \Delta_1^{\frac{1}{m}},) \\
(\Delta_1^{\frac{2}{m}} \delta_{m-2}^{\frac{1}{m}}, \delta_2^{\frac{2}{m}} \delta_{m-4}^{\frac{1}{m}}, \delta_3^{\frac{2}{m}} \delta_{m-6}^{\frac{1}{m}}, \ldots, \delta_{m-1}^{\frac{2}{m}} \delta_2^{\frac{1}{m}},) \\
(\Delta_1^{\frac{3}{m}} \delta_{m-3}, \delta_2^{\frac{3}{m}} \delta_{m-6}^{\frac{1}{m}}, \delta_3^{\frac{3}{m}} \delta_{m-9}^{\frac{1}{m}}, \ldots, \delta_{m-1}^{\frac{3}{m}} \delta_3^{\frac{1}{m}},)
\end{array}\right\} \tag{59}$$

and so on, are the roots of a rational equation of the $(m - 1)^{\text{th}}$ degree. Also (compare Prop. X.) the first $\frac{m-1}{2}$ terms in the first of the groups (59) are the roots of a rational equation of the $\left(\frac{m-1}{2}\right)^{\text{th}}$ degree.

In the enunciation of the proposition the remark is made that the series (54) is not necessarily identical with the series

$$\Delta_1, \delta_2, \delta_3, \ldots, \delta_{m-1}.$$

The former consists of the unequal particular cognate forms of $\Delta$; the latter consists of the roots of the auxiliary equation $\varphi(x) = 0$. These two series are identical only when the auxiliary is irreducible. To prove the first part of the proposition, take the terms forming the second of the groups (59). Because $\delta_{m-2}^{\frac{1}{m}}$ represents $e_1 \Delta_1^{\frac{m-2}{m}}$,

$$e_1 \Delta_1 = \Delta_1^{\frac{2}{m}} \delta_{m-}^{\frac{1}{m}} .$$

Let $E$ be the generic symbol under which the simplified expression $e_1$ falls. By Prop. XVIII., when $\Delta_1$ is changed successively into the $c$ terms in (54), $e_1$ receives successively the determinate values $e_1, e_2, \ldots, e_c$; and therefore $e_1 \Delta_1$ receives successively the determinate values

$$e_1 \Delta_1 , \; e_2 \Delta_2 , \; \ldots , \; e_c \Delta_c . \tag{60}$$

There is therefore no particular cognate form of $E\Delta$ that is not equal to a term in (60). By Prop. XVI. there is a value of the $m^{\text{th}}$ root of unity $t$ for which the terms in (55) are severally equal, in some order, to those in (39). Let the term in (39) to which $t \Delta_2^{\frac{1}{m}}$ is equal be $q_1 \Delta_1^{\frac{n}{m}}$ Then, applying the principle of Cor. Prop. XV., as in Prop. XVI., it follows that the term in (39) to which $t^{m-2} e_2 \Delta_2^{\frac{m-2}{m}}$ in (55) is equal is $k_1 \Delta_1^{\frac{M-2n}{m}}$, $M$ being a multiple of $m$, and $M - 2n$ being less than $m$. Therefore $e_2 \Delta_2$ is equal to $q_1^2 k_1 \Delta_1^{\frac{M}{m}}$, which is the product of two of the terms in (39) occuring respectively at equal distances from opposite extremities of the series. In other words, $e_2 \Delta_2$ is equal to an expression $\delta_m^{\frac{2}{m}} \delta_{m-2n}^{\frac{1}{m}}$ in the second of the groups (59). In like manner every term in (60) is equal to an expression in the second of the groups (59). Let the unequal terms in (60) be

$$e_1 \Delta_1 , \text{ etc.} \tag{61}$$

Then, by Prop. III., the terms in (61) are the roots of a rational irreducible equation, say $f_1(x) = 0$. Rejecting these, which are distinct terms in the second of the groups (59), it can in like manner be shown that certain other terms in that group are the roots of a rational irreducible equation, say $f_2(x) = 0$. And so on. Ultimately, if $f(x)$ be the continued product of the expressions $f_1(x)$, $f_2(x)$, etc., the terms forming the second of the groups (59) are the roots of a rational equation of the $(m-1)^{\text{th}}$ degree. The proof applies substantially to each of the other groups. To prove the second part, it is only necessary to observe that, in the first of the groups (59), the last term is identical with the first, the last but one with the second, and so on.

§56. *Cor.* 1. The reasoning in the proposition proceeds on the assumption that the prime number $m$ is odd. Should $m$ be even, the series $\Delta_1$, $\delta_1$, etc., is reduced to its first term. The law may be considered even then to hold in the following form. The product $\Delta_1^{\frac{1}{m}}\ \Delta_1^{\frac{1}{m}}$ is the root of a rational equation of the $(m-1)^{\text{th}}$ degree, or is rational. For this product is $\Delta_1$, which, by Prop. XVII., is the root of an equation of the $(m-1)^{\text{th}}$ degree.

§56. *Cor.* 2. I merely notice, without farther proof, that the generalization in §45 in the case when the equation $F(x) = 0$ is of the first (see §30) class holds in the present case likewise.

## Analysis of Solvable Equations of the Fifth Degree.

§58. Let the solvable irreducible equation of the $m^{\text{th}}$ degree, which we have been considering, be of the fifth degree. Then, by Prop. IX. and §47, whether the equation belongs to the first or to the second of the two classes that have been distinguished, assuming the sum of the roots $g$ to be zero,

$$r_1 = \tfrac{1}{5}\left(\Delta_1^{\frac{1}{5}} + a_1\,\Delta_1^{\frac{2}{5}} + e_1\,\Delta_1^{\frac{3}{5}} + h_1\,\Delta_1^{\frac{4}{5}}\right), \tag{62}$$

though, when the equation is of the first class, the root, as thus presented, is not in a simple state.

§59. Proposition XX. If the auxiliary biquadratic has a rational root $\Delta_1$ not zero, all the roots of the auxiliary biquadratic are rational.

Because $\Delta_1$ is rational, the auxiliary biquadratic $\varphi(x) = 0$ is not irreducible. Therefore, by Prop. VII., the equation $F(x) = 0$ is of the second (see §30) class. Therefore, by Prop. XIV., $\Delta_1^{\frac{1}{5}}$ is the only principal surd in $r_1$. Consequently, because $\Delta_1$ is rational, $a_1$, $e_1$ and $h_1$ are rational. Therefore $\Delta_1$, $a_1^5\,\Delta_1^2, e_1^5\,\Delta_1^3$, $h_1^5\,\Delta_1^4$, which are the roots of the auxiliary biquadratic, are rational.

§60. Proposition XXI. If the auxiliary biquadratic has a quadratic sub-auxiliary $\psi_1(x) = 0$ with the roots $\Delta_1$ and $\Delta_2$, then $\Delta_2 = h_1^5\,\Delta_1^4$, and $\Delta_1 = h_2^5\,\Delta_2^4$; and $h_1\,\Delta_1$ is rational.

As in §52, $t$ being a certain fifth root of unity, each term in (55) is equal to a term in (39). The first term in (55) cannot be equal to the first in (39), for this would make $\Delta_2 = \Delta_1$. Suppose if possible that the first in (55) is equal to the second in (39). Then, by equations (50), applied as in Prop. XVI.,

$$\left.\begin{array}{ll} t\,\Delta_2^{\frac{1}{5}} = a_1\,\Delta_1^{\frac{2}{5}}, & t^2\,a_2\,\Delta_2^{\frac{2}{5}} = h_1\,\Delta_1^{\frac{4}{5}}, \\ t^3\,e_2\,\Delta_2^{\frac{3}{5}} = \Delta_1^{\frac{1}{5}}, & t^4\,h_2\,\Delta_2^{\frac{4}{5}} = e_1\,\Delta_1^{\frac{3}{5}}, \\ \text{therefore } \Delta_2 = a_1^5\,\Delta_1^2, & a_2^5\,\Delta_2^2 = h_1^5\,\Delta_1^4, \\ e_2^5\,\Delta_2^3 = \Delta_1, & h_2^5\,\Delta_2^4 = e_1^5\,\Delta_1^3. \end{array}\right\} \quad (63)$$

Now $a_1^5\,\Delta_1^2$, being equal to $\Delta_2$, is a root of the equation $\psi_1(x) = 0$. And $a_1^5\,\Delta_1^2$, involving only surds that occur in $r_1$, is in a simple state. Therefore, by Prop. III., $a_2^5\,\Delta_2^2$ is a root of the equation $\psi_1(x) = 0$. Therefore $h_1^5\,\Delta_1^4$, and therefore also $h_2^5\,\Delta_2^4$ or $e_1^5\,\Delta_1^3$, are roots of that equation. Hence all the terms

$$\Delta_1,\ a_1^5\,\Delta_1^2,\ e_1^5\,\Delta_1^3,\ h_1^5\,\Delta_1^4, \qquad (64)$$

are roots of the equation $\psi_1(x) = 0$. But $a_1$, $e_1$, $h_1$, are all distinct from zero; for, by (63), if one of them was zero, all would be zero, and therefore $\Delta_1^{\frac{1}{5}}$ would be zero; which by §6, is impossible. From this it follows that no two terms in (64) are equal to one another; for taking $a_1^5\,\Delta_1^2$ and $e_1^5\,\Delta_1^3$, if these were equal, we should have $e_1\,t'\,\Delta_1^{\frac{1}{5}} = a_1$, $t'$ being a fifth root of unity; which; which by §8, is impossible. This gives the equation $\psi_1(x) = 0$ four unequal roots; which, because it is of the second degree, is impossible. Therefore the first term in (55) is not equal to the second in (39). In the same way it can be shown that it is not equal to the third. Therefore it must be equal to the fourth. In like manner the first in (39) is equal to the fourth in (55). Because then $t\,\Delta_2^{\frac{1}{5}} = h_1\,\Delta_1^{\frac{4}{5}}$, and $\Delta_1^{\frac{1}{5}} = t^4\,h_2\,\Delta_2^{\frac{4}{5}}$, $h_2\,\Delta_2 = h_1\,\Delta_1$. But, just as it was proved in §56 that, the roots of the sub-auxiliary $\psi_1(x) = 0$ being the $c$ terms $\Delta_1$, $\Delta_2$, etc., there is no particular cognate form of $E\Delta$ that is not a term in the series $e_1\,\Delta_1$, $e_2\,\Delta_2$, ...., $e_c\,\Delta_c$, it follows that, if $h_1$ be a particular cognate form of $H$, there is no particular cognate form of $H\Delta$ that is not equal to one of the terms $h_1\,\Delta_1$ and $h_2\,\Delta_2$. Hence, since $h_1\,\Delta_1 = h_2\,\Delta_2$, $H\Delta$ has no particular cognate form different in value from $h_1\,\Delta_1$. Therefore, by Prop. III., $h_1\,\Delta_1$ is rational.

§61. Proposition XXII. The auxiliary biquadratic $\varphi(x) = 0$ either has all its roots rational, or has a sub-auxiliary (see §53) of the second degree, or is irreducible.

It will be kept in view that the sub-auxiliaries are, by the manner of their formation, irreducible. First, let the series (54), containing the roots of the sub-auxiliary $\varphi_1(x) = 0$ consist of a single term $\Delta_1$. Then, by Prop. III., $\Delta_1$ is rational. Therefore, by Prop. XX., all the roots of the auxiliary are rational. Next, let the series (54) consist of the two terms $\Delta_1$ and $\Delta_2$. By this very hypothesis, the auxiliary biquadratic has a quadratic sub-auxiliary. Lastly, let the series (54) contain more than two terms. Then it has the three terms $\Delta_1$, $\Delta_2$, $\Delta_3$. We have shown that these must be severally equal to terms in (64). Neither $\Delta_2$ nor $\Delta_3$ is equal to $\Delta_1$. They cannot both be equal to $h_1^5\,\Delta_1^4$. Therefore one of them is equal to one of the terms $a_1^5\,\Delta_1^2$, $e_1^5\,\Delta_1^3$. But in §60 it appeared that, if $\Delta_2$ be equal either to $a_1^5\,\Delta_1^2$ or to $e_1^5\,\Delta_1^3$, all the terms in (64) are roots of the irreducible equation of which $\Delta_1$ is a root. The same thing holds regarding $\Delta_3$. Therefore, when the series (54) contains more than two terms, the irreducible equation which has $\Delta_1$ for one of its roots has the four unequal terms in (64) for roots; that is to say, the auxiliary biquadratic is irreducible.

§62. Let $5u_1 = \Delta_1^{\frac{1}{5}}$, $5u_2 = a_1\,\Delta_1^{\frac{2}{5}}$, $5u_3 = e_1\,\Delta_1^{\frac{3}{5}}$, $5u_4 = h_1\,\Delta_1^{\frac{4}{5}}$; and, $n$ being any whole number, let $S_n$ denote the sum of the $n^{\text{th}}$ powers of the roots of the equation $F(x) = 0$. Then

$$S_1 = 0\,;\ S_2 = 10\,(u_1 u_4 + u_2 u_3)\,;\ S_3 = 15\,\left\{\Sigma\,(u_1 u_2^2)\right\};$$

$$S_4 = 20\left\{\Sigma\,(u_1^3 u_2)\right\} + 30\,(u_1^2 u_4^2 + u_2^2 u_3^2) + 120\,u_1 u_2 u_3 u_4\,;$$

$$S_5 = 5\left\{\Sigma\,(u_1^5)\right\} + 100\left\{\Sigma\,(u_1^3 u_3 u_4)\right\} + 150\left\{\Sigma\,(u_1 u_3^2 u_4^2)\right\};$$

where such an expression as $\Sigma\,(u_1 u_2^2)$ means the sum of all such terms as $u_1 u_2^2$; it being understood that, as any one term in the circle $u_1$, $u_2$, $u_4$, $u_3$, passes into the next, that next passes into its next, $u_3$ passing into $u_1$.

### The Roots of the Auxiliary Biquadratic all Rational.

§63. Any rational values that may be assigned to $\Delta_1$, $a_1$, $e_1$, and $h_1$ in $r_1$, taken as in (62), make $r_1$ the root of a rational equation of the fifth degree, for they render the values of $S_1$, $S_2$, etc., in §62, rational. In fact, $S_1 = 0$, $25\,S_2 = 10\,\Delta_1\,(h_1 + a_1 e_1)$, and so on,

THE AUXILIARY BIQUADRATIC WITH A QUADRATIC SUB-AUXILIARY.

§64. PROPOSITION XXIII. In order that $r_1$, taken as in (62), may be the root of an irreducible equation $F(x) = 0$ of the fifth degree, whose auxiliary biquadratic has a quadratic sub-auxiliary, it must be of the form

$$r_1 = \tfrac{1}{5} \left\{ (\Delta_1^{\frac{1}{5}} + \Delta_2^{\frac{1}{5}}) + (a_1 \Delta_1^{\frac{2}{5}} + a_2 \Delta_2^{\frac{2}{5}}) \right\}; \qquad (65)$$

where $\Delta_1$ and $\Delta_2$ are the roots of the irreducible equation $\psi_1(x) = x^2 - 2px + q^5 = 0$; and $a_1 = b + d\surd(p^2 - q^5)$, $a_2 = b - d\surd(p^2 - q^5)$; $p$, $b$ and $d$ being rational; and the roots $\Delta_1^{\frac{1}{5}}$ and $\Delta_2^{\frac{1}{5}}$ being so related that $\Delta_1^{\frac{1}{5}} \Delta_2^{\frac{1}{5}} = q$.

By Prop. VII., when a quintic equation is of the first (see §30) class, the auxiliary biquadratic is irreducible. Hence, in the case we are considering, the quintic is of the second class. The quadratic sub-auxiliary may be assumed to be $\psi_1(x) = x^2 - 2px + k = 0$, $p$ and $k$ being rational. By Prop. XXI., the roots of the equation $\psi_1(x) = 0$ are $\Delta_1$ and $h_1^5 \Delta_1^4$. Therefore $k = (h_1 \Delta_1)^5$; or, putting $q$ for $h_1 \Delta_1$, $k = q^5$. By the same proposition, $h_1 \Delta_1$ is rational. Therefore $q$ is rational. Hence $\psi_1(x)$ has the form specified in the enunciation of the proposition. Next, by Proposition XVI., there is a fifth root of unity $t$ such that $t\Delta_2^{\frac{1}{5}} = h_1 \Delta_1^{\frac{4}{5}}$. If we take $t$ to be unity, which we may do by a suitable interpretation of the symbol $\Delta_2^{\frac{1}{5}}$, $\Delta_2^{\frac{1}{5}} = h_1 \Delta_1^{\frac{4}{5}}$. This implies that $e_1 \Delta_1^{\frac{3}{5}} = a_2 \Delta_2^{\frac{2}{5}}$, $a_2$ being what $a_1$ becomes in passing from $\Delta_1$ to $\Delta_2$. Substituting these values of $e_1 \Delta_1^{\frac{3}{5}}$ and $h_1 \Delta_1^{\frac{4}{5}}$ in (62), we obtain the form of $r_1$ in (65), while at the same time $\Delta_1^{\frac{1}{5}} \Delta_2^{\frac{1}{5}} = h_1 \Delta_1 = q$. The forms of $a_1$ and $a_2$ have to be more accurately determined. By Prop. XIV., $\Delta_1^{\frac{1}{5}}$ is the only principal surd that $r_1$, as presented in (62), contains. Therefore $a_1$ involves no surd that does not occur in $\Delta_1$; that is to say, $\surd(p^2 - q^5)$ is the only surd in $a_1$. Hence we may put $a_1 = b + d\surd(p^2 - q^5)$; $b$ and $d$ being rational. But $a_2$ is what $a_1$ becomes in passing from $\Delta_1$ to $\Delta_2$. And $\Delta_2$ differs from $\Delta_1$ only in the sign of the root $\surd(p^2 - q^5)$. Therefore

$$a_2 = b - d\surd(p^2 - q^5).$$

§65. Any rational values that may be assigned to $b$, $d$, $p$ and $q$ in $r_1$, taken as in (65), make $r_1$ the root of a rational equation of the fifth degree; for they render the values of $S_1$, $S_2$, etc., in §62, rational. In fact, $S_1 = 0$, $25\, S_2 = 10\{q + q^2 b^2 - q^2 d^2 (p^2 - q^5)\}$, and so on.

### The Auxiliary Biqadratic Irreducible.

§66. When the auxiliary biquadratic is irreducible, the unequal particular cognate forms of $\Delta$ are, by Prop. III., four in number, $\Delta_1$, $\Delta_2$, $\Delta_3$, $\Delta_4$. As explained in §55, because the equation $\varphi(x) = 0$ is irreducible, these terms are severaly identical with $\Delta_1$, $\delta_2$, $\delta_3$, $\delta_4$. Hence, putting $m = 5$, the first two terms in the first of the groups (59) may be written in the notation of (37),

$$\Delta_1^{\frac{1}{5}}\, \Delta_4^{\frac{1}{5}},\ \Delta_2^{\frac{1}{5}}\, \Delta_3^{\frac{1}{5}}\,; \tag{66}$$

and the second and third groups may be written

$$\left.\begin{array}{l} (\Delta_1^{\frac{2}{5}}\, \Delta_3^{\frac{1}{5}},\ \Delta_2^{\frac{2}{5}}\, \Delta_1^{\frac{1}{5}};\ \Delta_3^{\frac{2}{5}}\, \Delta_4^{\frac{1}{5}},\ \Delta_4^{\frac{2}{5}}\, \Delta_2^{\frac{1}{5}}) \\ (\Delta_1^{\frac{3}{5}}\, \Delta_2^{\frac{1}{5}},\ \Delta_2^{\frac{3}{5}}\, \Delta_4^{\frac{1}{5}};\ \Delta_3^{\frac{3}{5}}\, \Delta_1^{\frac{1}{5}},\ \Delta_4^{\frac{3}{5}}\, \Delta_3^{\frac{1}{5}}). \end{array}\right\} \tag{67}$$

§67. Proposition XXIV. The roots of the auxiliary biquadratic equation $\varphi(x) = 0$ are of the forms

$$\left.\begin{array}{l} \Delta_1 = m + n\sqrt{z} + \sqrt{s},\ \Delta_2 = m - n\sqrt{z} + \sqrt{s_1}, \\ \Delta_4 = m + n\sqrt{z} - \sqrt{s},\ \Delta_3 = m - n\sqrt{z} - \sqrt{s_1}; \end{array}\right\} \tag{68}$$

where $s = p + q\sqrt{z}$, and $s_1 = p - q\sqrt{z}$; $m$, $n$, $z$, $p$ and $q$ being rational; and the surd $\sqrt{s}$ being irreducible.

By Propositions XIII. and XIX., the terms in (66) are the roots of a quadratic. Therefore $\Delta_1\, \Delta_4$ and $\Delta_2\, \Delta_3$ are the roots of a quadratic. Suppose if possible that $\Delta_1\, \Delta_3$ is the root of a quadratic. By Propositions IX. and XIX., $\Delta_3^{\frac{1}{5}} = e_1\, \Delta_1^{\frac{3}{5}}$. Therefore $e_1^5\, \Delta_1^4$ is the root of a quadratic. From this it follows (Prop. III.) that there are not more than two unequal terms in the series,

$$e_1^5\, \Delta_1^4,\ e_2^5\, \Delta_2^4,\ e_3^5\, \Delta_3^4,\ e_4^5\, \Delta_4^4. \tag{69}$$

But suppose if possible that $e_1^5\, \Delta_1^4 = e_2^5\, \Delta_2^4$. Then, $t$ being one of the fifth roots of unity, $te_1\, \Delta_1^{\frac{4}{5}} = e_2\, \Delta_2^{\frac{4}{5}}$ But, by Propositions IX. and XIX., $\Delta_2^{\frac{1}{5}} = h_1\, \Delta_1^{\frac{4}{5}}$. Therefore, $te_1\, \Delta_1^{\frac{4}{5}} = e_2\, h_1^4\, \Delta_1^3\, \Delta_1^{\frac{1}{5}}$. Therefore, by §8, $e_1 = 0$. Therefore one of the roots of the auxiliary biquadratic is zero; which because the auxiliary biquadratic is assumed to be irreducible, is impossible. Therefore $e_1^5 \varDelta_1^4$ and $e_2^5 \varDelta_2^4$ are unequal. In the same way all the terms in (69) can be shown to be unequal; which, because it has been proved that there are not more than two unequal terms in (69), is impossible. Therefore $\varDelta_1 \varDelta_3$ is not the root of a quadratic equation. Therefore the product of two of the roots, $\varDelta_1$ and $\varDelta_4$, of the auxiliary biquadratic is the root of a quadratic equation, while the product of a different pair, $\varDelta_1$ and $\varDelta_3$, is not the root of a quadratic. But the only forms which the roots of an irreducible biquadratic can assume consistently with these conditions are those given in (68).

§68. Proposition XXV. The surd $\sqrt{s_1}$ can have its value expressed in terms of $\sqrt{s}$ and $\sqrt{z}$.

By Propositions XIII. and XIX, the terms of the first of the groups (67) are the roots of a biquadratic equation. Therefore their fifth powers

$$\varDelta_1^2 \varDelta_3 ,\ \varDelta_2^2 \varDelta_1 ,\ \varDelta_3^2 \varDelta_4 ,\ \varDelta_4^2 \varDelta_2 , \tag{70}$$

are the roots of a biquadratic. From the values of $\varDelta_1$, $\varDelta_2$, $\varDelta_3$ and $\varDelta_4$ in (68), the values of the terms in (70) may be expressed as follows:

$$\left.\begin{aligned}
\varDelta_1^2 \varDelta_3 = {} & F + F_1 \sqrt{z} + (F_2 + F_3 \sqrt{z}) \sqrt{s} \\
& + (F_4 + F_5 \sqrt{z}) \sqrt{s_1} + (F_6 + F_7 \sqrt{z}) \sqrt{s} \sqrt{s_1} , \\
\varDelta_2^2 \varDelta_1 = {} & F - F_1 \sqrt{z} + (F_2 - F_3 \sqrt{z}) \sqrt{s_1} \\
& - (F_4 - F_5 \sqrt{z}) \sqrt{s} - (F_6 - F_7 \sqrt{z}) \sqrt{s} \sqrt{s_1} , \\
\varDelta_4^2 \varDelta_2 = {} & F - F_1 \sqrt{z} - (F_2 - F_3 \sqrt{z}) \sqrt{s_1} \\
& + (F_4 - F_5 \sqrt{z}) \sqrt{s} - (F_6 - F_7 \sqrt{z}) \sqrt{s} \sqrt{s_1} , \\
\varDelta_3^2 \varDelta_4 = {} & F + F_1 \sqrt{z} - (F_2 + F_3 \sqrt{z}) \sqrt{s} \\
& -(F_4 + F_5 \sqrt{z}) \sqrt{s_1} + (F_6 + F_7 \sqrt{z}) \sqrt{s} \sqrt{s_1} ,
\end{aligned}\right\} \tag{71}$$

where $F$, $F_1$, etc., are rational. Let $\Sigma(\varDelta_1^2 \varDelta_3)$ be the sum of the four expressions in (70). Then, because these expressions are the roots of a biquadratic, $\Sigma(\varDelta_1^2 \varDelta_3)$ or $4F + 4F_7 \sqrt{s} \sqrt{s_1}$, must be rational. Suppose if possible that $\sqrt{s_1}$ cannot have its value expressed in terms of $\sqrt{s}$ and $\sqrt{z}$. Then, because $\sqrt{s} \sqrt{s_1}$ is not rational, $F_7 = 0$. By (68), this implies that $n = 0$. Let

$$\begin{aligned}
(\varDelta_1^2 \varDelta_3)^2 = {} & L + L_1 \sqrt{z} + (L_2 + L_3 \sqrt{z}) \sqrt{s} \\
& + (L_4 + L_5 \sqrt{z}) \sqrt{s_1} + (L_6 + L_7 \sqrt{z}) \sqrt{s} \sqrt{s_1} ,
\end{aligned}$$

where $L$, $L_1$, etc., are rational. Then, as above, $L_7 = 0$. Keeping in view that $n = 0$, this means that $m^2 q = 0$. But $q$ is not zero, for this would make $\surd s = \surd s_1$; which, because we are reasoning on the hypothesis that $\surd s_1$ cannot have its value expressed in terms of $\surd s$ and $\surd z$, is impossible. Therefore $m$ is zero. And it was shown that $n$ is zero. Therefore $\Delta_1 = \surd s$, and $\Delta_3 = -\surd s$. Therefore $\Delta_1 \Delta_3 = -\surd(p^2 - q^2 z)$; which, because it has been proved that $\Delta_1 \Delta_3$ is not the root of a quadratic equation, is impossible. Hence $\surd s_1$ cannot but be a rational function of $\surd s$ and $\surd z$.

§69. PROPOSITION XXVI. The form of $s$ is

$$h(1 + e^2) + h\surd(1 + e^2), \tag{72}$$

$h$ and $e$ being rational, and $1 + e^2$ being the value of $z$.

By Prop. XXV., $\surd s_1 = v + c\surd s$, $v$ and $c$ being rational functions of $\surd z$. Therefore $s_1 = v^2 + c^2 s + 2vc\surd s$. By Prop. XXIV., $\surd s$ is irreducible. Therefore $vc = 0$. But $c$ is not zero, for this would make $\surd s_1 = v$, and thus $\surd s_1$ would be the root of a quadratic equation. Therefore $v = 0$, and $\surd s_1 = c\surd s = (c_1 + c_2\surd z)\surd s$, $c_1$ and $c_2$ being rational. Therefore

$$\begin{aligned}\surd(ss_1) = \surd(p^2 - q^2 z) &= (c_1 + c_2\surd z)(p + q\surd z) \\ &= (c_1 p + c_2 q z) + \surd z(c_1 q + c_2 p) = P + Q\surd z.\end{aligned}$$

Here, since $p^2 - q^2 z$ is rational, either $P = 0$ or $Q = 0$. As the latter of these alternatives would make $\surd(p^2 - q^2 z)$ rational, and therefore would make $\surd(p + q\surd z)$ or $\surd s$ reducible, it is inadmissible. Therefore $c_1 p + c_2 qz = 0$, and

$$\surd(p^2 - q^2 z) = (c_1 q + c_2 p)\surd z.$$

Now $qz$ is not not zero, for this would make $\surd(ss_1) = \pm p$; which, because $\surd s$ is irreducible, is impossible. Therefore $c_2 = 0$. But, by hypothesis, $c_1 = 0$; therefore $\surd s_1$, which is equal to $(c_1 + c_2\surd z)\surd s$, is zero; which is impossible. Hence $c_1$ cannot be zero. We may therefore put $ce = 1$, and $h(1 + e^2) = p$. Then $s = p + q\surd z = h(1 + e^2) + h\surd(1 + e^2)$. Having obtained this form, we may consider $z$ to be identical with $1 + e^2$, $q$ with $h$, and $p$ with $h(1 + e^2)$.

§70. The reasoning in the preceding section holds good whether the equation $F(x) = 0$ be of the first (see §30) or of the second class. If we had had to deal simply with equations of the first class, the proof given would have been unnecessary, so far as the form of $z$ is concerned; because, in that case, by Prop. VIII., $\Delta_1$ is a rational function of the primitive fifth root of unity.

§71. Proposition XXVII. Under the conditions that have been established, the root $r_1$ takes the form given without deduction in *Crelle* (Vol. V., p. 336) from the papers of Abel.

For, by *Cor.* Prop. XIII. (compare also *Cor.* 2, Prop. XIX.,) the expressions

$$\Delta_1^{\frac{1}{5}}\ \Delta_3^{\frac{2}{5}}\ \Delta_4^{\frac{3}{5}}\ \Delta_2^{\frac{3}{5}},\quad \Delta_2^{\frac{1}{5}}\ \Delta_1^{\frac{2}{5}}\ \Delta_3^{\frac{3}{5}}\ \Delta_4^{\frac{3}{5}},$$

$$\Delta_3^{\frac{1}{5}}\ \Delta_4^{\frac{2}{5}}\ \Delta_2^{\frac{3}{5}}\ \Delta_1^{\frac{3}{5}},\quad \Delta_4^{\frac{1}{5}}\ \Delta_2^{\frac{2}{5}}\ \Delta_1^{\frac{3}{5}}\ \Delta_3^{\frac{3}{5}}, \qquad (73)$$

are the roots of a biquadratic equation. In the corollaries referred to, it is merely stated that each of the expressions in (73) is the root of a biquadratic; but the principles of the propositions to which the corollaries are attached show that the four expressions must be the roots of the same biquadratic. Let the terms in (73) be denoted respectively by

$$5A_1^{-1}, \qquad 5A_2^{-1}, \qquad 5A_3^{-1}, \qquad 5A_4^{-1}.$$

Then $\Delta_1^{\frac{1}{5}}\ \Delta_3^{\frac{2}{5}}\ \Delta_4^{\frac{4}{5}}\ \Delta_2^{\frac{3}{5}} = \Delta_4^{\frac{1}{5}}\ (\Delta_1^{\frac{1}{5}}\ \Delta_3^{\frac{2}{5}}\ \Delta_4^{\frac{3}{5}}\ \Delta_2^{\frac{3}{5}})$ is an identity. Therefore

$$\tfrac{1}{5}\ \Delta_4^{\frac{1}{5}} = A_1\ (\Delta_1^{\frac{1}{5}}\ \Delta_3^{\frac{2}{5}}\ \Delta_4^{\frac{4}{5}}\ \Delta_2^{\frac{3}{5}}). \text{ Similarly,}$$

$$\tfrac{1}{5}\ \Delta_3^{\frac{1}{5}} = A_3\ (\Delta_3^{\frac{1}{5}}\ \Delta_4^{\frac{2}{5}}\ \Delta_2^{\frac{4}{5}}\ \Delta_1^{\frac{3}{5}})$$

$$\tfrac{1}{5}\ \Delta_2^{\frac{1}{5}} = A_2\ (\Delta_2^{\frac{1}{5}}\ \Delta_1^{\frac{2}{5}}\ \Delta_3^{\frac{4}{5}}\ \Delta_4^{\frac{3}{5}}), \text{ and}$$

$$\tfrac{1}{5}\ \Delta_1^{\frac{1}{5}} = A_1\ (\Delta_4^{\frac{1}{5}}\ \Delta_2^{\frac{2}{5}}\ \Delta_1^{\frac{4}{5}}\ \Delta_3^{\frac{3}{5}}).$$

Substituting these values in (62), we get

$$r_1 = A_1\,(\Delta_1^{\frac{1}{5}}\ \Delta_3^{\frac{2}{5}}\ \Delta_4^{\frac{4}{5}}\ \Delta_2^{\frac{3}{5}}) + A_2\,(\Delta_2^{\frac{1}{5}}\ \Delta_1^{\frac{2}{5}}\ \Delta_3^{\frac{4}{5}}\ \Delta_4^{\frac{3}{5}})$$

$$+ A_3\,(\Delta_3^{\frac{1}{5}}\ \Delta_4^{\frac{2}{5}}\ \Delta_2^{\frac{4}{5}}\ \Delta_1^{\frac{3}{5}}) + A_4\,(\Delta_4^{\frac{1}{5}}\ \Delta_2^{\frac{2}{5}}\ \Delta_1^{\frac{4}{5}}\ \Delta_3^{\frac{3}{5}}). \qquad (74)$$

This, with immaterial differences in the subscripts, is Abel's expression; only we need to determine $A_1$, $A_2$, $A_3$ and $A_4$ more exactly. These terms are the reciprocals of the terms in (73) severally divided by 5. Therefore they are the roots of a biquadratic. Also, no surds can appear in $A_1$ except those that are present in $\Delta_1$, $\Delta_2$, $\Delta_3$ and $\Delta_4$. That is to say, $A_1$ is a rational function of $\surd s$, $\surd s_1$ and $\surd z$. But it was shown that $\surd s_1 \surd s = he \surd z$. Therefore $A_1$ is a rational function of $\surd s$ and $\surd z$. We may therefore put

$$A_1 = K + K'\,\Delta_1 + K''\,\Delta_4 + K'''\,\Delta_1\,\Delta_4,$$

$K$, $K'$, $K''$ and $K'''$ being rational. But the terms $A_1$, $A_2$, $A_4$, $A_3$ circulate with $\Delta_1$, $\Delta_2$, $\Delta_4$, $\Delta_3$. Therefore

$$A_2 = K + K' \Delta_2 + K'' \Delta_3 + K''' \Delta_2 \Delta_3,$$
$$A_4 = K + K' \Delta_4 + K'' \Delta_1 + K''' \Delta_1 \Delta_4,$$
$$A_3 = K + K' \Delta_3 + K'' \Delta_2 + K''' \Delta_2 \Delta_3,$$

These are Abel's values.

§72. Keeping in view the values of $\Delta_1$, $\Delta_2$, etc., in (67), and also that $z = 1 + e^2$, and s $= hz + h\surd z$, any rational values that may be assigned to $m$, $n$, $e$, $h$, $K$, $K'$, $K''$ and $K'''$ make $r_1$, as presented in (74), the root of an equation of the fifth degree. For, any rational values of $m$, $n$, etc., make the values of $S_1$, $S_2$, etc., in §62, rational.

§73. It may be noted that, not only is the expression for $r_1$ in (74) the root of a quintic equation whose auxiliary biquadratic is irreducible, but on the understanding that the surds $\surd s$ and $\surd z$ in $\Delta_1$ may be reducible, the expression for $r_1$ in (74) contains the roots both of all equations of the fifth degree whose auxiliary biquadratics have their roots rational, and of all that have quadratic sub-auxiliaries. It is unecessary to offer proof of this.

§74. The equation $x^5 - 10x^3 + 5x^2 + 10x + 1 = 0$ is an example of a solvable quintic with its auxiliary biquadratic irreducible. One of its roots is

$$\omega^{\frac{1}{5}} + \omega\omega^{\frac{2}{5}} + \omega^3\omega^{\frac{3}{5}} + \omega^4\omega^{\frac{4}{5}},$$

$\omega$ being a primitive fifth root of unity. It is obvious that this root satisfies all the conditions that have been pointed out in the preceding analysis as necessary. A root of an equation of the seventh degree of the same character is

$$\omega^{\frac{1}{7}} + \omega^4\omega^{\frac{2}{7}} + \omega^4\omega^{\frac{3}{7}} + \omega^2\omega^{\frac{4}{7}} + \omega^3\omega^{\frac{5}{7}} + \omega^6\omega^{\frac{6}{7}},$$

$\omega$ being a primitive seventh root of unity. The general form under which these instances fall can readily be found. Take the cycle that contains all the primitive $(m^2)^{\text{th}}$ roots of unity,

$$\theta,\ \theta^{\beta},\ \theta^{\beta^2},\ \text{etc.} \tag{75}$$

$m$ being prime. The number of terms in the cycle is $(m-1)^2$. Let $\theta_1$ be the $(m+1)^{\text{th}}$ term in the cycle (75), $\theta_2$ the $(2m+1)^{\text{th}}$ term, and so on. Then the root of an equation of the $m^{\text{th}}$ degree, including the instances above given, is

$$r_1 = (\theta + \theta^{-1}) + (\theta_1 + \theta_1^{-1}) + \dots + (\theta_{\frac{m-3}{2}} + \theta_{\frac{m-3}{2}}^{-1}).$$

[*Read before the Canadian Institute, March 3rd, 1883*].

# RESOLUTION

OF

# SOLVABLE EQUATIONS OF THE FIFTH DEGREE,

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## CONTENTS.



§1. By means of the laws established in the paper entitled "Principles of the Solution of Equations of the Higher Degrees," which is concluded in the present issue of the Journal of Mathematics, a criterion of the solvability of equations of the fifth degree may be found, and the roots of solvable quintics obtained in terms of given numerical coefficients. In certain classes of cases, the roots can be determined in terms of coefficients to which particular numerical values have not been assigned, but which are only assumed to be so related as to make the equations solvable.

## Sketch of the Method Employed.

§2. Let $r_1$, $r_2$, $r_3$, $r_4$, $r_5$, be the roots of the solvable irreducible equation of the fifth degree wanting the second term,

$$F(x) = x^5 + p_2 x^3 + p_3 x^2 + p_4 x + p_5 = 0. \quad (1)$$

It was proved in the "Principles" that

$$r_1 = \tfrac{1}{5}\left(\Delta_1^{\frac{1}{5}} + \Delta_2^{\frac{1}{5}} + \Delta_3^{\frac{1}{5}} + \Delta_4^{\frac{1}{5}}\right),$$

where $\Delta_1$, $\Delta_2$, $\Delta_3$, $\Delta_4$ are the roots of a biquadratic equation auxiliary to the equation $F(x) = 0$. It was also shown that the root can be expressed in the form

$$r_1 = \tfrac{1}{5}\left(\Delta_1^{\frac{1}{5}} + a_1 \Delta_1^{\frac{2}{5}} + e_1 \Delta_1^{\frac{3}{5}} + h_1 \Delta_1^{\frac{4}{5}}\right), \quad (2)$$

where $a_1$, $e_1$, $h_1$, involve only surds occurring in $\Delta_1$; and no surds occur in $\Delta_1$ except $\sqrt{(hz + h\sqrt{z})}$ and its subordinate $\sqrt{z}$; $z$ being equal to $1 + e^2$, and $h$ and $e$ being rational. As in the "Principles," we may put $5u_1 = \Delta_1^{\frac{1}{5}}$, $5u_2 = \Delta_2^{\frac{1}{5}}$, $5u_3 = \Delta_3^{\frac{1}{5}}$, $5u_4 = \Delta_4^{\frac{1}{5}}$. Then

$$r_1 = u_1 + u_2 + u_3 + u_4. \quad (3)$$

Let $S_1$ be the sum of the roots of the equation $F(x) = 0$, $S_2$ the sum of their squares, and so on. Also let

$$\left.\begin{aligned}
\Sigma(u_1^2 u_3) &= u_1^2 u_3 + u_2^2 u_1 + u_3^2 u_4 + u_4^2 u_2, \\
\Sigma(u_1^3 u_2) &= u_1^3 u_2 + u_2^3 u_4 + u_3^3 u_1 + u_4^3 u_3, \\
\Sigma(u_1 u_3^2 u_4^2) &= u_1 u_3^2 u_4^2 + u_2 u_1^2 u_3^2 + u_3 u_4^2 u_2^2 + u_4 u_2^2 u_1^2; \\
\Sigma(u_1^5) &= u_1^5 + u_2^5 + u_3^5 + u_4^5; \\
\text{Then}\quad S_2 &= 10(u_1 u_4 + u_2 u_3),\ S_3 = 15\left\{\Sigma(u_1^2 u_3)\right\}, \\
S_4 &= 20\left\{\Sigma(u_1^3 u_2)\right\} + \tfrac{3}{10}(S_2^2) + 60\, u_1 u_2 u_3 u_4, \\
S_5 &= 5\left\{\Sigma(u_1^5)\right\} + \tfrac{5}{6}(S_2 S_3) + 50\left\{\Sigma(u_1 u_3^2 u_4^2)\right\}.
\end{aligned}\right\} \quad (4)$$

§3. It was proved in the "Principles" that $u_1 u_4$ and $u_2 u_3$ are the roots of a quadratic equation. But

$$25\, u_1 u_4 = h_1 \Delta_1, \text{ and } 25\, u_2 u_3 = a_1 e_1 \Delta_1.$$

Therefore, because $a_1$, $e_1$, $h_1$, involve no surds that are not subordinate to $\Delta_1^{\frac{1}{5}}$, $\sqrt{z}$ is the only surd that can appear in $u_1 u_4$ and $u_2 u_3$. Consequently we may put

$$u_1 u_4 = g + a \sqrt{z}, \text{ and } u_2 u_3 = g - a \sqrt{z}, \tag{5}$$

where $g$, $a$, are rational. It scarcely needs to be pointed out that these forms are valid whether the surd $\sqrt{z}$ is irreducible or not. Now $S_2 = 10 (u_1 u_4 + u_2 u_3) = -2 p_2$. Therefore

$$g = -\tfrac{1}{10} (p_2). \tag{6}$$

Again, it was shown in the "Principles" that the four expressions $u_1^2 u_3$, $u_2^2 u_1$, $u_3^2 u_4$, $u_4^2 u_2$, are the roots of a biquadratic equation. And, by the same reasoning as that employed in the case of $u_1 u_4$ and $u_2 u_3$, the only surds that can appear in these expressions are $\sqrt{(hz + h\sqrt{z})}$, $\sqrt{(hz - h\sqrt{z})}$, and $\sqrt{z}$. Let $hz + h\sqrt{z} = s$, and $hz - h\sqrt{z} = s_1$. Then

$$\sqrt{s_1} = \left(\frac{\sqrt{z} - 1}{e}\right) \sqrt{s}, \text{ and } \sqrt{s}\sqrt{s_1} = he\sqrt{z}.$$

Hence the expressions $u_1^2 u_3$, $u_2^2 u_1$, $u_3^2 u_4$, $u_4^2 u_2$, may have their values exhibited in terms of $\sqrt{z}$ and either of the surds $\sqrt{s}$, $\sqrt{s_1}$. Put

$$\left.\begin{aligned}
u_1^2 u_3 &= k + c\sqrt{z} + (\theta + \varphi\sqrt{z})\sqrt{s}, \\
u_4^2 u_2 &= k + c\sqrt{z} - (\theta + \varphi\sqrt{z})\sqrt{s}, \\
u_2^2 u_1 &= k - c\sqrt{z} + (\theta - \varphi\sqrt{z})\sqrt{s_1}, \\
u_3^2 u_4 &= k - c\sqrt{z} - (\theta - \varphi\sqrt{z})\sqrt{s_1};
\end{aligned}\right\} \tag{8}$$

where $k$, $c$, $\theta$, $\varphi$, are rational. These coefficients must bear a relation to $g$, $a$, in (5). In fact, because

$$(u_1^2 u_3)(u_4^2 u_2) = (u_1 u_4)^2 (u_2 u_3),$$

$$(g^2 - a^2 z)(g + a\sqrt{z}) = (k + c\sqrt{z})^2 - (\theta + \varphi\sqrt{z})^2 (hz + h\sqrt{z}).$$

Equating the rational parts to one another, and also the irrational parts,

$$\left.\begin{aligned}
hz(\theta^2 + \varphi^2 z + 2\theta\varphi) &= k^2 + c^2 z - g(g^2 - a^2 z, \\
h(\theta^2 + \varphi^2 z + 2\theta\varphi z) &= 2kc - a(g^2 - a^2 z).
\end{aligned}\right\} \tag{9}$$

Because $s_2 = 15 \{\Sigma u_1^2 u_3)\} = -3p_3$,

$$k = -\tfrac{1}{20}(p_3). \tag{10}$$

It will be convenient to retain the symbols $g$ and $k$, whose values are given in (6) and (10). Again, because $u_1^3 u_2 = \dfrac{(u_1^2 u_3)(u_2^2 u_1)}{u_2 u_3}$, we have, from (5) and (8),

$$u_1^3\, u_2 = \frac{g + a\sqrt{z}}{g^2 - a^2 z}\left\{k + c\sqrt{z} + (\theta + \varphi\sqrt{z})\sqrt{s}\right\}$$
$$\left\{k - c\sqrt{z} + (\theta - \varphi\sqrt{z})\sqrt{s_1}\right\}$$
$$= A + A'\sqrt{z} + (A'' + A'''\sqrt{z})\sqrt{s},$$

where $A$, $A'$, $A''$, $A'''$, are rational. The value of $A$ is

$$A = \frac{1}{g_2 - a^2 z}\left\{g\,(k^2 - c^2 z) + ahez\,(\theta^2 - \varphi^2 z)\right\}. \tag{11}$$

Again, $u_1^5 = \dfrac{(u_1^2\, u_3)^2\ (u_2^2\, u_1)}{(u_2\, u_3)^2}$. That is, from (8) and (5) and (7).

$$u_1^5 = \frac{(g + a\sqrt{z})^2}{(g^2 - a^2 z)^2}\left\{\ 2\,(k + c\sqrt{z})^2 - (g^2 - a^2 z)\,(g + a\sqrt{z})\right.$$
$$\left. + 2\,(k + c\sqrt{z})\,(\theta + \varphi\sqrt{z})\sqrt{s}\right\}$$
$$\left\{k - c\sqrt{z} + (\theta - \varphi\sqrt{z})\sqrt{s_1}\right\}$$
$$= B + B'\sqrt{z} + (B'' + B'''\sqrt{z})\sqrt{s};$$

where $B$, $B'$, $B''$, $B'''$, are rational. Now, by (4),

$$S_4 = 20\left\{\Sigma\,(u_1^3\, u_2)\right\} + \tfrac{3}{10}\,(S_2^2) + 60\, u_1\, u_2\, u_3\, u_4\,.$$

And $S_4 = 2p_2^2 - 4p_4$. Also $\Sigma\,(u_1^3\, u_2) = 4A$; and, by (6), $10g = -p_2$; and, by (5), $u_1\, u_2\, u_3\, u_4 = g_2 - a_2\, z$. Therefore

$$p_4 = -20A + 5g^2 + 15a^2 z. \tag{12}$$

Again, $S_5 = 5\left\{\Sigma\,(u_1^5)\right\} + \tfrac{2}{3}\,(S_2\, S_3) + 50\left\{\Sigma\,(u_1\, u_3^2\, u_4^2)\right\}$.

And $\Sigma\,(u_1^5) = 4B$, $S_2\, S_3 = 6\, p_2\, p_3 = 1200\, gk$, and

$\Sigma\,(u_1\, u_3^3\, u_4^2) = u_1\, u_4\,(u_2^2\, u_1 + u_3^2\, u_4) + u_2\, u_3\,(u_1^2\, u_3 + u_4^2\, u_2)$.

Therefore $S_5 = 20B + 1000gk - 200acz$.

But $S_5 - 5p_2\, p_3 + 5p_5 = S_5 - 1000gk + 5p_5 = 0$.

Therefore
$$p_5 = -4B + 40acz. \tag{13}$$

The values of $p_4$ and $p_5$ in (12) and (13) make the quintic

$$F(x) = x^5 + p_2\, x^3 + p_3\, x^2 + (5g^2 + 15a^2 z - 20A)\, x$$
$$+ (40acz - 4B) = 0. \tag{14}$$

§4. Assuming the coefficients $p_2$, $p_3$, etc., in (1), to be known, the coefficients in the equation $F(x) = 0$ as exhibited in (14) involve six unknown quantities, namely, $a$, $c$, $\theta$, $\varphi$, $e$, $h$. The list does not include $z, g, k$; because $z = 1 + e^2$; and $g$ and $k$ are known by (6) and (10). To find the six unknown quantities we have six equations, which are here gathered together.

$$\left.\begin{aligned} p_4 &= -20A + 5g^2 + 15a^2 z, \\ p_5 &= -4B + 40acz, \\ B'' &= 1, \\ B''' &= 0, \\ hz(\theta^2 + \varphi^2 z + 2\theta\varphi) &= k^2 + c^2 z - g(g^2 - a^2 z) \\ h(\theta^2 + \varphi^2 z + 2\theta\varphi z) &= 2kc - a(g^2 - a^2 z). \end{aligned}\right\} \quad (15)$$

The first two of these equations are the equations (12) and (13). As to the third and fourth, it was proved in the "Principles" that the form of $u_1^5$ is $m + n\sqrt{z} + \sqrt{(hz + h\sqrt{z})}$, $m$ and $n$ being rational. This is saying in other words that $B'' = 1$ and $B''' = 0$. The last two of the equations (15) are the equations (9).

§5. The criterion of solvability of the equation $F(x) = 0$ may now be stated in a general way to be that the coefficients $p_2$, $p_3$, etc., must be so related that rational quantities, $a, c, \theta, \varphi, e, h$, exist satisfying the equations (15). We also see what requires to be done in order to find the roots of the equation $F(x) = 0$ in terms of the given coefficients. By (3), $r_1$ is known when $u_1$, $u_2$, $u_3$, $u_4$ are known. But, $B''$ and $B'''$ being respectively unity and zero,

$$u_1^5 = B + B'\sqrt{z} + \sqrt{s}, \quad u_2^5 = B - B'\sqrt{z} + \sqrt{s_1},$$
$$u_4^5 = B + B'\sqrt{z} - \sqrt{s}, \quad u_3^5 = B - B'\sqrt{z} - \sqrt{s_1}.$$

Therefore, to find $r_1$ we need to find $B$, $B'$, $z$ and $h$; which is equivalent to saying that we need to find the six unknown quantities $a, c, \theta, \varphi, e, h$. Before pointing out how this may be done in the most general case, I will refer to some special forms of soluble quintics.

## Case in which $u_1 u_4 = u_2 u_3$.

§6. A notable class of solvable quintics is that in which $u_1 u_4 = u_2 u_3$. It includes, as was proved in the "Principles," all the Gaussian equations of the fifth degree for the reduction of $x^n - 1 = 0$, $n$ prime. It includes also other equations, of which examples will presently be given. Now, when $u_1 u_4 = u_2 u_3$, the root of the quintic can be found in terms of the coefficients $p_2$, $p_3$, etc., even while these coefficients retain their general symbolic forms; in other words, the root can be found in terms of $p_2$, $p_3$, etc., without definite numerical values being assigned to $p_2$, $p_3$, etc. This I proceed to show.

§7. By (5), because $u_1 u_4 = u_2 u_3$, $a = 0$. Thus, one of the six unknown quantities is determined, while we have still the six equations (15) to work with. It might be sufficient to say, that, from six equations five unknown rational quantities can be found. I will recur to this idea; but in the meantime the following line of reasoning may be pursued. From (11), $A = \frac{k^2 - c^2 z}{g}$. Therefore equation (12) becomes

$$gp_4 = -20(k^2 - c^2 z) + 5g^3. \tag{16}$$

Also, because $a = 0$, equations (7) being kept in view,

$$u_1^5 = \frac{1}{g^2}$$

$$\left\{2(k^2 - c^2 z)(k + c\sqrt{z}) - g^3(k - c\sqrt{z}) + 2(k + c\sqrt{z})(\theta^2 - \varphi^2 z)he\sqrt{z}\right\}$$
$$+ B'' + B'''\sqrt{z})\sqrt{s}.$$

$$\therefore Bg^2 = k\left\{2(k^2 - c^2 z) - g^3\right\} + 2chez(\theta^2 - \varphi^2 z)$$

and $$B'g^2 = c\left\{2(k^2 - c^2 z) + g^3\right\} + 2khe(\theta^2 - \varphi^2 z);$$

$$\therefore u_1^5 = \frac{1}{g^2}[k\left\{2(k^2 - c^2 z) - g^3\right\} + 2chez(\theta^2 - \varphi^2 z)]$$

$$+ \frac{\sqrt{z}}{g_2}[c\left\{2(k^2 - c^2 z) + g^3\right\} + 2khe(\theta^2 - \varphi^2 z)] + \sqrt{s}. \tag{17}$$

Substitute in the second of equations (15) the value of $B$ that has been obtained. Then

$$g^2 p_5 = -4k\left\{2(k^2 - c^2 z) - g^3\right\} - 8chez(\theta^2 - \varphi^2 z). \tag{18}$$

The values of $B''$ and $B'''$ are

$$\left.\begin{aligned} B''eg^2 &= \theta\left\{M + 2e(k^2 - c^2 z)\right\} - \varphi zN = eg^2, \\ B'''eg^2 &= \theta N - \varphi\left\{M - 2e(k^2 c^2 z)\right\} = 0; \end{aligned}\right\} \tag{19}$$

$$\left.\begin{aligned} &\text{where } M = -2(k^2 + c^2 z) + g^3 + 4kcz, \\ &\text{which may be written } M = 5kcz - P, \\ &\text{and } N = 2(k^2 + c^2 z) - g^3 - 4kc, \\ &\text{which may be written } N = P - 4kc. \end{aligned}\right\} \tag{20}$$

The two equations (19) give us

$$\left.\begin{aligned} &\theta\left\{M^2 - zN^2 - 4e^2(k^2 - c^2 z)^2\right\} = eg^2\left\{M - 2e(k^2 - c^2 z)\right\}, \\ &\varphi\left\{M^2 - zN^2 - 4e^2(k^2 - c^2 z)^2\right\} = eg^2 N. \\ &\text{Therefore} \\ &\frac{\theta}{\varphi} = \frac{M - 2e(k^2 - c^2 z)}{N}. \end{aligned}\right\} \tag{21}$$

Equating the value of $\frac{\theta^2 + \varphi^2 z + 2\theta\varphi}{\theta^2 + \varphi^2 z + 2\theta\varphi z}$ obtained from (21) with that derived from the last two of equations (15),

$$\frac{k^2 + c^2 z - g^3}{2kcz} =$$

$$\frac{\{M - 2e(k^2 - c^2 z)\}^2 + N^2 z + 2N\{M - 2e(k^2 - c^2 z)\}}{\{M - 2e(k^2 - c^2 z)\}^2 + N^2 z + 2Nz\{M - 2e(k^2 - c^2 z)\}}. \quad (22)$$

The coefficients $p_2$, $p_3$, etc., in the equation $F(x) = 0$, being given, $g$ and $k$ are known by (6) and (10). Therefore, by (16), $c^2 z$ is known. Then (22) will be found to be a quadratic equation determinative of $c$. For, keeping in view the value of $P$ in (20), (22) may be written

$$\frac{k^2 + c^2 z - g^3}{2kc^2 z} =$$

$$\frac{\{4(k^2 + c^2 z)^2 + P^2\} - 8kPc - 16k(k^2 - c^2 z)(ce)}{\{4(k^2 - c^2 z)^2 - 16k^2 c^2 z - P^2\} c + 8kc^2 zP - 4(k^2 - c^2 z) P(ce)}$$

Because $g$, $k$, $c^2 z$ and $P$ are known, this equation is of the form

$$H(ce) = Kc + L,$$

where $H$, $K$, $L$, are known. Therefore, since $c^2 e^2 = c^2 z - c^2$,

$$c^2(H^2 + K^2) + 2KLc + (L^2 - H^2 c^2 z) = 0;$$

from which $c$ is known. Therefore, since $c^2 z$ is known, $z$ is known. Therefore $e$ is known. Therefore, by (21), $\theta$ and $\varphi$ are known. Therefore, by (18) or either of the equations (9), $h$ is known. Therefore, by (17), $u_1^5$ is known. In like manner, $u_2^5$, $u_3^5$, $u_4^5$, are known. Hence finally, by (3), $r_1$ is known.

§8. *Example First.* I will now give some numerical verifications of the theory. The Gaussian equation of the fifth degree for the reduction of $x^{11} - 1 = 0$, when deprived of its second term, is

$$x^5 - \frac{22}{5}x^3 - \frac{11}{25}x^2 + \frac{11 \times 42}{125}x + \frac{11 \times 89}{3125} = 0.$$

When a root of this equation is expressed as in (1), the value of $r_1$, as given by Lagrange, is

$$u_1^5 = \frac{11}{4(5)^5}\{-89 - 25\sqrt{5} + 5(19 - 9\sqrt{5})(-5 - 2\sqrt{5})\};$$

which, reduced to the form that we have adopted, is

$$u_1^5 = \frac{11}{4(5)^5}\left\{ - 89 + 25 \times \frac{89}{41} \sqrt{\left(\frac{5 \times 41^2}{89^2}\right)}\right\} + \sqrt{(hz + h\sqrt{z})};$$

where $h = - \dfrac{11^2 \times 89^2}{8 \times 41 \times (5)^8}, \sqrt{z} = - \dfrac{41}{89}\sqrt{5}$, and $e = - \dfrac{22}{89}$.

We have to show that this is the result to which the equations of the preceding section lead. The simplest way will be to find $g$, $k$ and $c^2 z$ by means of (6), (10) and (16), and then to take the values of $e$ and $\sqrt{z}$ given above, and to substitute them in equation (22). If the theory is sound, the equation ought in this way to be satisfied. When this equation has been satisfied, it will be unnecessary to pursue the verification farther. Because

$$p_2 = - \frac{22}{5}, \text{ and } p_3 = - \frac{11}{25},\ g = \frac{11}{25} \text{ and } k = \frac{11}{20 \times 25}.$$

From (18), taken in connection with (21), $che$ must be negative. Therefore

$$c = - \frac{11 \times 89}{4 \times 25 \times 41},\ kc = - \frac{89}{80 \times 41}\left(\frac{11}{25}\right)^2,$$

$$kcz = - \frac{41}{16 \times 89}\left(\frac{11}{25}\right)^2,\ k^2 - c^2 z = - \frac{31}{100}\left(\frac{11}{25}\right)^2,$$

$$M = - \frac{2716}{89 \times 100}\left(\frac{11}{25}\right)^2,\ N = \frac{1224}{41 \times 100}\left(\frac{11}{25}\right)^2,$$

$$M - 2e\,(k^2 - c^2 z) = - \frac{4080}{89 \times 100}\left(\frac{11}{25}\right)^2.$$

These values reduce the equation (22) to the identity

$$\frac{89}{41} = \frac{89}{41}\left\{\frac{41\,(4080^2 + 5 \times 1224^2) - 89\,(2448 \times 4080)}{89\,(4080^2 + 5 \times 1224^2) - 205\,(2448 \times 4080)}\right\}.$$

§9. *Example Second.* The example that has been given is one in which the auxiliary biquadratic is irreducible, I will now take an example,

$$x^5 + 10x^3 - 80x^2 + 145x - 480 = 0, \tag{23}$$

in which the auxiliary biquadratic has a sub-auxiliary quadratic. When the root of the equation (23) is put in the form (1),

$$u_1 = (1 + \sqrt{2})^{\frac{1}{5}},\ u^4 = (1 - \sqrt{2})^{\frac{1}{5}},$$

$$u_2 = (1 + \sqrt{2})\,(1 + \sqrt{2})^{\frac{2}{5}},$$

$$u_3 = (1 - \sqrt{2})\,(1 - \sqrt{2})^{\frac{2}{5}},$$

the product of the roots $(1 + \surd 2)^{\frac{1}{5}}$, $(1 - \surd 2)^{\frac{1}{5}}$, being $-1$. Putting $\beta$ for 28560, and $\lambda$ for 28562,

$$g = -1, k = 4, c\surd z = -3, z = \frac{\lambda^2}{\beta^2}, c = \frac{3\beta}{\lambda},$$

$$k^2 + c^2 z = 25, kc = \frac{12\beta}{\lambda}, \ kcz = \frac{12\lambda}{\beta},$$

$$P = 2(k^2 + c^2 z) - g^3 = 51,$$

$$M = \frac{48\lambda - 51\beta}{\beta}, N = \frac{51\lambda - 48\beta}{\lambda},$$

$$M - 2e(k^2 - c^2 z) = \frac{48\lambda - 51\beta + 14 \times 338}{\beta}.$$

These values cause (22) to become

$$\frac{13}{12} = \frac{\lambda\{Q^2 + (51\lambda - 48\beta)^2\} + 2\beta(51\lambda - 48\beta)Q}{\beta\{Q^2 + (51\lambda - 48\beta)^2\} + 2\lambda(51\lambda - 48\beta)Q}$$

where $Q = 48\lambda - 51\beta + 14 \times 338$. This may be written

$$\frac{13}{12} = \frac{H\lambda + 2K\beta}{H\beta + 2K\lambda}.$$

In order that this equation may subsist, it is necessary that

$$H(13\beta - 12\lambda) = 2K(12\beta - 13\lambda);$$

$$\text{or } \frac{H}{2}\left(\frac{\beta - 24}{2}\right) = -\frac{K(\beta + 26)}{2}.$$

But $H = (-80852)^2 + (85782)^2 = 6537045904 + 7358551524 = 13895597428$; $-K = (80852)(85782) = 6935646264$; $\frac{\beta - 24}{2} = 14268$; $\frac{\beta + 26}{2} = 14293$; and $6947798714 \times 14268 = 6935646264 \times 14293 = 99131192051352$.

§10. *Example Third.* I will finally take an example,

$$x^5 + 20x^3 + 20x^2 + 30x + 10 = 0, \tag{24}$$

in which the roots of the auxiliary biquadratic are all rational. By (6) and (10) and (16), $g = -2$, $k = -1$, $c^2 z = 0$. Therefore the denominator of the expression on the left of (22) is zero, while the numerator is not zero. Therefore the denominator of the expression on the right of (22) is zero. Or, $-g^6 + 4k^2g^3 - 8ek^4 + 4eg^3k^2 = 0$. Therefore $e = -\frac{12}{5}$. Therefore $z = \left(\frac{13}{5}\right)^2$, and $c = 0$. Hence $M = -10$, $N = 10$; and, if

$$D = M^2 - zN^2 - 4e^2(k^2 - c^2 z)^2,$$

$$D = -104e^2. \text{ Therefore, by (21), } \theta = -\frac{1}{12},$$

$$\varphi = \frac{25}{12 \times 13}, \ \theta^2 - \varphi^2 z = -\frac{1}{6}. \text{ Therefore by (9), } h = \frac{225}{26}.$$

Therefore using the symbols, $B$, $B'$, as in §3,

$$B = -\frac{5}{2}, \ B' = -\frac{45}{26}, \ s = h(z + \sqrt{z}) = 81,$$

$$s_1 = h(z - \sqrt{z}) = 36.$$

Therefore $\quad u_1^5 = -7 + 9 = 2, \ u_4^5 = -7 - 9 = -16,$

$$u_2^5 = 2 - 6 = -4, \ u_3^5 = 2 + 6 = 8.$$

Hence, by (3),

$$r_1 = 2^{\frac{1}{5}} - 2^{\frac{2}{5}} + 2^{\frac{3}{5}} - 2^{\frac{4}{5}};$$

which is the solution of the equation (24).

§11. It was pointed out in §7 that, in the case we are considering, there are six equations and five unknown quantities. All the unknown quantities may be eliminated, and an equation $p' = 0$ obtained; where $p'$ is a rational function of the coefficients $p_2$, $p_3$, etc. This elimination has been performed, under the direction of the author of the paper, by Mr. Warren Reid of Toronto, with the following result. Putting $P$, as in §7, for $2(k^2 + c^2 z) - g^3$, let

$$A = -2kc^2 zg^3 \{8(k^2 + c^2 z) - 3g^3\},$$

$$B = g^3 \{16k^2 c^2 z + 4(k^2 + c^2 z)^2 - 5g^3(k^2 + c^2 z) + g^6\},$$

$$D = -4(k^2 - c^2 z)\{-g^6 + 3g^3(k^2 + c^2 z) - 2(k^2 - c^2 z)^2\},$$

$$A_1 = -8kc^2 z[32kc^2 z(k^2 - c^2 z) - P\{p_5 g^2 + 8k(k^2 - c^2 z) - 4kg^3\}]$$

$$B_1 = \{p_5 g^2 + 8k(k^2 - c^2 z) - 4kg^3\}[-32k^2 c^2 z + g^3\{4(k^2 + c^2 z) - g^3\}] + 64kc^2 z P(k^2 - c^2 z),$$

$$D_1 = -16kc^2 zg^3\{4(k^2 + c^2 z) - g^3\} + 4P(k^2 - c^2 z)\{p_5 g^2 + 8k(k^2 - c^2 z) - 4kg^3\}.$$

Then, since $10g = -p_2$, and $20k = -p_3$, and

$$20c^2 z = p_4 g - 5g^3 + 20k^2,$$

the quantities $A$, $B$, $D$, $A_1$, $B_1$, $D_1$, are known rational functions of $p_2$, $p_3$, etc. And

$$(B^2 + D^2)(A_1^2 - D_1^2 c^2 z) - (B_1^2 + D_1^2)(A^2 - D^2 c^2 z)$$
$$+ 4\{AB(B_1^2 + D_1^2) - A_1 B_1 (B^2 + D^2\}$$
$$\{AB(A_1^2 - D_1^2 c^2 z) - A_1 B_1 (A^2 - D^2 c^2 z)\} = 0. \qquad (25)$$

§12. To verify this result, the Gaussian equation in §8 may be used. Here

$$A = -\frac{11^6}{2^5 \times 5^{12}}\left(\frac{11^3 + 11^2 \times 19}{5^6}\right) = -\frac{11^8 \times 3}{2^4 \times 5^{17}}$$

$$B = \frac{11^3}{5^6}\left(\frac{11^4}{2^4 \times 5^9} + \frac{3^4 \times 7^2 \times 11^4}{2^4 \times 5^{12}} - \frac{9 \times 35 \times 11^5}{8 \times 5^{12}} + \frac{11^6}{5^{12}}\right)$$

$$= -\frac{9 \times 11^7}{4 \times 5^{16}}$$

$$D = \frac{11^2 \times 31}{5^{18}}\left(-11^6 + \frac{7 \times 27 \times 11^5}{8} - \frac{31^2 \times 11^4}{8}\right)$$

$$= \frac{3 \times 31 \times 11^6}{4 \times 5^{16}}.$$

$$A_1 = \frac{11^8}{2^6 \times 5^{18}}(19 + 31) = \frac{11^8}{2^5 \times 5^{16}}$$

$$B_1 = \frac{11^7}{2^4 \times 5^{18}}(-5^3 + 44 \times 41 - 19 \times 31) = \frac{11^7 \times 109}{8 \times 5^{17}}$$

$$D_1 = -\frac{11^6}{4 \times 5^{12}}\left(\frac{63 \times 11^2}{2 \times 5^6} - \frac{11^3}{5^6}\right) - \frac{11^7 \times 19 \times 31}{8 \times 5^{18}}$$

$$= -\frac{11^7 \times 26}{5^{17}}$$

Therefore

$$B^2 + D^2 = \frac{9 \times 11^{12} \times 41}{8 \times 5^{30}}, \quad B_1^2 + D_1^2 = \frac{11^4 \times 11029}{2^6 \times 5^{33}},$$

$$A^2 - D^2 c^2 z = -\frac{9 \times 11^{14} \times 89}{2^6 \times 5^{35}},$$

$$A_1^2 - D_1^2 c^2 z = -\frac{11^{16} \times 40139}{2^{10} \times 5^{37}}.$$

By the substitution of these values, equation (25) becomes

$$\frac{11^{56} \times 3^4}{2^{26} \times 5^{136}} \{ 626533^2 - 2886277 \times 13600357 \} =$$
$$\frac{11^{56} \times 3^4}{2^{26} \times 5^{136}} \{ 39254397600889 - 39254397600889 \} = 0.$$

§13. As an additional verification, the equation

$$x^5 + 10x^3 - 80x^2 + 145x - 480 = 0$$

may be taken. Here, by §9,

$$g = -1,\ k = 4,\ k^2 - c^2 z = 7,\ k^2 + c^2 z = 25.$$

Therefore

$$A = 2^3 \times 3^2 \times 7 \times 29,\ B = -2 \times 5 \times 17 \times 29,$$
$$D = 2^3 \times 3 \times 7 \times 29,$$
$$A_1 = -2^9 \times 3^4 \times 141,\ B_1 = 2^4 \times 3 \times 17 \times 2393,$$
$$D_1 = -2^7 \times 3^2 \times 13 \times 19.$$
$$B^2 + D^2 = 2^2 \times 29^2 \times 14281,$$
$$B_1^2 + D_1^2 = 2^8 \times 3^2 \times 5 \times 338016989,$$
$$A^2 - D^2 c^2 z = 0,$$
$$A_1^2 - D_1^2 c^2 z = 2^{14} \times 3^6 \times 5 \times 7 \times 17^2 \times 277.$$

By the substitution of these values, equation (25) becomes

$$2^{18} \times 3^6 \times 5 \times 7 \times 17^2 \times 29^4 \{ 277 \times 14281^2$$
$$+ 5^2 \times 7 \times 338016989 - 2^3 \times 3 \times 141 \times 2393 \times 14281 \} = 0.$$

*The Trinomial Quintic* $x^5 + p_4 x + p_5 = 0$.

§14. In this case, by (6) and (10), $g = 0$, and $k = 0$. Therefore, by (11), $A = -\dfrac{he(\theta^2 - \varphi^2 z)}{a}$. Therefore, by (12),

$$p_4 = \frac{20he(\theta^2 - \varphi^2 z)}{a} + 15a^2 z. \qquad (26)$$

Also, by §3, $B = \dfrac{1}{a^2 z}\{ -a^3 z^2 c + 2hecz(\theta - \varphi^2) \}$. Therefore, by (13),

$$p_5 = -\frac{8hec}{a^2}(\theta^2 - \varphi^2 z) + 44acz. \qquad (27)$$

Hence the quintic becomes

$$F(x) = x^5 + \left\{ \frac{20he\,(\theta^2 - \varphi^2 z)}{a} + 15a^2 z \right\} x$$

$$+ \left\{ - \frac{8hec}{a^2} (\theta^2 - \varphi^2 z) + 44acz \right\} = 0. \tag{28}$$

The criterion of solvability of a trinomial quintic of the kind under consideration is therefore that the coefficients $p_4$ and $p_5$ be related in the manner indicated in the form (28); while at the same time the last four of the equations (15), modified by putting $g = k = 0$, subsist between the rational quantities $a, c, e, h, \theta, \varphi$. From these data, the three following equations may be deduced, $v$ being put for $\frac{c^2}{a^3}$:

$$\left.\begin{aligned} &8ev^3 - 4zv^2 + z(3 - 4e)v - z^2 = 0, \\ &\frac{2p_4}{a^2} + \frac{5p_5}{ac} = 250z, \\ &4v(ze + 4zv - 8v^2) = \left(- 3z + \frac{p_4}{5a^2}\right)\{z + 4v(e - 1) + 8v^2\}. \end{aligned}\right\} \tag{29}$$

The first of these equations is obtained from a comparison of the two equations (9), the second is obtained by putting $p_4$ and $p_5$ respectively equal to the values they have in (28); and the third is obtained by putting $p_4$ equal to the coefficient of the first power of $x$ in (28).

§15. If any rational values of $e$ and $v$ can be found satisfying the first of equations (29), let such values be taken. Then, from the second and third of (29), $a^2$ and $ac$ can be found. Therefore $a$ and $c$ are known. Therefore, by (21), $\theta$ and $\varphi$ are known. Therefore, by (9), $h$ is known. In this way all the elements for the solution of the quintic are obtained.

§16. For example, the three equations (29) are satisfied by the values.

$$e = \frac{1}{2}, \; z = v = \frac{5}{4}, \; c = \frac{25}{2},$$

$$a = 5, \therefore \theta = 0, \; \varphi = -\frac{4}{75}, \; h = \frac{45 \times 25^3}{16}.$$

When these values are substituted in (28), the quintic becomes

$$x^5 + \frac{625x}{4} + 3750 - 0.$$

Then the values of $u_1^5$, $u_2^5$, $u_3^5$, $u_4^5$, obtained from the expression for $u_1^5$, in §3, are

$$u_1^5 = \frac{625}{4}\left\{-1-\sqrt{\left(\frac{5}{4}\right)}+\frac{3}{\sqrt{5}}\sqrt{\left(\frac{5}{4}+\sqrt{\frac{5}{4}}\right)}\right\},$$

$$u_4^5 = \frac{625}{4}\left\{-1-\sqrt{\left(\frac{5}{4}\right)}-\frac{3}{\sqrt{5}}\sqrt{\left(\frac{5}{4}+\sqrt{\frac{5}{4}}\right)}\right\},$$

$$u_2^5 = \frac{625}{4}\left\{-1+\sqrt{\left(\frac{5}{4}\right)}-\frac{3}{\sqrt{5}}\sqrt{\left(\frac{5}{4}-\sqrt{\frac{5}{4}}\right)}\right\},$$

$$u_3^5 = \frac{625}{4}\left\{-1+\sqrt{\left(\frac{5}{4}\right)}+\frac{3}{\sqrt{5}}\sqrt{\left(\frac{5}{4}-\sqrt{\frac{5}{4}}\right)}\right\}.$$

Hence, $r_1 = u_1 + u_2 + u_3 + u_4 = -1.52887 - 2.25035 + 2.48413 - 3.65639 = -4.95148.$

## When any Relation is Assumed between the Six Unknown Quantities.

§17. In the case in which $u_1 u_4$ was taken equal to $u_2 u_3$ a relation was in fact assumed betwixt the six unknown quantites $a$, $c$, $e$, $h$, $\theta$, $\varphi$; for, as we saw, to put $u_1 u_4 = u_2 u_3$ is tantamount to putting $a = 0$. Hence, as was noticed in §7, we had only five unknown quantities to be found from six equations. Now, when any relation whatever is assumed betwixt the six unknown quantities, the root of the quintic can be found in terms of the given coefficients $p_2$, $p_3$, etc., without any definite numerical values being assigned to the coefficients, because six rational quantities can always be found from seven equations.

## The General Case.

§18. We have hitherto been dealing with solvable quintics, assumed to be subject to some condition additional to what is involved in their solvability. We have now to consider how the general case is to be dealt with. That is to say, we here make no supposition regarding the equation of the fifth degree $F(x) = 0$ except that it wants the second term and is solvable algebraically. In this case it is impossible to find the roots in terms of the coefficients $p_2$, $p_3$, etc., while these coefficients retain their general symbolic forms. But the equations in §3 enable us to find the roots when the coefficients receive any definite numerical values that render the equation solvable. For, we have the six equations (15) to determine the six unknown quantities $a$, $c$, $e$, $h$, $\theta$, $\varphi$; and we can eliminate five of the unknown quantities, and obtain an equation involving only one unknown quantity. The unknown quantity appearing in this equation has a rational value; but there are known methods of finding the rational roots of any algebraical equation with definite numerical coefficients. Therefore the unknown quantity can be found. In this way all the six unknown quantities $a$, $c$, $e$, $h$, $\theta$, $\varphi$, can be found. Hence the roots of the quintic can be found.

§19. *Note.*—From my friend, Mr. J. C. Glashan, of Ottawa, who read in manuscript the paper on the "*Principles of the Solution of Equations of the Higher Degrees*," but did not see the present paper on the "*Resolution of Solvable Equations of the fifth Degree*," I learn that, setting out from propositions demonstrated in the "Principles," he has arrived at important conclusions in the theory of Quintics, which will be made public without delay; but he has not communi cated to me either his method or the results he has obtained.

# PROCEEDINGS

OF

# THE CANADIAN INSTITUTE,

SESSION 1884.

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## NINTH ORDINARY MEETING.

The Ninth Ordinary Meeting of the Session 1883-4 was held on Saturday, January the 12th, the President in the chair.

The minutes of last meeting were read and confirmed.

Mr. James Bain, jun. and Mr. John Notman, were appointed to represent the Institute on the Board of the Industrial Exhibition Association.

The Rev. William Clark of Trinity College was elected a member.

The following list of donations and exchanges were presented:

1. Transactions of the Royal Geological Society of Cornwall, Vol. X, Part 5.
2. Science, Vol. II, Nos. 46, 47 and 48.
3. The Ornithologist and Oölogist, for Jan., 1884.
4. Proceedings of the Royal Geographical Society for December, 1883.
5. Transactions of the Royal Scottish Society of Arts, Vol. XI, Part 1.
6. Science Record, Vol. II, No. 2, Dec. 15th, 1883.
7. Historical Collections of the Essex Institute, Vol. XX, Nos. 1 to 9, Jan. to Sept., 1883.
8. Journal of the Royal Microscopical Society, Vol. III, Part 6, Dec., 1883.
9. Journal of the Franklin Institute, for Jan., 1884.
10. Journal of the Transactions of the Victoria Institute, Vol. XVII, No. 67.
11. The Canadian Practitioner, Jan., 1884.
12. Micrometry, Reprinted from the Proceedings of the American Society of Microscopists, Chicago Meeting, 1883.
13. An Examination of some Controverted Points of the Physiology of Voice, by J. Wesley Mills, M. A., M. D. Read before the American Association for the Advancement of Science at Montreal, Aug., 1882.

14. Proceedings of the Philosophical Society of Glasgow, Vol. XIV.
15. The Canadian Entomologist for Nov., 1883.
16. Bulletin de la Société Géologique de France, Vol. XII, No. 1.
17. Mémoires des Travaux de la Société des Ingénieurs Civils for Oct., 1883.
18. Transactions of the Manchester Geological Society, Vol. XVII, Part 11.

Prof. R. Ramsay Wright, then presented the substance of a paper on the "Nervous System of the Cat-fish." Special attention was directed to the 'clavate' cells of the epidermis, to the branching of the fifth nerve, and to the relation existing between the air-bladder and the auditory organ. The paper is the first of a series on the cat-fish (*aminras catus*) and will appear in a subsequent fasciculus of the Proceedings.

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## TENTH ORDINARY MEETING.

The Tenth Ordinary Meeting of the Session 1883-'84, was held on Saturday, the 19th of January, the President in the chair.

The minutes of last meeting were read and confirmed.

The following gentlemen were elected members of the Institute:—R. E. Kingsford, M.A.; Mr. D. O'Brooke, and Mr. J. Alfred Wilson.

The following list of donations and exchanges was read by the Hon. Secretary:

1. Science, Vol. III., No. 49, for January 11, 1884.
2. Journal of Speculative Philosophy, Vol. XVII., No. 4, October, 1883.
3. Proceedings of the Royal Geographical Society, Vol. VI., No. 1, Jan., 1884.
4. Trübner's American, European, and Oriental Literary Record, Vol. IV., Nos. 9 to 10, September to October, 1883.

Mr. W. Waugh Lauder then read a paper entitled, "The History of Musical Instruments." The instruments specially noticed were the Piano, Violin and Organ. In the discussion which followed, Mr. Notman, Mr. Wm. Anderson, Mr. Geo. E. Shaw, Mr. Paul Frind and Mr. Geo. Murray, took part.

## ELEVENTH ORDINARY MEETING.

The Eleventh Ordinary Meeting of the Session 1883-'84, was held on Saturday, January the 26th, 1884, the Second Vice-President, Mr. Geo. Murray, in the chair.

The Minutes of last meeting were read and confirmed.

Mr. Stephen Nairn and Dr. John McConnell were elected members of the Institute.

The following list of donations and exchanges was read by the Hon. Secretary :

1. Science, Vol. III., No. 50, January 18th, 1884.
2. The Monthly Weather Review for December.
3. Map of Winnipeg and environs, by Alan Macdougall, Esq., C. E., F.R.S.E. Presented by the author.
4. Proceedings of the Boston Society of Natural History, Vol. XXII., Part 2, Nov., 1882, to Feb., 1883.

The President, Mr. J. M. Buchan, then read a paper entitled "Flora Hamiltonensis," a list of plants collected in the vicinity of Hamilton.

## FLORA HAMILTONENSIS.

In preparing this list I have adopted the classification and nomenclature employed by Professor Gray, in the fifth edition of his Manual. Plants, the names of which are marked with an asterisk, are admitted on the authority of the late Judge Logie. All plants included occur within seventeen miles of Hamilton :—

RANUNCULACEÆ.

Clematis verticillaris, DC. Chedoke.
" Virginiana, L.
Anemone cylindrica, Gray.
" Virginiana, L.
" Pennsylvanica, L.
" nemorosa, L.
* " nemorosa, L., var. quinquefolia. Oaklands.
Hepatica triloba, Chaix.
" acutiloba, DC.
Thalictrum anemonoides, Mx.
" dioicum, L.
" Cornuti, L.
Ranunculus aquatilis, L., var. trichophyllus, Chaix.
* " multifidus, Pursh.
" abortivus, L.
" sceleratus, L.

RANUNCULACEÆ—*Continued.*

Ranunculus recurvatus, Poir.
" Pennsylvanicus, L. Also at Fullarton.
" fascicularis, Muhl. Also at Walkerton.
" repens, L.
" bulbosus, L.
" acris, L.
Caltha palustris, L.
Coptis trifolia, Salisb.
Aquilegia Canadensis, L.
Delphinium Consolida, L.
Actaea spicata, L. var. rubra, Mx.
" alba, Bigel.

MAGNOLIACEÆ.

Liriodendron tulipifera, L.

MENISPERMACEÆ.

Menispermum Canadense, L.

BERBERIDACEÆ.

* Berberis vulgaris, L.
Caulophyllum thalictroides, Mx.
Podophyllum peltatum, L.

NYMPHÆACEÆ.

Nymphæa tuberosa, Paine.
Nuphar advena, Ait.

SARRACENIACEÆ.

Sarracenia purpurea, L.

PAPAVERACEÆ.

Papaver argemone, L.
Chelidonium majus, L.
Sanguinaria Canadensis, L.

FUMARIACEÆ.

* Adlumia cirrhosa, Raf. Rare.
Dicentra cucullaria, DC.
" Canadensis, DC.
* Fumaria officinalis, L. Burlington Beach.

CRUCIFERÆ.

Nasturtium officinale, R. Br.
" silvestre, R. Br., Dundas.
" palustre, DC.
" " " var. hispidum.
Dentaria diphylla, Mx.
" heterophylla, Nutt.
" laciniata, Muhl.
Cardamine rhomboidea, DC.
* Cardamine rhomboidea, DC. var. purpurea, Torr.
* Cardamine patensis, L. Millgrove.
" hirsuta, L.
Arabis hirsuta, Scop.
" laevigata, DC.
" Canadensis, L.
Erysimum cheiranthoides, L.
Sisymbrium officinale, Scop.
" canescens, Nutt. Burlington Beach.
Brassica sinapistrum, Boissier.
" nigra, Gray.
Camelina sativa, Crantz. Also at Paris.
Capsella Bursa-pastoris, Moench.
Lepidium Virginicum, L.
" ruderale, L.
" campestre, L.
Cakile Americana, Nutt.

CAPPARIDACEÆ.

Polanisia graveolens, Raf.

VIOLACEÆ.

Viola blanda, Willd.
" cucullata, Ait.
" " " var. cordata.
* " sagittata, Ait. The Cemetery.

VIOLACEÆ—*Continued.*

Viola canina L. var. silvestris, Regel.
" rostrata, Pursh.
" Canadensis, L.
" pubescens, Ait.

CISTACEÆ.

Helianthemum Canadense, Mx.
Lechaea minor, Lam.

DROSERACEÆ.

* Drosera rotundifolia, L. Ancaster.

HYPERICACEÆ.

* Hypericum Kalmianum, L.
* " ellipticum, Hook. Freeman's Lot.
" perforatum, L.
" corymbosum, Muhl.
" mutilum, L.
Elodes Virginica, Nutt.

CARYOPHYLLACEÆ.

Saponaria officinalis, L.
* Silene inflata, Smith.
" antirrhina, L.
" noctiflora, L.
Lychnis Githago, Lam.
Arenaria serpyllifolia, L. Also at St. Thomas.
" stricta, Mx.
* " lateriflora, L. Burlington Beach.
Stellaria media, Smith.
" longiflora, Muhl.
" longipes, Goldie.
Cerastium vulgatum, L.
" viscosum, L.
* " oblongifolium, Torr. [Query.] Woods behind Captain Nichols's Farm.
" arvense, L.

PORTULACACEÆ.

Portulaca oleracea, L.
" grandiflora, Hook.
Claytonia Virginica, L.

MALVACEÆ.

Malva rotundifolia, L.
" moschata, L.
Abutilon Avicennæ, Gaertn. Dundas. Mouth of Stony Creek.

TILIACEÆ.

Tilia Americana, L.

LINACEÆ.

Linum Virginianum, L.

GERANIACEÆ.

Geranium maculatum, L.
" pusillum, L.
" Robertianum L.

GERANIACEÆ—*Continued.*

Erodium Cicutarium, L'Her.
Impatiens pallida, Nutt.
" fulva, Nutt.
Oxalis stricta, L.

RUTACEÆ.

Xanthium Americanum, Mill.

ANACARDIACEÆ.

Rhus typhina, L.
" toxicodendron, L.
" " " var. radicans. Mountain, above Reservoir.

VITACEÆ.

Vitis Labrusca, L. Mountain, East of Reservoir.
" cordifolia, Lam.
" cordifolia. Lam., var. riparia, Gray. This well-marked variety is very common, but I have never seen it in either flower or fruit.
Ampelopsis quinquefolia, Mx.

RHAMNACEÆ.

* Rhamnus alnifolia, L'Her. Millgrove.
Ceanothus Americanus, L.

CELASTRACEÆ.

Celastrus scandens, L.
Euonymus Americanus L., var. obovatus, Torr. and Gray.

SAPINDACEÆ.

Staphylea trifolia, L.
Acer spicatum, Lam.
" saccharinum, Wang.
" dasycarpum, Ehrhart.
" rubrum, L.

POLYGALACEÆ.

* Polygala Nuttallii, Torr. and Gray. [Query.] Prince's Island.
" verticillata, L
" Senega, L
" paucifolia, Willd.

LEGUMINOSÆ.

Trifolium arvense, L.
" pratense, L
" repens, L.
Melilotus officinalis, Willd.
" alba, Lamm.
Medicago lupulina, L.
Robinia Pseudacacia, L.
Astragalus Canadensis, L.
" Cooperi, Gray.
Desmodium nudiflorum, DC.
" acuminatum, DC.

LEGUMINOSÆ—*Continued.*

Desmodium cuspidatum, Torr. & Gr.
" paniculatum, DC.
" Canadense DC.
* Lespedeza repens, Torr. and Gray. The Dell, Ancaster.
* " violacea, Pers. The Dell, Ancaster.
" hirta, Ell.
" capitata, Mx.
*Vicia hirsuta, Koch.
Lathyrus maritimus, Bigelow.
* " pratensis, L. Ancaster.
" ochroleucus, Hook.
" palustris, L.
" palustris, L., var. myrtifolius, Gray. Also at Toronto.
Apios tuberosa, Moench
Phaseolus diversifolius, Pers.
Amphicarpæa monoica, Nutt.
* Baptisia tinctoria, R. Br.

ROSACEÆ

Prunus Americana, Marshall.
" Pennsylvanica, L.
" Virginiana, L.
" serotina, Ehrhart.
* Spiræa salicifolia, L. Millgrove.
Gillenia trifoliata, Moench.
Agrimonia Eupatoria, L.
Geum album, Gmelin.
" strictum, Ait.
" rivale, L.
Waldsteinia fragarioides, Tratt.
Potentilla Norvegica, L.
" paradoxa, Nutt.
" Canadensis, L.
" argentea, L. Also at Paris.
" anserina, L.
" palustris, Scop.
Fragaria Virginiana, Ehrhart.
" vesca, L.
* Dalibarda repens, L.
Rubus odoratus, L.
" triflorus, Richardson.
" strigosus, Mx.
" occidentalis, L.
" villosus, Ait.
" Canadensis, L.
Rosa Carolina. L.
" lucida, Ehrhart.
" blanda, Ait.
" rubiginosa, L.
* " micrantha, Smith.
Cratægus oxyacantha, L. Spontaneous on bluff overlooking Dundas Marsh.
" coccinea, L.

ROSACEÆ—*Continued.*

Cratægus tomentosa, L.
" tomentosa, L., var. pyrifolia, Gray.
" Crus-Galli, L.
Pyrus coronaria, L.
* " arbutifolia, L., var. melanocarpa. Millgrove Marsh.
" aucuparia, Gærtn. Apparently indigenous near Dundas Marsh.
Amelanchier Canadensis, Torr. and Gray, var. Botryapium, Gray.
" Canadensis, Torr. and Gray, var. rotundifolia, Gray.
" Canadensis, Torr. and Gray, var. oblongifolia, Gray.
" Canadensis, Torr. and Gray, var. with notched petals 2-4 feet high flowering a few days later than the preceding variety.

SAXIFRAGACEÆ.

Ribes cynosbati, L.
* " hirtellum, Mx.
" rotundifolium, Mx.
" lacustre, Poir.
" floridum, L.
* " rubrum, L. Millgrove.
Saxifraga Virginiensis, Mx.
*Parnassia Caroliniana, Mx. Ancaster.
Mitella diphylla, L.
" nuda, L.
Tiarella cordifolia, L.
* Chrysosplenium Americanum, Schwein. Ancaster.

CRASSULACEÆ.

Penthorum sedoides, L.
Sedum ternatum, Mx. The Mountain.
" Telephium, L.

HAMAMELACEÆ.

Hamamelis Virginica, L.

HALORAGEÆ.

Myriophyllum spicatum, L.
* " verticillatum, L.
* " heterophyllum, Mx. Waterdown Creek.

ONAGRACEÆ.

Circæa Lutetiana, L.
" Alpina, L.
Epilobium angustifolium, L.

ONAGRACEÆ—*Continued.*

Epilobium coloratum, Muhl.
Œnothera biennis, L., var. grandiflora.
" biennis, L., var. muricata.
* " pumila, L. Land's Inlet.

LYTHRACEÆ.

Nesaea verticillata, H. B. K.

CUCURBITACEÆ.

* Sicyos angulatus, L.
Echinocystis lobata, Torr. and Gray. In a thicket near Waterdown Creek, and apparently indigenous.

UMBELLIFERÆ.

* Hydrocotyle Americana, L. Ancaster.
Sanicula Canadensis, L.
" Marilandica, L.
Heracleum lanatum, Mx.
Pastinaca sativa, L.
Archangelica atropurpurea, Hoffm.
Conioselinum Canadense, Torr. and Gray.
* Thaspium aureum, Nutt. Prince's Island.
Zizia integerrima, DC.
Cicuta maculata, L.
" bulbifera, L.
Sium lineare, Mx.
Cryptotænia Canadensis, DC.
Osmorrhiza longistylis, DC.
" brevistylis, DC.
Carum carui, L.

ARIALIACEÆ.

Aralia racemosa, L.
" nudicaulis, L.
" quinquefolia, Gray.
" trifolia, Gray.

CORNACEÆ.

Cornus Canadensis, L.
" florida, L.
" circinata, L'Her.
" stolonifera, Mx.
" paniculata, L'Her.
" alternifolia, L.

CAPRIFOLIACEÆ.

* Linnæa borealis, Gronov. Lake Medad.
Symphoricarpus racemosus, Mx.
* Symphoricarpus vulgaris, Mx.
* Lonicera flava, Sims.
" parviflora, Lam.
" hirsuta, Eaton.
" ciliata, Muhl.
Lonicera Tartarica, L. Mountain side, west of Queen Street.

CAPRIFOLIACEÆ—*Continued.*

Diervilla trifida, Moench.
Triosteum perfoliatum, L.
Sambucus Canadensis, L.
" pubens, Mx.
* Viburnum nudum, L., var. cassinoides. Millgrove.
" pubescens, Pursh.
" acerifolium, L.
" Opulus, L. Also at Fullarton.

RUBIACEÆ.

Galium Aparine, L.
" asprellum, Mx.
" trifidum, L.
" triflorum, Mx.
" boreale, L.
" verum, L.
Cephalanthus occidentalis, L.
Mitchella repens, L.

DIPSACEÆ.

Dipsacus silvestris, Mill.

COMPOSITÆ.

Liatris cylindracea, Mx. Railway cutting in Burlington Heights. Also at the Humber.
Eupatorium purpureum, L.
" perfoliatum, L.
" ageratoides, L.
Aster corymbosus, Ait.
" macrophyllus, L.
" lævis, L., var. lævigatus, Willd.
" lævis, L., var. cyaneus, Hoffm.
" azureus, Lindley.
" undulatus, L.
" cordifolius, L.
" sagittifolius, Willd.
" multiflorus, Ait.
" Tradescanti, L.
" miser, L.
" simplex, Willd.
" tenuifolius L. Also at Port Rowan.
" carneus, Nees.
" puniceus, L.
" Novæ Angliæ.
" graminifolius, Pursh.
" ptarmicoides, Torr. and Gray.
Erigeron Canadense, L.
Erigeron bellidifolium, L.
" Philadelphicum, L.
" annuum, Pers.
" strigosum, Muhl.
Diplopappus umbellatus, Torr. and Gray.
Solidago squarrosa, Muhl.
" bicolor L.

COMPOSITÆ—*Continued.*

Solidago bicolor L. var. concolor.
" latifolia, L.
" caesia, L.
* " stricta, Ait.
" speciosa, Nutt.
" Virga-aurea, L., var. humilis.
" rigida, L.
" patula, Muhl.
" arguta, Ait., var. juncea.
" " " " scabrella.
" Muhlenbergii, Torr. and Gray.
" altissima, L.
" ulmifolia, Muhl.
" nemoralis, Ait.
* " Canadensis, L.
" " " var. scabra.
" serotina, Ait.
" gigantea, Ait.
" lanceolata, L.
Inula Helenium, L.
Polymnia Canadensis, L.
" " var. discoidea.
Ambrosia artemisiæfolia, L.
Xanthium strumarium, L., var. echinatum.
Xanthium spinosum, L.
Rudbeckia laciniata, L.
" hirta, L.
Helianthus strumosus, L.
" divaricatus, L.
* " divaricatus, L., var. with leaves whorled in threes. Prince's Island.
" decapetalus, L.
Bidens frondosa, L.
" connata, Muhl.
" " var. petiolata.
" cernua, L.
" chrysanthemoides, Mx.
" Beckii, Torr.
* Helenium autumnale, L.
Maruta cotula, DC.
Achillea millefolium, L.
Leucanthemum vulgare, Lam.
Tanacetum vulgare, L.
Artemisia Canadensis, Mx.
Gnaphalium decurrens, Ives. Also at Fullarton.
* Gnaphalium polycephalum, Mx.
" uliginosum, L.
Antennaria margaritacea, R. Brown.
" plantaginifolia, Hook.
Erechthites hieracifolia, Raf.
Senecio vulgaris, L.
* Senecio palustris, Hook. Roadside, Burlington.

COMPOSITÆ—*Continued.*

Cirsium lanceolatum, Scop.
" discolor, Spreng.
" arvense, Scop.
Onopordon Acanthium, L.
Lappa officinalis, Allioni.
* Lampsana communis, L.
Leontodon autumnale, L.
Hieracium Canadensis, Mx.
" scabrum, Mx.
* " venosum, L Ancaster.
" paniculatum, L.
Nabalus albus, Hook.
" " var. serpentarius.
" altissimus, Hook.
* Nabalus Fraseri, DC., var. integrifolius. Prince's Island.
Taraxacum Dens-leonis, Desf.
Lactuca sativa, L. Apparently spontaneous below Mountain View Hotel.
" Canadensis, L.
Mulgedium leucophæum, DC.
Sonchus oleraceus, L
" asper, Vill.
" arvensis, L.

LOBELIACEÆ.

* Lobelia cardinalis, L. Near Waterdown.
" syphilitica, L.
" inflata, L.
" spicata, Lam.

CAMPANULACEÆ.

Campanula rotundifolia, L.
" aparinoides, Pursh.
" Americana, L.
Specularia perfoliata, DC.

ERICACEÆ.

Gaylussacia resinosa, Torr. and Gray.
Vaccinium vacillans, Solander.
* Chiogenes hispidula, Torr. and Gray. Millgrove.
Gaultheria procumbens, L.
* Cassandra calyculata, Don. Millgrove.
Ledum latifolium, Ait. Lake Medad.
Pyrola rotundifolia, L., var. asarifolia.
" " " uliginosa.
" elliptica, Nutt.
" secunda, L.
* Moneses uniflora, L. Lake Medad.
Chimaphila umbellata, Nutt.
* Pterospora Andromedea, Nutt. Wood on Cline's Farm.
Monotropa uniflora, L.

AQUIFOLIACEÆ.

Ilex verticillata, Gray.
Nemopanthes Canadensis, DC. Millgrove Marsh.

PLANTAGINACEÆ.

Plantago major, L.
" Kamtschatica, Cham. Also at Toronto and London.
" lanceolata, L.

PRIMULACEÆ.

Trientalis Americana, Pursh.
Lysimachia thyrsiflora, L.
* " stricta, Ait. East Flamboro'.
" quadrifolia, Ait.
" ciliata, L.
* Anagallis arvensis, L.
Samolus Valerandi, L., var. Americanus, Gray.

LENTIBULACEÆ.

Utricularia vulgaris, L.
" intermedia, Hayne.

OROBANCHACEAE.

Epiphegus Virginiana, Bart.
* Conopholis Americana, Wallroth. Wood behind Cline's Mill.
Aphyllon uniflorum, Torr. and Gray.

SCROPHULARIACEÆ.

Verbascum Thapsus, L.
" Blattaria, L.
Linaria vulgaris, Mill.
Scrophularia nodosa, L.
Chelone glabra, L.
Pentstemon pubescens, Solander.
Mimulus ringens, L.
* Gratiola Virginiana L. Hall's Corners.
Ilysanthes gratioloides, Benth.
Veronica Anagallis, L.
" Americana, Schweinitz.
* " scutellata, L. Millgrove.
" officinalis, L.
" serpyllifolia, L.
" peregrina, L.
" arvensis, L Also at Fullarton.
* " triphyllos.
* Gerardia purpurea, L. Waterdown Creek.
* " tenuifolia, Vahl. Prince's Island.
" flava, L.
Gerardia quercifolia, Pursh.
" pedicularia, L.
Castilleia coccinea, Spreng.
Pedicularis Canadensis, L.
Melampyrum Americanum, Mx.

VERBENACEÆ.

Verbena hastata, L.
" urticifolia, L.
Phryma Leptostachya, L.

LABIATÆ.

Teucrium Canadense, L.
Mentha viridis, L.
" piperita, L.
" Canadensis, L.
Lycopus Virginicus, L.
" Europæus, L. var. sinuatus.
* Pycnanthemum incanum, Mx. Oaklands.
Calamintha Clinopodium, Benth. Red Creek.
Satureia hortensis, L. Burlington Heights.
Hedeoma pulegioides. Pers.
Collinsonia Canadensis, L.
Monarda didyma, L. West of Capt. Nichols's Farm.
" fistulosa, L.
Lophanthus nepetoides, Benth. Waterdown Creek.
Nepeta cataria, L.
Brunella vulgaris, L.
Scutellaria galericulata, L.
" lateriflora, L.
* Marrubium vulgare, L.
Galeopsis tetrahit, L.
Stachys palustris, L., var. aspera.
Leonurus cardiaca, L.
* Lamium amplexicaule, L. Wylde's Grounds.
" album, L.

BORRAGINACEÆ.

Echium vulgare, L.
* Symphytum officinale, L. Cumminsville.
Onosmodium Carolinianum, DC. Burlington Beach.
Lithospermum arvense, L.
* " longiflorum, Spreng. Burlington Heights.
Myosotis palustris, Withering.
" " var. laxa.
Echinospermum Lappula, Lehm.
Cynoglossum officinale, L.
" Morisoni, DC.

HYDROPHYLLACEÆ.

Hydrophyllum Virginicum, L.
" Canadensis, L. Chedoke.
" appendiculatum, Mx. Red Creek.

POLEMONIACEÆ.

Phlox divaricata, L.

CONVOLVULACEÆ.

Convolvulus arvensis, L.
Calystegia sepium, R. Br.
* " sepium, R. Br., var. repens Railway Track, East.
* " spithamœa, Pursh. Dundas.
Cuscuta Gronovii, Willd.

SOLANACEÆ.

Solanum dulcamara, L.
" nigrum, L.
Physalis viscosa, L.
Lycium vulgare, Dunal. Near Van Wagner's Farm. Saltfleet.
Hyoscyamus niger, L.
Datura Stramonium, L.
" tatula, L. Burlington Beach.
Nicotiana rustica, L. West Flamboro and Shore of Bay, near G. W. R. Station.

GENTIANACEÆ.

* Halenia deflexa, Grisebach. Ancaster.
Gentiana crinita, Froel.
* " alba, Muhl. Rare.
" Andrewsii, Griseb. Dundas Marsh.
* " acuta, Mx. [Query].
* Menyanthes trifoliata, L. Lake Medad.

APOCYNACEÆ.

Apocynum androsæmifolium, L.
" cannabinum, L.

ASCLEPIADACEÆ.

Asclepias Cornuti, Decaisne.
" phytolaccoides, Pursh.
" incarnata, L.
" tuberosa, L.

OLEACEÆ.

Fraxinus Americana, L.
" sambucifolia, Lam.

ARISTOLOCHIACEÆ.

Asarum Canadense, L.

PHYTOLACCACEÆ.

Phytolacca decandra, L. Stony Creek. Also at Port Rowan.

CHENOPODIACEÆ.

Chenopodium album, L.
" glaucum, L.
" hybridum, L.
" Botrys, L.
" ambrosioides, L.

CHENOPODIACEÆ—*Continued.*

Blitum capitatum, L.
" Bonus Henricus, Reichenbach.
Atriplex patula, L. var. littoralis.
" " " " hastata.

AMARANTACEÆ.

Amarantus hypochondriacus, L.
" paniculatus, L. Also at Guelph.
" retroflexus, L.
" albus, L.

POLYGONACEÆ.

Polygonum Pennsylvanicum, L.
" incarnatum, Ell.
" Persicaria, L
" Hydropiper, L.
" acre, H. B. K.
" hydropiperoides, Mx.
" amphibium, L., var. aquaticum.
" amphibium, L., var. terrestre.
" Virginianum, L. Red Creek.
" aviculare, L.
" " " var. erectum.
" arifolium, L.
" sagittatum, L.
" Convolvulus, L.
" dumetorum, L.
Fagopyrum esculentum, Moench.
Rumex orbiculatus, Gray.
" verticillatus, L.
" crispus, L.
" obtusifolius, L. East of City.
" acetosella, L.

CERATOPHYLLACEÆ

Ceratophyllum demersum, L.

LAURACEÆ.

Sassafras officinale, Nees.
* Lindera Benzoin, Meisner. The Dell Ancaster.

THYMELEACEÆ.

Dirca palustris, L. Carlisle.

ELÆAGNACEÆ.

Shepherdia Canadensis, Nutt.

SANTALACEÆ.

Comandra umbellata, Nutt.

EUPHORBIACEÆ.

Euphorbia polygonifolia, L.
" maculata, L.
" hypericifolia, L. Waterdown.

EUPHORBIACEÆ—*Continued.*

* Euphorbia platyphylla, L. The beach near Stony Creek.
* " obtusata, Pursh. [Query].
" Helioscopia, L.
" cyparissias, L.
" Peplus, L.
Acalypha Virginica, L.

URTICACEÆ.

Ulmus fulva, Mx.
" Americana, L.
Urtica gracilis, Ait.
Laportea Canadensis, Gaudichaud.
Pilea pumila.
Boehmeria cylindrica, Willd.
Cannabis sativa, L.
Humulus Lupulus, L. Red Creek.

PLATANACEÆ.

Platanus occidentalis, L.

JUGLANDACEÆ.

Juglans cinerea, L.
" nigra, L.
Carya alba, Nutt.
" porcina, Nutt.
" amara, Nutt.

CUPULIFERÆ.

Quercus alba, L.
" macrocarpa, Mx. E. Flamborough and Burlington Beach.
" Prinus, L., var. acuminata, Mx.
" coccinea, Wang., var. tinctoria, Gray.
" rubra, L.
Castanea vesca, L., var. Americana, Mx.
Fagus ferruginea, Ait.
Corylus rostrata, Ait.
Ostrya Virginica, Willd.
Carpinus Americana, Mx.

BETULACEÆ.

Betula lenta, L.
" lutea, Mx.
" papyracea, Ait.
Alnus incana, Willd.

SALICACEÆ.

* Salix tristis, Ait. Rocks near Ancaster.
" humilis, Marshall.
" discolor, Muhl.
" cordata, Muhl., var. myricoides, Gray.
" livida, Wahl., var. occidentalis, Gray.

SALICACEÆ—*Continued.*

Salix lucida, Muhl.
" nigra, Marsh.
" longifolia, Muhl. Burlington Beach.
Populus tremuloides, Mx.
" grandidentata, Mx.
" balsamifera, L.

CONIFERÆ.

Pinus strobus, L.
Abies nigra, Poir. Millgrove.
" alba, Mx. Lake Medad.
" Canadensis, Mx.
" balsamea, Marshall.
Larix Americana, Mx.
Thuja occidentalis, L.
Juniperus Virgiania, L.
" communis, L.
Taxus baccata, L., var. Canadensis, Gray.

ARACEÆ.

Arisæma triphyllum, Torr.
Calla palustris, L.
Symplocarpus fœtidus, Salish.
Acorus Calamus, L.

LEMNACEÆ.

Lemna minor, L.
" polyrrhiza, L.
" trisulca, L.
Wolffia Columbiana, Karsten.
" Brasiliensis, Weddell.

TYPHACEÆ.

Typha latifolia, L.
Sparganium eurycarpum, Engelm.
" simplex, Hudson, var. angustifolium, Gray.

NAIADACEÆ.

Potamogeton natans, L.
" amplifolius, Tuckerm.
" lucens, L., var. minor.
" perfoliatus, L.
" compressus, L.
" pauciflorus, Pursh.
" pectinatus, L.

ALISMACEÆ.

Alisma plantago, L., var. Americanum, Gray.
Sagittaria variabilis, Engelm.

HYDROCHARIDACEÆ.

Anacharis Canadensis, Planchon.
Vallisneria spiralis, L.

ORCHIDACEÆ.

Orchis spectabilis, L.

ORCHIDACEÆ—*Continued.*

* Habenaria tridentata, Lindl. Millgrove.
* " virescens, Spreng. Prince's Island.
* " viridis, R. Br., var. bracteata, Reichenbach. Mountain at head of Queen Street.
* " hyperborea, R. Br. Sulphur Spring.
" Hookeri, Torr.
* " orbiculata, Torr.
* " leucophæa, Gray. Millgrove.
* " psychodes, Gray. Millgrove.
* " fimbriata, R. Br. Land's Farm.
Goodyera pubescens, R. Br.
* Spiranthes cernua, Richardson. The Dell, Ancaster.
* Pogonia ophioglossoides, Nutt. Millgrove.
* Calypso borealis, Salisb. Lake Medad.
* Corallorhiza innata, R. Br. Prince's Island.
" odontorhiza, Nutt.
" multiflora, Nutt.
Cypripedium parviflorum, Salisb.
" pubescens, Willd.
* " spectabile, Swartz. Lake Medad.
* " acaule, Ait. Millgrove.

AMARYLLIDACEÆ.

* Hypoxys erecta, L. Prince's Island.

IRIDACEÆ.

Iris versicolor, L.
Sisyrinchium Bermudiana, L., var. anceps, Gray.

DIORCOREACEÆ.

Dioscorea villosa. L. Near Dundas Marsh.

SMILACEÆ.

Smilax hispida, Muhl.
" herbacea, L.

LILIACEÆ.

Trillium grandiflorum, Salisb.
" erectum, L.
" erectum, L., var. album, Pursh.

LILIACEÆ—*Continued.*

Medeola Virginica, L.
Uvularia grandiflora, Smith.
Prosartes lanuginosa, Don.
Streptopus roseus, Mx.
Clintonia borealis, Raf.
Smilacina racemosa, Desf.
" stellata, Desf.
" trifolia, Desf.
" bifolia, Ker.
Polygonatum biflorum, Ell.
Lilium Philadelphicum, L.
* Lilium Canadense, L. Ancaster.
" superbum, L.
Erythronium Americanum, Smith.
Allium tricoccum, Ait.
Asparagus officinalis, L. Burlington Beach.

JUNCACEÆ.

Luzula pilosa, Willd.
" campestris, DC.
Juncus effusus, L.
" bufonius, L.
" tenuis, Willd.
" Alpinus, Villars, var. insignis, Fries.
" acuminatus, Mx.
" nodosus, L.
" nodosus, L., var. megacephalus, Torr.

PONTEDERIACEÆ.

Pontederia cordata L.
Schollera graminea, Willd.

CYPERACEÆ.

Cyperus diandrus, Torr.
" strigosus, L.
" filiculmis, Vahl.
Eleocharis obtusa, Schultes.
" palustris, R. Br.
" acicularis, R. Br.
* Scirpus pungens, Vahl.
" validus, Vahl.
" fluviatilis, Gray.
" atrovirens, Muhl.
" Eriophorum, Mx., var. cyperinus.
Eriophorum Virginicum, L. Millgrove.
* " polystachyon, L. The Dell, Ancaster.
Carex polytrichoides, Muhl.
" bromoides, Schk.
" teretiuscula, Good.
" vulpinoides, Mx.

CYPERACEÆ—*Continued.*

Carex stipata, Muhl.
" sparganioides, Muhl.
" cephalophora, Muhl.
" rosea, Schk.
" tenella, Schk.
" trisperma, Dew.
" stellulata, L., var. scirpoides.
" scoparia, Schk.
" lagopodioides, Schk.
" cristata, Schw.
" straminea, Schk., var. tenera, Dew.
" stricta, Lam.
" crinita, Lam.
" aurea, Nutt.
" gracillima, Schw.
" platyphylla, Carey.
" digitalis, Willd.
" retrocurva, Dew.
" laxiflora, Lam.
" " " var. blanda.
" " " " plantaginea, Booth.
" " " var. latifolia.
" pedunculata, Muhl.
" Novæ Angliæ, Schw.
" Emmonsii, Dew.
" Pennsylvanica, Lam.
" varia, Muhl.
" scabrata, Schw.
" riparia, Curtis.
" comosa, Booth.
" hystricina, Willd.
" tentaculata, Muhl.
" intumescens, Rudge.
" lupulina, Muhl.
" Schweinitzii, Dew.
" Tuckermani, Boott.
" retrorsa, Schw.

GRAMINEÆ.

Leersia Virginica, Willd.
" oryzoides, Swartz.
Zizania aquatica, L.
Alopecurus aristulatus, Mx.
Phleum pratense, L.
Vilfa aspera, Beauv. Burlington Beach.
Vilfa vaginæflora, Torr.
Sporobolus cryptandrus, Gray.
Agrostis scabra, Willd.
" perennans, Tuckerm.
" vulgaris, With.
" alba, L.
Muhlenbergia Mexicana, Trin.
* " diffusa, Schreber.

GRAMINEÆ—*Continued.*

Muhlenbergia glomerata, Trin.
" silvatica, Torr. & Gray.
Cinna arundinacea, L.
Brachyelytrum aristatum, Beauv.
Calamagrostis Canadensis, Beauv.
" confinis, Nutt.
Oryzopsis asperifolia, Mx.
" melanocarpa, Muhl.
* Eleusine Indica, Gærtn.
Dactylis glomerata, L.
Eatonia Pennsylvanica, Gray.
Glyceria Canadensis, Trin.
* " elongata, Trin. Binbrook.
" nervata, Trin.
" pallida, Trin.
" aquatica, Smith.
" fluitans, R. Br.
Poa annua, L.
" compressa, L.
" caesia, Smith.
" serotina, Ehrhart.
" pratensis, L.
" debilis, Torr.
Eragrostis poæoides, Beauv.
* Festuca tenella, Willd.
" ovina, L.
" elatior, L., var. pratensis, Gray.
" nutans, Willd.
Bromus secalinus, L.
" Kalmii, Gray.
" ciliatus, L.
Phragmites communis, Trin.
Lolium perenne, L.
Triticum repens, L.
" " " var. nemorale.
" caninum, L.
Elymus Virginicus, L.
" Canadensis, L.
" " " var. glaucifolius.
" striatus, Willd.
Gymnostichum Hystrix, Schreber.
Danthonia spicata, Beauv.
Avena striata, Mx. Lake Medad.
* Aira flexuosa, L.
Holcus lanatus, L.
* Anthoxanthum odoratum, L.
Phalaris arundinacea, L.
" canariensis, L.
Panicum glabrum, Gaudin.
" sanguinale, L.
" capillare, L.
" latifolium, L.
" xanthophysum, Gray.
" dichotomum, L.

GRAMINEÆ—*Continued.*

Panicum depauperatum, Muhl.
" Crus-Galli, L.
" " " var. hispidum, Gray.
Setaria glauca, Beauv.
" verticillata, Beauv.
" viridis, Beauv.
" Italica, Kunth.
Cenchrus tribuloides, L. G. W. Ry., about a mile east of Dundas.
Andropogon furcatus, Muhl.
" scoparius, Mx.
Sorghum nutans, Gray.

EQUISETACEÆ.

Equisetum arvense, L.
" pratense, Ehrhart.
" silvaticum, L.
" limosum, L.
* " palustre, L. Oaklands.
" hiemale, L.
" variegatum, Schleicher.
" scirpoides, Mx.

FILICES.

Polypodium vulgare, L.
Adiantum pedatum, L.
Pteris aquilina, L.
Pellæa atropurpurea, Link. Mountain below Chedoke.
Woodwardia Virginica, Smith.
* Asplenium Trichomanes, L. Lake Medad.
" thelypteroides, Mx.
" Filix-fœmina, Bernh.
Camptosorus rhizophyllus, Link.
Phegopteris hexagonoptera, Fée.
* " Dryopteris, Fée. Sulphur Spring.
Aspidium Thelypteris, Swartz.
" Noveboracense, Willd.
* " spinulosum, Swartz, var. dilatatum.
" spinulosum, Swartz, var. Boottii.
" spinulosum, Swartz, var. intermedium.
" spinulosum, Swartz, var. dumentorum. Ravine below Chedoke.
" cristatum, Swartz, var. Clintonianum.
" Goldianum, Hook.
" marginale, Swartz.
" acrostichoides, Swartz.

FILICES—*Continued.*

Cystopteris bulbifera, Bernh.
" fragilis, Bernh.
Struthiopteris Germanica, Willd.
Onoclea sensibilis, L.
Dicksonia punctilobula, Kunze.
Osmunda regalis, L. Millgrove.
" Claytoniana, L.
" cinnamomea, L.

FILICES—*Continued.*

Botrychium Virginicum, Swartz.
" lunarioides, Swartz.

LYCOPODIACEÆ.

Lycopodium clavatum, L.

HYDROPTERIDES.

Azolla Caroliniana, Willd. Dundas Marsh and Burlington Beach.

NOTES.

*Viola striata*, Ait. In Professor Macoun's Catalogue of Canadian Plants, this is stated on the authority of the late Judge Logie to be common near Hamilton. I have never found it, and I am sure that it is not common.

*Lathyrus venosus*, Muhl., occurs at St. Thomas.

*Cichorium Intybus*, L., has naturalized itself at Port Rowan and Toronto.

*Mimulus Jamesii*, Torr., is abundant along the stream flowing into Grenadier Pond near the Humber.

*Phlox subulata*, L. I can confirm, from personal observation, the fact which Mr. Wilkins was, I believe, the first to discover, that this species is indigenous in the County of Norfolk.

*Rumex sanguineus*, L., occurs at London and Barrie.

*Ulmus racemosa*, Thomas, occurs at St. Thomas.

*Juniperus Sabina*, L., *var. procumbens*, Pursh., which I formerly reported as occurring, proves to be J. *Virginiana*, L.

In the discussion which followed, Mr. Geo. E. Shaw, Mr. T. Mackenzie, Mr. Henry Montgomery, Mr. James Bain, jun., and the reader of the paper took part.

Mr. Fred. Phillips read a paper on "The Antiquity of the Negro Race," the object of which was to show that the negro race made its appearance before the white races.

A discussion ensued, in which the President, Mr. John Notman, and Mr. Montgomery took part.

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## TWELFTH ORDINARY MEETING.

The Twelfth Ordinary Meeting of the Session 1883-'84 was held on Saturday, February 2nd, 1884, Dr. Geo. Kennedy, Third Vice-President, in the chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges received since last meeting was read :—

1. The Financial Reform Almanack for 1884 ; presented by the Cobden Club.

2. Museum of Comparative Zoölogy at Harvard College, Vol. XI., Nos. 5, 6, 7.
3. Proceedings of the American Academy of Arts and Sciences, Vol. XI., pp. 45—210.
4. Journal of the Franklin Institute for February, 1884.
5. Science Record, January 15, 1884.
6. Science, for January 25, 1884.
7. Proceedings of the Academy of Natural Sciences of Philadelphia, Part 2, June to October, 1883.
8. Nye Alcyonider Gorgonider, og Pennatulider, tilhorende Norges Fauna; from the Royal Museum of Bergen. (Norwegian Fauna.)

Prof. G. P. Young then read a paper entitled, "The Real Correspondents of Imaginary Points."

After the reading of the paper, remarks were made upon the subject by Prof. Galbraith and Mr. Alfred Baker.

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## THIRTEENTH ORDINARY MEETING.

The Thirteenth Ordinary Meeting of the Session 1883-'84 was held on Saturday, February 9th, 1884, the President in the Chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges received since last meeting was read :—

1. Transactions of the New York Academy of Sciences, Vol. II., Nos. 3 to 8. Contents and Title Page, Vol. I.
2. Annals of the New York Academy of Sciences, Nos. 12 and 13, Vol. II.
3. The Canadian Practitioner, for February, 1884.
4. Science, Vol. III., No. 52, for February, 1884.
5. Mémoires et Compte Rendu des Travaux de la Société des Ingénieurs Civils, November, 1883.
6. Bulletin of the Museum of Comparative Zoology at Harvard College, Vol. XI., No. 8.

It was moved and seconded "That the Council be a Committee, with power to add to their number, to arrange for the reception and entertainment of such members of the British Association as may visit Toronto during the month of September."—*Carried.*

Mr. W. H. VanderSmissen then read a paper by the Rev Prof. Campbell of Montreal, on

## THE KHITAN LANGUAGES; THE AZTEC AND ITS RELATIONS.

My translation of the Hittite Inscriptions found at Hamath and Jerabis, in Syria, is the only one yet published with an explanation of the process by which it was accomplished. The Rev. Dunbar I Heath has sent me copies of his papers in which the Hamath inscriptions are translated as Chaldee orders for musical services, but no process is hinted at by the learned author. In the discussion which followed the reading of one of these papers, a well-known Semitic scholar remarked, "that so long as no principle was laid down and explained as to the system by which the characters had been transliterated, it would be impossible to express an opinion on the value of the proposed reading." Whatever may be the merits of my translation, it does not make default in this respect. The process is simple and evident. The phonetic values of the Aztec hieroglyphic system are transferred to corresponding hieroglyphic characters in the Hittite inscriptions. Common Hittite symbols are the arm, the leg, the shoe, the house, the eagle, the fish. These are also found as Mexican hieroglyphics. There is nothing to tell us what their phonetic values are in Hittite, because hardly any other remains of the Hittite language have survived. But in Aztec we know that these values are the first syllables of the words they represent. Thus an arm being called *neitl*, gives the phonetic value *ne* for the hieroglyphic representing an arm. A leg being called *meztli*, furnishes *me*. A shoe gives *ca* from *cactli*; a house, also, *ca* from *calli*; an eagle, *qua* from *quauhli*; and a fish, *mi* from *michin*. But the question has been raised, "What possible connection can there be between the Hittites or Khita of ancient Syria and the Aztecs of Mexico?" As well might we ask what connection can there be between Indian Brahmins and Englishmen; between European Osmanli and Siberian Yakuts. Geographical separation in such case, is simply the result of a movement that has been going on from early ages. Men are not plants nor mere animals to be restricted to floral and faunal centres. The student of history, who has followed the Hunnic and Mongolian hordes in their devastating course across two continents, will not be surprised to find that well-known Iroquois scholar, the Abbé Cuoq, suggesting the relationship of the Iroquois with the wandering and barbarous Alans and Huns. Still less surprise should be experienced when the more cultured Aztecs of Mexico are connected with an ancient Old World civilization. Aztec history does not begin till the 11th century of our era, and even that of the Toltecs, who preceded the Aztecs, and were of the same or of an allied race, goes no farther back than the 8th. The period of their connection with Old World history as a displaced Asiatic people is thus too early to be accounted for by the invasions of the Mongols, but coincides with the eastern movements of the Khitan, who, after centuries of warfare on the borders of Siberia, disappeared from the historian's view in 1123. It is certainly a coincidence that the Aztecs should claim to be of the noble race of the Citin, and that *citli*, the hare, or, in the plural, *citin*, should be the totem or heraldic device of their nation.

Since I wrote the article on the Khitan Languages, in which I traced the Chinese Khitan backwards to central Siberia about the sources of the Yenisei, where, according to Malte Brun, the Tartars called their mounds Li Katei, or the tombs of the Cathayans, I have received from Mr. Vl. Youferoff, of the Imperial Society of Geography at St. Petersburg, copies of the chief inscriptions from that region. These triumphantly confirmed my supposition that the Katei and the Khita or Hittites were the same people, by presenting characters occupying a somewhat intermediate position in form between the Hittite hieroglyphics and the more cursive script of our Mound Builders. The rude representations of animals and other natural objects accompanying some of the inscriptions are precisely of the type furnished by the Davenport Stone. One inscription, which I deciphered and the translation of which is now before the Imperial Society of Geography, relates the victory of Sekata, a Khitan monarch, the Sheketang of the Chinese hostorians, over two revolted princes or chiefs dwelling at Uta or Utasa in Siberia. As in the case of the Syrian Hittite inscriptions, I have translated the Siberian one by means of the Japanese, using the Basque, the Aztec, and other languages of the Khitan family, for confirmation. Whatever foreign influences may have done to modify the physical features, the character, language, religion, and arts of the Japanese, and, in lesser measure, of the Coreans, there can be no doubt that these are at basis Hittite or Khitan. Already at the commencement of my Hittite studies I had noted the agreement of many characters in the Corean alphabet with those of Hamath and Jerabis on the one hand, and, on the other, with those on our mound tablets. The Rev. John Edwards of Atoka with great kindness procured for me, from a member of the Japanese Imperial Household at Tokio, a work on the ancient writing of the Japanese. One of the forms of writing exhibited in this work and occupying much space is very similar to the Corean, and is undeniably of the same origin. I have not yet had time to investigate the volumes thoroughly, but as they appear to contain samples of ancient alphabets with guesses at their signification rather than complete inscriptions, little progress may be anticipated by means of them. Nevertheless the existence in Japan of a syllabary of so Hittite a type as the Corean in ancient times is confirmatory of the Khitan origin of the Japanese. As for the relations of American civilizations, such as those of the Mexicans, Muyscas, and Peruvians, with that of Japan, I need only refer to the writings of so accurate and judicious an observer as Humboldt.

Returning to the Hittites of Syria, who figure so largely in the victorious annals of the Egyptian Pharaohs and Assyrian kings, and whose empire came to an end towards the close of the 8th century B.C., we find that, although apart from my own conclusions no definite opinion has been reached regarding their language beyond the mere fact that it was Turanian, guesses have been made by scholars whose hypotheses even are worthy of consideration. Professor Sayce believes the Hittite language to have been akin to that furnished by the ancient Vannic inscriptions of Armenia. The Vannic language, according to Lenormant, belongs to the Alarodian family, of which the best known living example is the Georgian of the Caucasus. Now it is the Caucasus that I have made the starting point of Hittite migration, which terminated at Biscay in the west, and in the east, reaching the utmost bounds of Northern Asia, overflowed into America. Not only the Georgians, I unhesitatingly assert, but most of the other Caucasian families, the Circassians, Lesghians, and Mizjeji at least, should be classed as Alarodians, or better still as Khitan. So far I have found no evidence from ancient Caucasian inscriptions, though such I believe have been discovered; but an evidence as conclusive is furnished by the languages of the Caucasian families I have named as compared with those which are presumably of Hittite origin in the Old World and in the New. In the remainder of this paper, I propose chiefly to set forth the relations of the Aztec language, by means of which I transliterated the Hittite inscriptions, with the Caucasian tongues, which of all Khitan forms of speech are in closest geographical propinquity to the ancient habitat of the Hittite nation. Before doing so I may set forth the principal members of the Khitan family at the present day.

## THE KHITAN FAMILY.

### 1. Old World Division.

Basque.
Caucasian = Georgian, Lesghian, Circassian, Mizjeji.
Siberian = Yeniseian, Yukahirian, Koriak, Tchuktchi, Kamtchadale.
Japanese = Japanese, LooChoo, Aino, Corean.

### 2. American Division.

Dacotah.
Huron-Iroquois including Cherokee.
Choctaw-Muskogee including Natchez.
Pawnee including Ricaree and Caddo.
Paduca = Shoshonese, Comanche, Ute, &c.
Yuma = Yuma, Cuchan, Maricopa.
Pueblos = Zuni, Tequa, &c.
Sonora = Opata, Cora, Tarahumara, &c.
Aztec including Niquirian.
Lenca = Guajiquiro, Opatoro, Intibuca.
Chibcha or Muysca.
Peruvian = Quichua, Aymara, Cayubaba, Sapibocono, Atacameno, &c.
Chileno = Araucanian, Patagonian, Fuegian, &c.

The Nahuatl, or language of the Aztecs, as distinguished from other tribes of diverse speech inhabiting Mexico, has long been a subject of no little difficulty to philologists. It is not that its grammatical construction is peculiar, but because its vocabulary exhibits combinations of letters or sounds that have come to be regarded as its almost peculiar property. The most important of these is the sound represented by *tl*, whether it be initial, medial or final. The Aztecs of Nicaragua drop the *tl* altogether or reduce it to *t*; hence some writers have supposed theirs to be the true form of the language, and the literary tongue of Mexico a corruption. Upon this an argument has been founded for the southern origin of the Nahua race. But, as Dr. Buschmann and others have shewn, a mere casual survey of the languages of more northern peoples, the Sonora and Pueblo tribes, and the great Paduca family, reveals the fact that they contain a considerable proportion of Aztec words, and that in them, as in the Nahuatl of Nicaragua, the Aztec *tl* disappears or is converted into *t*, *d*, *k*, *s*, *r* or *l*. Here therefore it is claimed by others is an argument for the northern derivation of the Mexicans.

If we carry forward the work of comparison, having regard to certain laws of phonetic change, we shall find, as I profess to have done, that the vocabulary, and to a large extent the grammar, of the Aztecs are those of all the greater families in point of culture and warlike character of the Northern and Southern Continents. Nor do the Aztec and its related American languages form a family by themselves. They have their counterparts, as I have indicated, in many regions of the Old World. If my classification of these languages be just, there should, among a thousand other subjects of interest, be found some explanation of the great peculiarity of Aztec speech to which I have referred.

The Aztec combination *tl* appears, although to no very great extent, in the Koriak, Tchuktchi, and Kamtchatdale dialects. It has no place in Corean, Japanese, or Aino, and only isolated instances of its use are found in the Yukahirian and Yeniseian languages. Of the four Caucasian tongues which pertain to the Khitan family, two, the Georgian, and Mizjeji, are almost as destitute of such a sound as the Corean and Japanese ; while the Circassian and Lesghian vocabularies, by their frequent employment of *tl*, reproduce in great measure the characteristic feature of the Nahuatl. It is altogether wanting in the Basque, and is a combination foreign to the genius of that language. Yet there is no simpler task in comparative philology than to show the radical unity of the Basque and Lesghian forms of speech. Such a comparison, as well as one of the Lesghian dialects among themselves and with the other Caucasian languages, will enable us to decide whether the *tl* of the Lesghian and Circassian forms part of an original phonetic system, or is an expedient, naturally adopted by speakers whose relaxed vocal organs made some other sound difficult or impossible, to stave off the process of phonetic decay by substituting for such sound the nearest equivalent of which they were capable.

In order first of all to exhibit the common origin of the Basque and the Lesghian, I submit the following comparison of forms, the relations of which are apparent to the most casual observer. The Lesghian vocabulary is that of Klaproth, contained in his Asia Polyglotta; the Basque is derived from the dictionaries of Van Eys and Lecluse. It will be observed that the Lesghian almost invariably differs from the Basque :—

1. In substituting *m* for initial *b*.
2. In dispensing with initial vowels; or, when they cannot be dispensed with, in prefixing to them *b* or *p*, *t* or *d*.
3. In generally rendering the Basque aspirate, together with *ch* and *g*, by the correspondingly harder forms *g*, *k* and *q*.
4. In occasionally adding final *l* or *r*.

(The last named letters *l* and *r* are interchangeable in the Khitan as they are in all other families of speech.)

COMPARISON OF BASQUE AND LESGHIAN.

| Rule 1. | English. | Basque. | Lesghian. |
|---|---|---|---|
| | beard | bizar | mussur, muzul |
| | head | buru | mier, maar |
| | nail | behatz | maats |
| | back | bizkhar | machol, michal |
| | to-morrow | bihar | michar (Georgian) |
| Rule 2, *a*. | skin | achala | quli |
| | hand | ahurra | kuer |
| | river | uharre | chyare, uor |
| | thunder | ehurzuria, curciria | gurgur |
| | hair | ileak | ras |
| | cold | otzo | zoto |
| | no | ez | zu |
| | left hand | ezquerra, ezker | kuzal, kisil |
| | milk | eznea | sink |
| | star | izarra | suri |
| | day | eguna | kini |
| Rule 2, *b*. | deer | oreina | burni |
| | clothes | aldar | paltar |
| | child | aurra | durrha |
| | stone | arri, harri | tsheru, gul |
| Rule 3. | great | handi | kundi |
| | house | eche | akko |
| | hail | harri | goro |
| | smoke | gue | kui |
| | tooth | hortz | kertschi |
| | leaf | orri | kere |
| | finger | erhi | kilish |
| Rule 4. | rain | uria | kural |
| | son | seme | chimir |
| | great | zabala | chvallal |

The following, though generally agreeing, present same exceptions to the above rules.

| English. | Basque. | Lesghian. |
|---|---|---|
| heaven | cern | ser |
| bird | chori | zur |
| red | gori, gorri | hiri |
| blue, green | urdin | crdj'n |
| death | heriotze | haratz |
| old | agure, zar, zahar | herau, etshru |
| throat | cinzur | seker |
| white | churia, zuria | tchalasa |
| wood | zura | zul |
| leg | aztal | uttur |
| tree | zuhatsa | guet, hueta |
| fire | su | zo |
| high | gan | okanne |
| tongue | mia | mas |

A comparison of the Basque with the other Caucasian languages, Georgian, Circassian, and Mizjeji, would display similar relations with some modification of the laws of phonetic change.

If now we ask what the Basque does with the Lesghian *tl*, we shall find that it represents that sound chiefly by the letters *r* and *l*. This equivalency of *tl*, and sometimes of *ntl*, to *r* and *l* also appears in comparing the Lesghian dialects among themselves or with other Caucasian languages.

## COMPARISON OF LESGHIAN FORMS IN *tl* WITH OTHER CAUCASIAN AND BASQUE FORMS.

| English. | Lesghian. | Other Forms. |
|---|---|---|
| hair | tlozi | ras, *Lesghian.* |
| bone | tlusa | rekka " |
| wood | thludi | redu-kazu " |
| tomorrow | shishatla | shile " |
| night | retlo | rable " |
| sheep | betl | bura " |
| maize | zoroto-roodl | tzozal-lora " |
| goat | antle | arle |
| six | antlko | ureekul |
| nail | matl | mare, *Mizjeji* |
| low | tlukur | lochun " |
| eight | bitlno | bar, barl " |
| sun | mitli | malch |
| " | " beri, *Lesghian.* | marra, *Circassian.* |
| flesh | ytl | glli " |
| forehead | tlokva | illech " |
| easy | intlaugu | illesu " |
| " | " | errecha, *Basque.* |
| loins | tlono | errainac " |
| water | htli | ur " |
| butter | yetl | guri " |
| hair | tlozi | ileac " |
| earth | ratl | lurra, laur " |

The following represent the exceptions to the rule both in form and in numerical proportion :—

| English. | Lesghian. | Other Forms. |
|---|---|---|
| yellow | tlela | dula, *Lesghian.* |
| day | tlyal | thyal, tchzal " |
| horn | tlar | adar, *Basque.* |
| knee | tlon | belaun " |

From the preceding examples it appears that the Lesghian sounds represented by *tl, thl, ntl,* are the equivalents of *r* and *l* generally, and sometimes of *d* or *t*. The latter exception probably finds its explanation in Basque, for in the dialects of that language an occasional permutation of *r* and *l* into *t* and *d* takes place. Thus *ideki* to take away, becomes *ireki*, and *iduzki* the sun, becomes *iruzki*, while *elur* snow, sometimes assumes the form *edur*, and *belar* grass, that of *bedar*. The last exception cited, that in which the Lesghian *tlon* is compared with the Basque *belaun*, is really no exception, for *elaun* is the true representation of *tlon*, the initial *b* being prosthetic to the root, as is frequently the case in Basque. Among many examples that might be given, I may simply cite *belar* the ear, as compared with the Mizjeji *lerk*.

Turning now to the Aztec, on the supposition that it is related to the Basque and Caucasian languages, we naturally expect to find on comparison a coincidence of roots and even of words following upon the recognition of *tl* and *ntl* as the equivalents of *r* and *l* in these forms of speech. The fact that the Aztec alphabet is deficient in the letter *r* favours such an expectation. But our comparison must be made with due caution. Any one who has examined a Mexican dictionary, such as that of Molina, must have been struck with the remarkable preponderance of words commencing with the letter *t* over those beginning with any other letter of the alphabet. These words comprise considerably more than one third of the whole lexicon. A certain explanation of this is found in the fact that the two particles *te* and *tla* possess, the former an indefinite personal, and the latter a substantive, signification, and thus enter largely into the structure of compound words. Whatever its grammatical value in Aztec, however, it appears, on comparing the Aztec vocabulary with its related forms of speech, that initial *t* or *te*, which leaving *tl* out of account still occupies one fifth of the lexicon, is frequently prosthetic to the root.

The following are some of the chief laws of phonetic change derived from a comparison of the Aztec and Lesghian languages. These may be found operating to almost as great an extent in the Lesghian dialects among themselves :—

1. The Aztec combinations *tl*, *ntl*, are either rendered in Lesghian by the same sounds, or by *r* or *l*. In some cases in which phonetic decay has set in, the Aztec *tl* is either omitted or represented by a dental. The Lesghian occasionally renders the Aztec *l* and *ll* by *tl*.
2. The interchange of *p* and *m*, which appeared in comparing the Basque and the Lesghian, for the Aztec is deficient in the sound of *b*, characterizes a comparison of the Aztec with the Caucasian languages.
3. A similar interchange of *n* and *l*, or the ordinary equivalents of l, such as marked the Iroquois in comparison with the Basque, occasionally characterizes the relations of the Aztec and Caucasian tongues.
4. The Lesghian, as already indicated, persists in the rejection of initial vowels, and the same is generally true of reduplications and medial aspirates.
5. As in many Aztec words initial *t* forms no part of the root, but is a prosthetic particle, it finds no place in such cases in the corresponding Lesghian term.
6. The Lesghian occasionally strengthens a word by the insertion of medial *r* before a guttural, for which of course there can be no provision in Aztec.

I have not thought it desirable to burden this paper with laws relating to other changes, as the relation of the compared words will be sufficiently apparent ; but, for the purpose of illustration, I have added corresponding terms from other Khitan languages exemplifying the rules set forth.

## COMPARISON OF AZTEC AND LESGHIAN FORMS.

| English. | Aztec. | Phonetic Change. | Lesghian. | Illustrations. |
|---|---|---|---|---|
| water | atl | ar al | htli | ur, *Basque* |
| low | tlatzintli | latzili, latziri | tlukur | liuchtliu, *Koriak* |
| day | tlacatli | lacali, lacari | tlyal, djekul | allochal, teluchtat, *Koriak* |
| knee | tlanquaitl | lancail, lancair | tlon | zangar, *Basque*<br>cconcor, *Quichua* |
| deer | mazatl | mazal, mazar | mitli | mool, *Yuma* |
| earth | tlalli | ralli, larri | ratl | lurra, *Basque* |
| night | tlalli | " " | retlo, rahle | neillhe, *Choctaw* |
| yesterday | yalhua | alhua | hutl | hooriz, *Dacotah* |
| ice | cetl | cel, cer | zer, zar | kori, *Japanese* |
| wind | ehecatl | ehecal, ehecar | churi | gygalkei, *Koriak* |
| sheep | ichcatl | ichcal, ichcar | kir | achuri, *Basque*<br>ccaora, *Aymara* |

| ENGLISH. | ATZEC | PHONETIC CHANGE. | LESGHIAN. | ILLUSTRATIONS. |
|---|---|---|---|---|
| mud | zoquitl | zokil, zokir | zchur | chulu, *Corean* |
| stone | tetl | tel, ter | tsheru | tol " |
| dust | teuhtli | teuhli, teuhri | chur | turo, *Quichua* |
| grass | quilitl | kilil, kirir | cher, gulu | kyrau, *Yeniseian* |
| star | citlalli | cilalli, cirarri | suri | zirari, *Aino* |
| hair | tzontli | tzoli, tzori | tshara | thorok, *Corean* |
| skin | cuatl | cual, cuar | quli | ccara, *Quichua* |
| eye | ixtli | ishli, ishri | chuli | okahra, *Iroquois* |
| wood | quauitl | kauil, kauir | zul | kullu, *Quichna* |
| " | " | kauit | guet, hueta | zuhaitz, *Basque* |
| foot | icxitl | icshil, icshir | kash | ochsita, *Iroquois* |
| year | xiuitl | shiuil, shiuir | thahel | osera, " |
| god | teotl | teol, teor | saal, zalla | chail, koil, *Yukahiri* |
| clothes | tlatqtl | ratkl, latkr | paltar, retelkum | aldarri, aldagarri, *Basque* |
| cold | cecuiztli | cecuizli, cecuizri | chuatzala | hutseelo, xetchur, *Yuma* |
| mountain | tepetl | tepel, teper | dubura | neit-tippel, *Koriak* |
| moon | metztli | metzli, metzri | moots, bars | muarr, *Shoshonese* |
| leg | metztli | " " | maho | ouitsa, *Iroquois* |
| hand | maitl | mail, mair | ku-mur | masseer, *Shoshonese* |
| honey | necutli | neculi, necuri | nutzi, nuzo | miski, *Quichua* |
| | | | | mitzi, *Japanese* |
| bread | tlaxcalli | lashcalli, rashcalli | zulha | lagul, *Yukahiri* |
| | | | | rajali, *Yeniseian* |
| copper | tepuztli | tepuzli, tepuzri | dupsi | tup, thep, *Yeniseian* |
| | | | | tetiopulgun, *Kamtchatdale* |
| mouth | camatl | camal, camar | sumun, moli | simi, *Quichua* |
| | | | | homal-galgen, *Koriak* |
| belly | xillantli | shillal, shillar | siarad | kolid, *Kamtchatdale* |
| feather | yhuitl | ywil, ywir | bel, pala | puru, *Quichua* |
| rain | quiahuitl | kiavil, kiavir | gvaral | kufil-kishen, *Koriak* |
| woman | cihuatl | cival, civar | tshaba | sipi, *Corean* |
| | | | | sungwal, *Shoshonese* |
| bird | to-totl | tol, tor | adjari, zur | tori, *Japanese* |
| name | to-caitl | cail, cair | zyer, zar | chareigtsh, *Kamtchatdale* |
| | | | | teguala, *Sonora* |
| beard | te-nchalli | nchalli, ncharri | muzul, mussur | haunockquell, *Shoshonese* |
| river | at-oyatl | oyal, oyar | uor, chyare | hahuiri, *Aymara* |
| throat | t-uzquitl | uzkil, uzkir | seker | eztarri, *Basque* |
| back | to-puztli | puzli, puzri | machol | bizkhar, " |
| | | | | kaptcher, *Koriak* |
| sun | to-natiuh | natiuh | mitzi | nitchi, *Japanese* |
| | | | | inti, *Quichua* |
| evening | te-otlac | olak, orak | sarrach, *Mizjeji* | sonrek, *Iroquois* |
| snow | cepayauitl | payauil, payauir | marchala | pukoelli, *Yukahiri* |
| | | | | pagolka, *Koriak* |
| man | maceualli | maceualli | murgul | birkhjarjat, *Yeniseian* |
| | | | | mailik, *Pujuni* |
| small | tlocoton, tzocoton | locoton, tzocoton | chitina | cikadang, *Dakotah* |
| | | | | iskitini, *Choctaw* |
| sand | xalli | shalli, sharri | keru | challa, *Aymara* |
| shoulders | acolli | acolli, acorri | hiro | callachi, " |
| son | tepil-tzin | tepil, tepir | timir, chimir | comerse, *Yuma* |
| | | | | tiperic, *Sonora* |
| woman, wife | tenamic | tenamic | ganabi | kanafe, *Corean* |
| fish | michin | michin | migul, besuro | mughat, pughutsi, *Shoshonese* |
| to-day | axcan | ashcan | djekul | hichuru, *Aymara* |
| | | | | tachan, *Mizjeji* |
| give | maca | maca | beckish | eman, emak, *Basque* |
| stone | topecat | topecat | teb | tipi, *Shoshonese* |
| black | caputztic | caputztic | kaba | shupitkat, *Dacotah* |
| hard | tepitztic | tepitztic | debchase | kibichii, *Japanese* |
| old | veue | veue | vochor | vucha, *Araucanian* |
| | | | | apachi, *Aymara* |
| green | quiltic | kiltic | sholdisa | sherecat, *Dacotah* |
| great | yzachi | izachi | zekko | hashka, " |
| " | yzachipul | izachipul | chvallal | zabal, *Basque* |
| dog | chichi | chichi | choi | cocochi, *Sonora* |
| no | amo | amo | anu | ama, *Quichua* |
| I | ne | ne | na | ni, *Basque* |
| | | | | na, *Aymara* |
| than | te | te | duz | zu, *Basque* |
| | | | | ta, *Aymara* |
| he | ye, yehua | he, heua | heich | hau, *Basque* |
| | | | | uea, *Aymara* |

The Georgian does not exhibit the Aztec *tl*, but, as it is regarded by Professor Sayce as the living language most likely to represent the speech of the ancient Hittites, a brief comparison of its forms with those of the Aztec may not be out of place. Like the Lesghian it is impatient of initial vowels, and it generally agrees with that language in the laws of phonetic change, adding, however, this peculiarity, the occasional insertion of *v* before *l*. The *v* seems generally to represent *u*, or some similar vowel sound, and is probably such a corruption of the original as appears in the Samivel of Pickwick compared with the orthodox Samuel.

## COMPARISON OF AZTEC AND GEORGIAN FORMS.

| English. | Aztec. | Phonetic Change. | Georgian. | Illustrations. |
|---|---|---|---|---|
| fowl | tototl | totol, totor | dedali | totolin, *Sonora* |
| red | chichiltic | chichiltic | tziteli | tsatsal, *Kamtchatdale* |
| blood | eztli | ezli, ezri | sischli | odol, *Basque*<br>ehri, *Dacotah* |
| house | calli | calli | sachli | cari, caliki, *Sonora* |
| mountain | quautla | kaula, kaura | gora | kkollo, *Aymara* |
| horn | quaquauitl | kakaul, kakaur | akra | quajra, " |
| sheep | ichcatl | ichcal, ichcar | tschchuri | ccaora, " |
| wind | ehecatl | ehecal, ehecar | kari | helcala, *Sonora* |
| heart | yullotl | yullol, yullor | gulu | gullugu, *Kamtchatdale* |
| girl | ocuel | ocuel´ | okurza, kali | okulosoha, *Choctaw* |
| dog | yzcuintli | izkili, izkiri | dzagli, djogori | schari, *Shoshonese* |
| nose | yacatl | hacal, hacar | zchviri | surra, *Basque*<br>cher, *Pueblos* |
| hair | tzontli | tzoli, tzori | tzvere (beard) | tsheron, *Kamtchatdale* |
| moon | metztli | metzli, metzri | mtvare | muarr, *Shoshonese* |
| silver | teo-quitlatl | kilal, kilar | kvartshili | cilarra, *Basque* |
| shoulder | te-puztli | puzli, puzri | mchari | buhun, *Lesghian* |
| tomorrow | muztli | muzli, muzri | michar | mäyyokal, *Yuma* |
| leg | metztli | metzli, metzri | muchli | ametche, " |
| to kill | miclia | miclia | mokluli | wakerio, enkerio, *Iroquois* |
| mother | nantli | nali, nari | nana | nourha, *Iroquois* |
| snow | cepayauitl | cepayauil, cepayauir | tovli | repaliki, *Sonora* |
| snake | cohuatl | coval, covar | gveli | toeweroe, *Shoshonese* |
| boy | tepil-tzin | tepil . | shvili | tiperic, *Sonora* |
| lightning | tlapetlani | lapelani | elvai | illappa, *Quichua*<br>wilhyap, *Yuma* |
| leaf | iatla-pallo | iala-pallo, iala-parro | pur-zeli | bil-tlel, *Kamtchatdale* |
| small | tzocoton | tzocoton | katon | cikadaug, *Dacotah* |
| man | oquichtli | okichli, okichri | ankodj<br>oiakotsh, *Koriak*<br>guru, *Aino* | oonquich, *Iroquois*<br>aycootch, *Yuma*<br>ccari, *Quichua* |

The Circassian language abounds in labials, and thus finds its best American representatives among the Dacotah dialects. Nevertheless it presents many words which come under the same general laws in relation to the Aztec that have characterized the Lesghian and Georgian.

## COMPARISON OF AZTEC AND CIRCASSIAN FORMS.

| English. | Aztec. | Phonetic Change. | Circassian. | Illustrations. |
|---|---|---|---|---|
| hand | mapipi | mapipi | meppe | nape, *Dacotah*<br>mashpa, *Shoshonese* |
| black | caputztic | caputztic | kvatsha | shupitcat, *Dacotah*<br>yupikha, *Shoshonese* |
| heavy | etic | etic | ondogh | tekay, tekash, *Dacotah* |
| sister | teicu | teicu | tsheeyakh | itaku, itakisa, "<br>tshakyhetch, *Koriak* |
| " | tepi, teciuapo | tepi | tabcha, tsheebk | cuhuba, *Muysca* |
| shoulder | tepuztli | tepuzli | damasha | tapsut, *Aino*<br>gepuca, *Muysca* |
| smoke | poctli | pocli, pocri | bacha | ibusu, *Japanese* |
| lip | tenxi-palli | tenxi-palli | uku-fari | kuchi-biru, *Japanese* |
| meat | nacatl | nacal, nacar | mikel | niku, *Japanese* |
| easy | velchiu-aliztli | velchiu | plese, illesu | raku, "<br>errecha, *Basque*<br>arrangya, *Yukahiri* |
| child | acatl | acal, acar | kaala | jacuel, *Yuma* |
| boy, son | tepil-tzin | tepil | tshvalye, chvalay | akwal-nesuta, *Natchez* |
| man | tlacatl | lacal | tle | kelgola, *Kamchatdale* |
| blood | eztli | ezli, ezri | tleh, kleh | odol, *Basque*<br>huila, *Aymara* |
| dog | chichi | chichi | chhah | kahi, *Corean* |
| no | quixmo | kishmo | ekesima | hetscheu, *Lesghian* |
| summer | xupan | shupan | gapne (spring) | tofah, *Choctaw* |

As things which are equal to the same thing are equal to one another, it follows that, by the application of the same law of phonetic change, the vocabulary of the Aztec must coincide with that of the Basque, in spite of the fact that these two tongues have maintained a separate existence for some 2500 or 3000 years. Nothing can more convincingly prove the indestructibility of human speech, not only in mere thought-forms but in the *ipsissima verba*, than a comparison of the two vocabularies.

## COMPARISON OF AZTEC AND BASQUE FORMS.

| English. | Aztec. | Intermediate Forms. | Basque. |
|---|---|---|---|
| sheep | ichcatl | kir, *Lesghian*; ccaora, *Aymara* | achuri |
| nose | yacatl | zchviri, *Georgian*; cher. sodornah, *Pueblos* | sur, sudur |
| rain | quiavitl | gvaral, *Lesghian*; furi, *Japanese* | euri |
| star | citlalli | zirari, *Aino*; suri, *Lesghian* | izar |
| water | atl | litli, *Lesghian*; ul, ur, *Yeniseian* | ur |
| worm | ocuiloa | kihigir, *Aino*; kuru, *Quichua* | chicharia |
| bad | aquallotica | whalich, *Yuma*; achali, *Koriak* | char, charto |
| mountain | quautla | gora, *Georgian*; kar, *Yeniseian* | zerra |
| stone | tetl | tol, *Corean*; kell, *Yukahiri* | harri |
| ice | cetl | zer, *Lesghian*; chilen, *Mizjeji* | karroin |
| fish | atlan | enuen, *Koriak*; olloga, *Yukahiri* | arrain |
| wood | zalli | zul, *Lesghian*; kullu, *Quichua* | zura |
| bird | tototl | adjari, zur, *Lesghian*; garioha, *Iroquois* | chori |
| dog | yzcuintli | aghwal, schari, *Shoshonese*; tkari, *Mizjeji* | zacur |
| throat | tuzquitl | seker, *Lesghian*; iakwal, *Araucan* | eztar |
| old | veue | vochor " hachooli, *Choctaw* | agure |
| evening | teotlac | sarrach, *Mizjeji*; sonrek, *Iroquois* | arrax, arrats |
| axe | tlateconi | adaganu, *Koriak*; atacarte, *Yuma* | aizkor |
| bread | tlaxcalli | lagul, *Yukahiri*; tikaru, *Shoshonese* | hazkurri |
| bow | tlaoitolli | ratla, *Koriak*; gahlotrahde, *Cherokee* | uztadarra |
| thunder | tlaquaqualaca | yekilkegie, urgirgerkiu, *Koriak* | ehurzuri |
| river | atoyatl | uor, chyare, *Lesghian*; hahuiri, *Aymara* | uharre |
| earth | tlalli | delchel, *Koriak*; ratl, *Lesghian* | lur |
| child | acatl | jacuel, *Yuma*; jali, *Yeniseian* | aur |
| clothes | tlatqtl | retelkum, paltar, *Lesghian* | aldagarri, aldarri |
| knee | tlanquaitl | cconcor, *Quichua*; hizanosara, *Japanese* | zaugar |

| English. | Aztec. | Intermediate Forms. | Basque. |
|---|---|---|---|
| easy | velchiu-aliztli | illesu, *Circas;* arrangya, *Yukahiri* | errecha |
| shoulder | cuitlapantli | telpilgin, tschilpit, *Koriak* | sorbalda |
| silver | teoquitlatl | colaque. *Aymara ;* kvartschili, *Georgian* | cilarra |
| speak | tlatoa | raton, *Iroquois;* arusi, *Aymara* | erran, erraiten |
| " | notza | ni, *Quichua ;* hanasu, *Japanese* | mintza |
| five | macuilli | millgin, *Koriak ;* marqui, *Sonora* | bortz |
| ten | matlactli | mari, *Araucan ;* peeraga, *Dacotah* | amar |
| seven | chicome | shahemo, shacopi, *Dacotah* | zazpi |
| beard | tenchalli | hannockquell, *Shoshonese;* musur, *Lesghian* | bizar |
| to-morrow | muztli | mayyokal, *Yuma ;* michar, *Georgian* | bihar |
| back | topuztli | kaptcher, *Koriak ;* machol, *Lesghian* | bizkhar |
| " | " | hapar, *Yeniseian;* sobira, *Japanese* | guibel |
| walk | malquica | pulanujaha, *Yeniseian ;* puriy, *Quichua* | ibilcea |
| blood | eztli | tleh, kleh, *Circassian ;* huila, *Aymara* | odol |
| breast | telchiquiuh | tar, *Mizjeji ;* teyga, *Yeniseian* | thilia |
| skin | cuatl | tsholoh, *Lesghian ;* tshal, *Yukahiri* | azal, achal |
| nail | yztetl | oocheelah, *Iroquois ;* onzshil, *Yukahiri* | atzazal |
| frog | cueyatl | kayra, *Quichua ;* kayeru, *Japanese* | iguela |
| come | vallauh | ela, *Choctaw ;* or, *Corean.* | el, hel |
| great | yzachipul | oboloo, *Shoshonese;* chvallal, *Lesghian* | zabal |
| tree | quauitl | kotar, " guet, hueta, *Lesghian* | zuhaitz |
| to-day | axcan | wakum, *Araucan ;* tachan, *Mizjeji* | egun |
| cold | yztic | izits, *Shoshonese ;* echta, *Circassian* | ozt |
| " | cecuiztli | hutseelo, xetchur, *Yuma* | otsbero |
| child | tetel-puch | hailpit, *Yuma ;* bikh-jal, *Yeniseian* | mut-il |
| small | tepiton | dahab, tkivisa, *Lesghian* | tipia |
| boy, son | tepil-tzin | tiperic, *Sonora ;* timir, chimir, *Lesghian* | seme |
| lip | tenxipalli | kuchibiru, *Japanese ;* uku-fari, *Circassian* | ez-pana |
| man | oquichtli | chojashin, *Koriak ;* haasing, *Adahi* | gizon |
| mouse | vecacotl | achacollo, achaca, *Aymara ;* dsugoh, *Circass.* | sagu |
| mouth | camatl | simi, *Quichua ;* khaipi, *Atacama* | auba |
| name | tocaitl | zar, *Lesghian ;* chinna, *Iroquois* | izen, icen |
| sister | teciuapo | tsheebk, shupch, *Circass. ;* cuhuba, *Muysca* | aizpa |
| black | yapalli | millh, *Yuma ;* shawagare, *Shoshonese* | beltz |
| wind | ehecatl | acate, *Sonora ;* ahekin, " | aicea |
| all | ixquich | hoahcasse, *Dacotah ;* eezahk, *Circassian* | guci |
| enemy | teyaouh | toka, " taityok, *Corean* | etsaya |
| give | maca | muy-scua, *Muysca ;* beckish, *Lesghian* | eman, emak |
| sick | cocoxqui | ccotas, *Atacama ;* joatsh, *Yukahiri* | gaicho, gaitz |
| I | ne | nah, *Pueblo ;* na, *Aymara ;* na, *Lesghian* | ni |
| thou | te | too, " ta, " de, *Dacotah* | zu |
| he | ye | ihih, " uca, " eeah, " | hau |

Thanks to the survival of Lesghian forms in *tl*, the disguise of the Aztec has been penetrated, and we are thus enabled to assert, first of all, that the apparently widely divergent Peruvian dialects, the Quichua, Aymara, Atacameno, &c., are really its near relations. There is therefore every reason to believe that the Peruvians were the Toltecs, who preceded the Aztecs as rulers of Mexico, and who, under their king, Topiltzin Acxitl, withdrew to the south in 1062, and there founded the kingdom of the Sun. The Peruvian annals place the accession of their first historical monarch, Sinchi Rocca, in the same year. Passing over the intermediate kingdom of Bogota, the home of the Chibchas or Muyscas, which was distinctively Peruvian in character, and another Toltec remnant, the Lencas of Honduras, we come to the north of the Aztec country, where the Sonora, Pueblos, and Paduca tribes dwell, who have already been associated with the Aztecs by several writers. To these I would add the comparatively small but philologically important Yuma and Pujuni families. In all of these tribes we may recognize the barbarous Chichimecs through whom the Aztecs passed on their way to empire. But of the same race are the central stocks, the Dacotah and Pawnee; and to no other belong the eastern families of the Huron-Cherokees, and the Choctaw-Muskogees. The Algonquins of the north, like the Maya-Quichés of Central America, are of a totally distinct branch of the Great Turanian division. The samples of Mound Builder language furnished by the Davenport, the Grave Creek, and the Brush Creek Stones add their evidence to that of the written characters in favour of a connection of the Mound Builders with the Aztecs and related tribes. The Dacotah Mandans, the Choctaws, the Natchez, and the Aztecs, have been severally set forth as the Mound Builders. The true Mound Builders may have been none of these, but a distinct tribe of Allighewi or Alleghenies, for whom we must look elsewhere, still, however, to find them a portion of the same great family. Ancient traces of this tribe appear in the Hittite country of the Nairi in Mesopotamia, where Elisansu was situated; in the Alazonus river of Albania in the Caucasus; in the nation of the Halizoni of Pontus mentioned by Homer; in the Scythic Alazonians of Herodotus; and in Alzania, a mountain region of the Basques. It is not at all improbable that the ancient name survives in those of the Alasar and Allakaweah, sub-tribes of the Dacotahs, but this only tends to prove that a people of the same race as the Dacotahs, and not necessarily the Dacotahs themselves, were the Mound Builders.

There is abundant reason for believing the tradition of most of the American tribes I have mentioned to the effect that their ancestors passed over the sea or great river and traversed a region of intense cold before arriving at their destination in more hospitable climates. Kamtchatka must have been their point of departure from the Old World, whether they reached that point from the Siberian Desert or journeyed thitherward from Corea and Japan by the Kurile Islands. There they set foot on the Aleutian chain which carried them safely over to the coast of Alaska. In Kamtchatdale there are many Aztec traces, and some which exhibit an exaggeration of the peculiarity of Aztec speech with which this paper is mainly occupied. Such is the rendering of the Aztec verb *tlacotla*, to love, by the elongated but distinctly recognizable form *tallochtelasin*. And, with the Kamtchatdale, the Aztec connection, which has been illustrated by comparative vocabularies, embraces all the hitherto unclassified languages of Northern Asia and Europe. The same forms that prevail over a great part of the American continent, somewhat disguised yet easily recognizable, are found in Japan and in Siberia, in the Caucasus and in Biscay.

Some time ago I alluded to a passage in the Paschal Chronicle in which the Dardanians of the Troad are referred to as Hittites, and since then Professor Sayce has seen reason for connecting the whole Trojan family with that ancient and illustrious people. Strabo tells us that at Hamaxitus in the Troad the Teucri, near relations of the Dardani, consecrated a temple to Apollo Smintheus as a memorial of the destruction of their bow-strings and other leathern articles by an army of rats or mice. The same story is told by Herodotus of the Assyrian army, opposed by the Egyptian Sethos, whose name, being the equivalent of Sheth, is truly Hittite. This same story lives in America among the Utes of the Paduca or Shoshonese family, as related by Professor Powell, and among the Muskogees, as told by Dr. Brinton. Hamaxitus, the Trojan town where the legend was localized, was in all probability a transported Hittite Hamath, for in the form Hamaxia it occurs in the peculiarly Hittite country Cilicia, where Cetii dwelt in ancient times, and where Hittite kings held limited sway in the days of Rome's supremacy. The Scythic Hamaxoeci very probably bore no closer relation to the chariot or *Hamaxa* than the Muskogees do to *musk*. These words Hamaxitus, Hamaxia, and Hamaxoeci designated a tribe, sub-tribe or caste, which originally had its chief representatives in the Syrian Hamath. They were scribes, the most likely people to preserve and hand down traditions of the past, the Amoxoaquis of the Mexicans, and the Amautas of the Peruvians. Through them this legend, and many others which recall old world stories, have found a resting-place on the American continent. Many writers on comparative mythology have been led to connect American tribes with Aryans and Semites by failing to recognize what Accadian studies have fully established, that the Turanians were the instructors in mythology and in many other things of these more highly favoured divisions of the human race.

The decipherment of the Hittite and Siberian inscriptions by the Aztec is but the first step in the solution of problems relating to ancient Old World populations, which are supposed either to have been exterminated or to have lost their independent existence. And the superior purity of the Aztec language as preserved by a literary people, spite of its dialectic peculiarities, will enable the philologist to shed light on many points of etymology and construction in the languages of Europe and Asia to which it is related. Take, for instance, the world *totolh-tetl*, an egg. Its meaning is clear, for *totolh* is *tototl* a fowl, and *tetl* denotes a stone. By a simple postposition of the nominative, therefore, the Aztec word for egg means the stone of the bird. In Yukahirian the word used is *nonton-daul*. Now *nonda* means a bird in Yukahirian, a form doubtless of the Lesghian *onotsh*, and the Japanese *ondori*, a fowl; but *daul*, which is just the Aztec *tetl*, does not now designate a stone in that language. The form has undergone change and is now *kell*, but there can be no doubt that *daul* or *tol* was once the Yukahirian name for stone, as it now is the Mizjeji, Corean and Choctaw form. The Basque word, which I have not found any explanation of among the Basque etymologists, is *arrolchia* or *arroltz*. Here the order of the Aztec and the Yukahirian is inverted, for *arri* denotes a stone, and *ollo* or *oilo*, a fowl. The final *chi* or *zi* before the article *a*, is the mark of the genitive which is now *aco* or *eco*. Hence, literally translated, *arrolchia* is "stone fowl of the." The Iroquois has entirely lost the etymology of his word *onhonchia*, in which the Basque *r* and *l* have been replaced by *n*; and the same is the case with the Peruvian, who, by following his usual practice, like the Lesghian, of removing the initial vowel, and simply changing the *l* to *n*, makes the word *runto*. The Circassian *kutarr* is probably of the same composition, for *kut* should represent *kuttey*, fowl, and *arr*, though not now a Circassian word, was so at the time when Circassians and Basques were one people, and derived their respective tribal and local names, Chapsuch and Guipuzcoa, from the Hittite land of Khupuscai. It is interesting to note, as exhibiting the vicissitudes of language, that the Corean, who calls a stone *tol* or *tor*, retains *arr*, the primitive term, to denote an egg, just as the Aztecs frequently employed *tetl* to express the same without any prefix.

There is a Basque word, the derivation of which puzzles the lexicographers, although some have ventured to derive the only Basque term denoting a boy from the Latin. It is *mutil*, or with the article *mutilla*. In Lesghian, *motshi* is a boy, in Japanese, *musuko*, in Sonoro, *te-machi*; but, as a rule, the *m* of these languages is replaced in others of the Khitan family by an ordinary labial. A similar difficulty in Basque attends the connected word *illoba*, which may mean a nephew or niece, or a grandchild. I am disposed to see in these terms the same word as the Aztec *tetelpuch*, which appears to mean "the offspring of somebody," or "of a person," for *tetech*, which in composition becomes *tetel*, denotes personality. The Aztec *puch*, offspring, would thus be the same as the Basque *ba*, and *mut*. That the *mut* of *mutil* corresponds with the *mus* of the Japanese *musuko*, appears from the comparison of another Basque word of similar form, *mutchitu*, mouldy. This answers to the Japanese equivalent *museta*, as *mutil* does to *musuko*. The Aztec word for mouldy is *poxcauhqui*, and, although there can be no connection between mustiness and offspring, answers in form to *puch*, as *mutchitu* to *mutil* and *museta* to *musuko*. The *ba* of *illoba* is but an abbreviated form of *puch*, such as appears in the Aino *po*, the Yeniseian *puwo*, and the Circassian *ippa*. The Basque word for child is *nerabea*, *norhabe*, which connects with *nor*, *norbait*, somebody, just as the LooChoo *worrabi*, also meaning child, shows its relation to *waru*, the Japanese *aru*, likewise denoting "somebody." It appears therefore that "somebody's wean" is a thoroughly Khitan conception. In Georgian, *boshi* which may be taken as the root word, means "child," and in Lesghian *vashsho*. But the Aino *vas-asso* and *bog-otchi* seem to be compound terms, like the Choctaw *poos-koos* and the Dacotah *wah-cheesh* and *bak-katte*. Similar forms are the Iroquois *wocca-nanne*, and the inverted Muyscan *guasgua-fucha*. The abbreviation of *boshi* or *puch* to *ba*, *be* or *bi*, as in the Basque and LooChoo, finds its parallel in the Yeniseian *dul-bo*, a doubly apocopated *tetel-puch*. The Yuma *hail-pit* seems almost to reproduce the Basque form, which inverted would read *il-mut*. One of the Sonora dialects, as we have seen, gives *te-machi* for boy; one of the Iroquois, *ihiha-wog*; the Choctaw, *chop-pootche*; and the Shoshonese, *ah-pats*. In the Old World, the Corean furnishes *tung-poki*; the Kamtchatdale, *kamsanapatch*, a long form as in the Dacotah *menarkbetse*; and the Yeniseian, *pigge-dulb* and *bikh-jal*. But the Yeniseian and Kamtchatdale also designate a son by the simple word for offspring, *bit*, and *petsch* in the respective languages. In the Georgian, Circassian, and Peruvian Aymara, this simple form seems to be reserved for the girls, for daughter in these languages is *bozo*, *pchu*, and *ppucha*. The Aztec prefixes to the word offspring *puch*, one of its terms denoting woman, female, the whole being *teich-puch*. This is the *tshide-petch* of the Kamtchatdale, and, with inversion of parts, the *bai-taga* of the Yukahiri. Other corresponding Khitan forms for girl, daughter, are the Circassian *pus-pa*, the Yeniseian *bikh-jalja*, the Koriak *gna-fiku* and *goe-behkak*, the Kamtchatdale *uchtshi-petch*, the Corean *bao-zie*, and the Japanese *musu-me*; and, in America, the Paduca or Shoshonese *wya-pichi*, the Dacotah *weet-achnong*, and the Iroquois *kaunuh-wukh* and *echrojeha-wak*. The Basque word for girl, *ala-ba*, *ala-bichi*, is in harmony with *illoba*, *nerabea*, and the inverted *mut-illa*, and corresponds with the Yeniseian *bikh-jalja*. Besides these more conspicuous forms there are many others which exhibit a common formation. Among the Yuma words denoting boy, and the equivalents of *hail-pit* in other dialects, occur *her-mai* and *yle-moi*, in which the Basque *mut* and Japanese *musu* are abbreviated into *mai* and *moi*. Of the same structure are the Peruvian Quichua *huar-ma* and the Circassian *ar-ps*. Two other words for boy, the Japanese *bo-san*, and the Araucanian *bo-tum*, belong to the same category; and there are many other forms, such as the Adahi *talla-hache*, in which the labial of *boshi* or *puch* has been converted into an aspirate, to which I need refer no farther. The Aztec *tetel-puch* and *teich-puch* are the types of the many terms mentioned, which exhibit the singular agreement, with phonetic variations, of the Khitan languages in the formation of these compounds.

A very common element in compound Aztec words is *palli*, which, besides denoting colour as in *ya-palli*, black, and *quil-palli*, green, appears to have the meaning of "contents, belonging to," just as the Japanese *iro* means colour, and *iru*, to hold or contain. So in Basque, *bal* is a root denoting colour in the abstract, and *bar*, a corresponding root signifying contents. In Aztec *tenxi-palli* means lip, but its derivation is only apparent in Japanese, in which language the word for lip is *kuchi-biru*. Now *kuchi* is the mouth, and *biru* is the original of *iru*, to hold, contain or enter. The Aztec *tenxi* does not appear in the dictionaries as a word for mouth, *camatl* being the term employed; but the related Shoshonese family furnishes *atongin*, *tungin*, and the Adahi, *tenanat*. The Circassian lip is *uku-fari*, plainly the same word as the Japanese and Aztec, although *uku* is not the present Circassian term for mouth. The Corean form is *ipsi-oor*, in which *ipsi* represents the Corean *ipkoo*, the mouth, and *oor*, the Japanese *iru* or *biru*. So also the Natchez adds *er* to *heche* the mouth, and calls the lip *ehec-er*. The Araucanian, from a primitive word *ia*, like the Dacotah *ea*, the Yuma *yu*, the Circassian *je*, *ja*, the Corean *ii* and the Basque *aho*, all meaning mouth, forms, with the equivalent of *palli*, *biru* and *fari*, *ia-pelk*, lip. The Circassian alone retains the sound of *itsha*, *utsha* for mouth, which appears in the inverted Lesghian *mur-tschi*, and Mizjeji *bar-dash*, their equivalenti for *uku-fari*. In Iroquois the lip is *osk-wenta*. By the conversion of *r* and *l* into *n*, which characterizes the Iroquois in comparison with most of the other Khitan languages, *wenta* represents an original *bar*, *pel*, *berta* or *palta*. The double meaning of this root which has appeared in the Aztec *palli*, the Japanese *iro* and *iru*, and the Basque *bel* and *bar*, holds good in the case of the Iroquois, for colour is *wensera*, in which *wen* is the radical, and *iowente* means "accompanying or belonging to." The form *wen* is by no means so common in Iroquois as to make this a chance coincidence. The first part of the word *osk-wenta* is an abbrevation of a common form denoting the mouth. In the Basque we are warranted in rejecting Van Eys's derivation of *ezpana*, the lip, from the root *es*, to shut, inasmuch as the same root in *eztarri*, the throat, would be manifestly out of place. In *ez* therefore we detect the ancient form for mouth which the Circassian gives as *itsha*, and the Natchez as *heche*. And in *pana*, when it is remembered that the change of *l* to *n* is not uncommon in the Basque dialects, there is no difficulty in seeing an archaic *pala*, even if the Iroquois *wen* did not justify the connection. The Aztec *tenxipalli* has derived its *enxi*, for the *t* is prosthetic, from such a strengthened form of the *ez*, *eche*, mouth, as is found in the Yukahiri *anga*, *angya*, and in the Lenca *ingh*. The following table will set more clearly before the eye these relations of the Khitan languages in the Old World and in the New :—

FORMS OF THE AZTEC *palli*.

| | Colour. | Contents, pertaining to | Lip. |
|---|---|---|---|
| Aztec | *palli* | *palli* | *tenxi-palli* |
| Japanese | *iro biro* | *iru, biru* | *kuchi-biru* |
| Iroquois | *wensera*, | *iowente* | *osk-wenta* |
| Basque | *bel* | *bar* | *ez-pana* |

A somewhat similar instance is afforded in the Aztec word for leaf, *iatla-pallo* or *quauhatla-palli*, of which the first part is the word denoting a tree. The same is the case with *eatcha* in the corresponding Yuma term *eatcha-berbetsen*. But the *tlel* of the inverted Kamtchatdale *bil-tlel*, the *djitsha* of the Yukahiri *pal-djitsha*, and the *zeli* of the Georgian *pur-zeli*, no longer mean tree in these tongues. The Kamtchatdale now uses *utha* and *uuda*, diminished forms of the

Lesghian *hueta* and the Basque *zuaitz.* The Yukahiri has conformed to the Lesghian *dzul* in *tshal;* and the Georgian, with its *che*, *tka*, and *tcheka*, more nearly approaches the Yuma and other American forms. Still *tlel*, *djitsha* and *zeli* are thoroughly Khitan in character, answering to the Circassian *zla*, the Basque *zuhatsa*, and the Lesghian *dzul* and Yukahiri *tshal.* Such examples suffice to show how difficult it must be to gain a thorough acquaintance with the structure of our American languages, without having reference to the stock from which they are derived, as well as the paramount value of these languages in all matters affecting the construction of the Basque and Caucasian, the Siberian and Japanese tongues.

Whether the Aztec *tl* was an original element in Hittite speech, or a corruption arising after the dispersion in 717 B.C., we shall not know definitely until the inscriptions of Syria and Asia Minor, of India, Siberia, and Japan, yield a vocabulary of sufficient extent to enable us to judge. It is very probable that it existed as a substitute for *r* in certain Khitan tribes from a very early period, since, in the land of the Nairi, the Assyrian inscriptions mention a town Citlalli, in which we recognize the Aztec word for star, the equivalents for which in Araucanian, Atacameno, Shoshonese, Aino, Lesghian and Basque are *schalela*, *halar*, *shul*, *zirari*, *suri*, and *izarra.* The land of the *Nairi* or *Nahri*, the *Naharina* of the Egyptian records, has been generally regarded as a form of the Semitic *Naharaim*, the rivers, whence the designation Mesopotamia. But the word is purely Turanian, and designates primarily a people, not a country. The Egyytian form is the most perfect, as it preserves the medial aspirate and retains the Hittite plural in *n.* It is just the Aztec national designation *Nahuatl*, *Nauatl*, or *Navatl*, which, by the application of the law of phonetic change, becomes *Nahuar*, *Nauar* or *Navar.* The Aztec word means "that which is well-sounding, or a fluent speaker," but most of the words derived from the same root have either the meaning of *law* or *measure* or of *interpretation.* The fluent speaker probably was looked upon as one who spoke with regard to the laws of language and in measured tones, and the interpreter as one who converted the idiom of barbarians into the well-regulated language of the Aztecs. The Japanese preserve the word in two forms, *nori*, meaning law or measure, and *naori*, translation. In Basque it is represented by *neurri*, measure, and this in all probability is the same word as Navarre, a Basque province. As Khupuscai and the land of the Nahri are united in the Assyrian inscriptions, so, in Basque geography, are Guipuzcoa and Navarre. The Scythic Neuri of Herodotus were probably members of the same family. The Niquirans, who are Aztecs, settled in Nicaragua, preserve the ancient name but have hardened the aspirate into a guttural.

More than thirty years ago that veteran ethnologist, Dr. Latham, wrote the following: "The Kamskadale, the Koriak, the Aino-Japanese, and the Korean, are the Asiatic languages most like those of America. (Afterwards he includes the Yukahiri and elsewhere connects that language with the Yeniseian.) Unhesitatingly as I make this assertion - an assertion for which I have numerous tabulated vocabularies as proof—I am by no means prepared to say that one-tenth part of the necessary work has been done for the parts in question; indeed it is my impression that it is easier to connect America with the Kurile Islands and Japan, &c., than it is to make Japan and the Kurile Islands, &c., Asiatic." Nothing can be truer than the above statement made by one whose name should carry the greatest weight with all his scientific utterances to the minds of scholars. It is therefore simply incomprehensible how a writer on philological subjects of such high standing as Mr. Horatio Hale could be led to say, "Philologists are well aware that there is nothing in the languages of the American Indians to favour the conjecture (for it is nothing else) which derives the race from Eastern Asia." I venture on the contrary to assert that there is no philologist worthy of the name who, having carefully studied the languages of the New World and the Old with which this paper deals, has come to any other conclusion than that reached by Dr. Latham and myself. And if Mr. Hale will simply follow up the relations of the Basque, which he wisely connects with our American aboriginal languages, he will soon find himself among those very peoples of Eastern Asia whom he so summarily dismisses. Dr. Latham's Peninsular Mongolidae, including the Yeniseians, and the Americans, are neither Mongolic, Tungusic, (with the exception of the Tinneh , Finno-Samoyedic, Dravidian, or Monosyllabic. They have relations in India among the aboriginal northern peoples, and the Kadun or red Kariens of Birmah belong to the same race. But, with these exceptions, the Khitan do not connect with the Asiatic populations. Not till we reach the confines of Europe and Asia in the Caucasus, where another unclassified group of languages makes its appearance, do we find the relatives of the colonizers of America, and through them effect, what Mr. Hale would do *per saltum* across the Atlantic, a union with the Basques.

From these general considerations I turn to the special work set forth in this paper, that namely which exhibits the relation of the Aztecs to the Khitan family in general, and in particular with those branches of it which are found in the neighborhood of the ancient Hittite civilization. The meagreness of my vocabularies of the Caucasian languages compelled me to illustrate their connection by the closely related Basque in the case of the Hittite inscriptions which I recently translated. Some examples of the relation of the Hittite language spoken in Syria and Mesopotamia in the 8th and preceding centuries B.C., may fitly close the argument in favour of the Hittite or Khitan origin of these and their related languages.

COMPARISON OF HITTITE FORMS EROM THE MONUMENTS.

| English. | Hittite. | Basque. | Japanese. | Aztec. |
|---|---|---|---|---|
| dependence | kakala | katalo | kakari | cacalic, cetilia |
| incite | kasakaka | kitzikatu, kilikatu | keshikake | cocolquitia |
| oppose | kakeka | jauki | giyaku | ixquaqua |
| desirous | manene | min | mune | mayanani |
| beseech | neka | nastu | negau | notza |
| modest | simaka | zimiko | tsume | temociui |
| country | kane | gune | kuni | cana |
| cut | kara | zilhetze | kiru | xeloa |
| he | ra | hura, hau | are | ye |
| small | sasa | chiki | sasai | xocoa |
| put | tara | ezarri | ateru | tlalia |
| fight | tiketi | zehatu, etsaigo | tekitai | teyaotia |
| between | neke | nas, nahas | naka | netech |
| hastily | sakasakasa | takataka | sekaseka | iciuhcayotica |
| destroy | kasa | chikitu | kachi | cacayaca |
| lay waste | susane | zuzi | susami | xixinia |
| accord | kane | on-gune | kanai | cen |
| come | al | el, hel | iru, kuru | vallauh |
| house | taku | tegi | taku | techan |
| I | ne | ni | mi | ne |
| within | tata | ta, hetan | tate | titech |
| at | ka | gau | oku | co |
| in | ne | an, n | ni | |
| vex | nebala | ———— | naburi | navallachia |
| hear | kika | ———— | kiki | caqui |
| ruler | basa | ———— | bushi | pachoa |
| friend | tineba | ———— | tomobito | tenamic |

From these examples it appears that the best living representative of ancient Hittite speech is the Japanese, which, with the Aztec down to the time of Spanish conquest, has never ceased to be a literary language. Standing midway between the long-forgotten Hittite civilization of Syria and the now extinct native civilization of Mexico, Japan affords the most satisfactory starting point for the investigation of problems of world-wide interest that find their centre in the Khitan name. In its name Yamato it shows a closer connection with Hamath than with the land of the Nahri in Mesopotamia. As the home, therefore, of the scribes, whom the Peruvians called Amautas and the Aztecs Amoxoaquis, literature naturally flourished in its islands; and the believer in Holy Writ will see in Japanese culture and prosperity the result of the blessing of Him who is governor among the nations upon the Kenite "scribes that came of Hamath, the father of Beth-Rehob," Hittites indeed, but nobler than their fellows.*

Mr. Buchan was of opinion that it was impossible to pronounce an opinion upon the paper without examining the lists of words carefully, but the conclusion that the American Indians reached this continent from north-eastern Asia seemed exceedingly reasonable. He must, however, differ from Prof. Campbell in regard to the relationship of the Hinos and Japanese. Recent accounts had confirmed him in the view that they were radically different in language as well as in physique. He might mention that it had been clearly established that the Hinos were, as according to a pet theory ot his they ought to be, a white race, seeing that they inhabited a moist and cloudy region. The contradicting accounts of previous travellers as to their colour were due to the Hino abhorrence of water, at least when applied externally.

Mr. Notman, Mr. Shaw, Mr. Dunlop and Mr. Murray also took part in the discussion.

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* Mr. VanderSmissen has kindly called my attention to the fact that Professor Schleicher, whom in my former paper on the Khitan Languages I inadvertently represented as constituting grammatical construction the soul of language, really gives great prominence to the phonetic element, especially to that portion of it which expresses relation. I am glad to acknowledge this correction of an extreme statement by so competent a disciple of the great German philologist.

Mr. VanderSmissen also read a paper by the Rev. Dr. MacNish, of Cornwall, entitled :—

## THE GAELIC TOPOGRAPHY OF WALES AND THE ISLE OF MAN.

In a paper which I had the pleasure of sending to the Canadian Institute during last year, I endeavoured to prove, by the examination of topographical names in England and Scotland and Ireland, that Celts who spoke Gaelic must have preceded the Cymry in the occupation of the British Isles. On the strength of evidence which appeared to me satisfactory, I came to the conclusion that "the first powerful stream of immigration into Great Britain and Ireland was Gaelic; that the Scottish Gaels are the representatives of those Celts who were the first to enter Britain and to travel northwards from the South of England to Scotland; and that the remote ancestors of the Scottish Gaels and the Celts who were the first to people Ireland, were one and the same people and spoke the same language."

I propose in this paper to examine the Topography of the Isle of Man and of Wales, in the hope that corroborative evidence can thus be obtained in favour of the theory, that Celts who spoke Gaelic preceded the Cymry in the occupation of Great Britain; and that the arrival of the Cymry must have been much later than that of the Gaels whose language is still discernible, after the glide of many centuries, in the names of headlands and mountains, and lochs, and bays, and rivers. It is reasonable to conjecture that the earliest occupants of Britain wended their way westward, and that a Celtic population settled in the Isle of Man long before the Romans invaded Britain; and that from Man many Celts must have passed into Ireland and at different times into Scotland. The Topography of the Isle of Man; the names which still survive and which a succession of foreign masters was powerless to obliterate; the language which the Manksmen speak down to our own day; and the literature which they have, though it is not very extensive,—combine to prove that the Isle of Man and its inhabitants are normally Gaelic, and that Manx is closely allied to Irish and especially to Scottish Gaelic. Dr. Joyce in his interesting work, *Irish Names of Places*, (Vol. I, p. 163), has this reference to Manannan Beg Mac y Leirr, who, the Manksmen aver, was the founder, father and legislator of their country. "One of the most celebrated characters among the people, *i.e.*, the Tuath de Danaan, was Manannan Mac Leir, of whom we are told in Cormac's Glossary and other ancient authorities, that he was a famous merchant who resided in and gave name to Inis Manann, or the Isle of Man . . ." The conjecture has been advanced, that the term Mannin is compounded of *meadhon*, middle, and *in*, an island; and that accordingly, it is a purely Gaelic word, signifying "*the middle island*." A glance at the map will show, that the Isle of Man is situated in a very convenient position so far as England, Ireland and Scotland are concerned; and that in the days of irregular and unprincipled warfare, it could not fail to be involved in the continual struggles that were going on in those kingdoms. Three armed legs form the present armorial bearing of the Isle of Man. The motto, *Quocunque jeceris stabit*, inasmuch as no transposition of the words can alter the true meaning, may be regarded as an ingenious allusion to the three alternatives which Man in the days of its independence possessed, of leaning for support on one or more of its more powerful neighbours. That the Manksmen could and can speak their own Gaelic after being subject to their Welsh neighbours for 400 years, and to the Danes for 153 years, and to the Norwegians for 200 years, and after owning the sway of England and Scotland for 139 years before the Isle of Man became the property of the Stanleys with whom it remained for 330 years, when it passed into the possession of the Lords and Dukes of Atholl, who surrendered every claim to it in 1829,—goes very far to show how strong the life of a language can be, and how its vitality can continue and be vigorous even when unfriendly forces of a powerful kind are, it may be, intent on destroying it.

Taylor in his *Words and Places*, (pp. 260, 261), maintains that *Man* signifies a district. He goes on to state that "the map of the Isle of Man contains about four hundred names, of which about 20 per cent. are English, 21 per cent. Norwegian, and 59 per cent. Celtic. These Celtic names are all of the most characteristic Erse type. It would appear that not a single colonist from Wales ever reached the island, which, from the mountains of Carnarvon, is seen like a faint blue cloud upon the water. There are 96 names beginning with *Balla*, and the names of more than a dozen of the highest mountains have the prefix *slieu*, answering to the Irish *sliebh* or *sliabh*. The Isle of Man has the Curraghs, the Loughs, and the Allens of Ireland faithfully reproduced." Taylor was doubtless at pains to make an accurate examination of the topographical names of Man. It is in the highest degree surprising that, after all the changes which passed over the Isle of Man, and in spite of the numerous languages which were spoken by those who successively exercised authority over its inhabitants, 59 per cent. of the topographical names should still be Gaelic, commemorating thus the early and powerful presence of the Gaels in the Island long before, it may be, Cæsar invaded Britain, or the Cymry forced their way as later Celts into the Albion of Aristotle. In his introduction to his Irish Grammar, Dr. O'Donovan thus writes: "The Manx is much further removed from the Irish than the Gaelic of Scotland. Its words are principally obscured by being written as they are pronounced without preserving the radical letters as in Irish." The translation of the Holy Scriptures into Manx forms the most important part of Manx Literature. The translators went avowedly on the principle of spelling words phonetically, of disregarding etymological considerations, and of making as near an approximation as might be possible to the manner in which the language was spoken, in order that every Manksman could easily read and understand the Scriptures in his native tongue. It naturally happens that no small ingenuity is at times necessary to discover the exact value of certain sounds and words in the Manx language as it is written. The judicious remarks of Dr. Joyce, (Vol. I, pp. 1, 2, 3,) apply with peculiar strikingness to the topographical names of Man: "The interpretation of a name involves two processes, the discovery of the ancient orthography, and the determination of the meaning of this original form. . . . A vast number of our local names are perfectly intelligible as they stand in their present Anglicized orthography, to any person who has studied the phonetic laws by which they have been reduced from ancient to modern forms . . . In numerous other cases, where the original forms are so far disguised by their English dress as to be in any degree doubtful, they may be discovered by causing the names to be pronounced in Irish by the natives of the respective localities. When pronounced in this manner they become in general perfectly intelligible to an Irish scholar . . . The meaning of a name otherwise doubtful will often be explained by a knowledge of the locality."

Words beginning with *Baile* are very common in Scotland, and especially in Ireland. *Baile* signifies a farm, a village, or town. Indeed, a casual comparison of the names in Man, and Scotland, and

Ireland, that begin with *Baile*, will show that there is a great similarity if not an identity between them. It will be sufficient to adduce a few examples of the presence of *Baile* in the Topography of Man :—

Bailegawne, *baile'ghobhainn :* the smith's town.
Bailenahown, *baile na h-aimhne :* the town of the river.
Balladoole, *baile 'n tulaich :* the town of the knoll.
Ballaquane, *baile'chuain :* the town of the ocean.
Ballaquinney, *baile'chuinne :* the town of the corner.
Balnabarna, *baile* and *bearna*, a gap or fissure.
Ballamahow, *baile* and *magh*, *a field ;* Irish, *Mayo.*
Baldwin, *baile* and *aoduinn*, a brow or face.
Ballamona, *baile* and *monadh*, *a moor.*
Ballawhane, *baile* and *uaine*, green.
Ballaharry, *Ballagharaidh*, *baile* and *garadh*, a den.
Balloun, *baile* and *amhainn*, a river.
Ballaglass, *baile* and *glas*, grey.
Balla Kilmorrey, *baile*, *cill*, a church or graveyard, and *Muire*, Mary.
Ballysallach, *baile* and *salach*, filthy.
Ballaugh, *bealach*, *Balloch :* an opening or defile.
Ballamonamoar, *baile* and *monadh mor*, the large moor.
Ballure, *baile* and *ur*, new.
Ballacowle, *baile* and *cuil*, a corner.
Ballacooley, *baile* and *coille*, a wood.
Ballaliece, *baile* and *leac*, a flat stone.
Ballacreggan, *baile* and *creag*, a rock.
Ballamagher, *baile* and *machair*, a field.
Ballnakilley, *baile* and *cill*, a church-yard.
Ballaskyr, *baile* and *sgeir*, a rock.
Ballabooie, *baile* and *buidhe*, yellow.

Words identical with those which have now been cited, are of frequent occurrence in the Topography of Scotland and Ireland. I have given the Gaelic derivation or equivalent of the names which have been taken from the Topography of the Isle of Man. Their Gaelic origin is unmistakable ; and hence the inference may be reasonably drawn, that the same people gave names in the Isle of Man, in Scotland, and in Ireland, to the places in which *Baile* is found as one of the constituent elements, and that the language which was then spoken in Man and Scotland and Ireland was one and the same.

The names of hills and glens in the Isle of Man are likewise Gaelic, *e.g.* :—

Slieu mayll, *sliabh*, hill : and *maol*, bare.
Cronk na h--eiric, *cnoc*, hill : *eirig*, a ransom.
Cronk na Kielan, *cnoc*, *hill :* and *ceolan*, faint music.
Slieuwhallin, *sliabh* and *aluinn*, lovely.
Cronk Keeillowan, *cnoc*, *cill*, and *Eoghann Hugh :* Ewan.
Knockaloe, *cnoc* and *loch*, a lake.
Cronk ny marroo, *cnoc na marbh*, dead.
Slieudhoo, *sliabh* and *dubh*, black.
Cronkbourne, *cnoc* and *burn*, water.
Cronkurleigh, *cnoc* and *iolaire*, an eagle.
Glentrammon, *gleann*, Manx *glione*, a valley, and *druman*, a ridge or boortree.
Glen Darragh, *gleann* and *darach*, oak.
Glen Moy, *gleann* and *magh*, a plain.
Glion Mooar, *gleann* and *mor*, large.
Gliongawne, *gleann* and *gobhainn*.
Glenfaba, *gleann*, *faigh*, pasture, and *ba*, cattle.
Glencutchery, *gleann* and *cruitearach*, the occupation of a harper.
Glendoo, *glenn* and *dubh*, black.

So apparent is the Gaelic origin of the names of hills and valleys in Man, that any one who has a knowledge of Gaelic can with great facility determine the meaning of the names in question.

Poolvash is compounded of poll, a pond or pool ; and *bas*, death, the pool of death.
Port ny-Hinshey, *port*, a harbour ; and *innis*, an island ; *port na h-innse*, the harbour of the island. Such was the original name of the harbour of Peel.
Maugherakew, *machair*, a plain ; and *ceo*, mist.
Bowmaken, *bogha*, a bow ; and *ceann*, head.
Rushen, *rudha*, a promontory ; and *sean*, old.
Rue, *rudha :* a point.
Rievalle, *righ*, a king, and *baile*.
Ayre, *airidh :* a shealing.
Shellach point, *seileach*, willow.

There are many words beginning with *ceann*, a head, whose Gaelic origin is quite evident, *e.g.* :—

Kentraugh, *ceann*, a head ; and *traighe*, shore.

Kiondroghad, *ceann* and *drochai l*, bridge.

Kenmoy, *ceann* and *magh*, a plain.

Kinskae, *ceann* and *sgiath*, a wing.

Kionsleau, *ceann* and *sliabh*.

Kenna, *ceann* and *ath*, a ford.

Such words as these indicate at once that they are of Gaelic origin, and that the Celts who imposed such names on the prominent physical features of the Isle of Man spoke the language which has been perpetuated over many centuries in the Highlands of Scotland.

Lhergydoo, *learg*, a slope, and *dubh*, black.

Slegaby, *slige*, a shell ; and *buidhe*, yellow.

Keillvael, *cill* and *maol*, bare.

Douglas, *dubh* and *glas*, grey.

Sulby, *suil*, an eye ; and *buidhe*, yellow.

Lazayre, *lios*, a fort ; and *airidh*, a shealing.

Lhen moar, *lean*, a plain ; and *mor*, large.

Garff, *garbh* : rough.

*Braddan* : a salmon.

*Cas na h-owne* : the foot of the water.

Strathallan, *srath*, a valley ; and *aluinn*, splendid.

Cloughbane, *clach*, a stone ; and *ban*, white.

Loughan a yeeah, *lochan* a little lake ; and *geadh*, a goose.

Cregnesh, *creag*, a rock ; and *innis*, an island.

Caoilban, *caol*, narrow ; and *ban*, white.

It would be very easy to adduce examples in abundance from the Topography of Scotland and Ireland in which such roots are present, as *baile, amhuinn, monadh, cill, magh, maol, creag, sgeir, cnoc, loch, gleann, port, innis, learg, ceann, rudha, clach* ; roots which are of constant occurrence in the Topography of the Isle of Man. It is reasonable to conclude, that the power of the Gaels in the Isle of Man was paramount at some time in the far-off past, seeing that the successive waves of conquest which passed over the Island have failed to obliterate the traces of the Gael, and to destroy the proofs that names of rivers and hills and valleys furnish, regarding the people whose time of predominant occupation was so long as to enable them to leave indelible footprints of themselves and of their language in the names which the Topography perpetuates for the information of posterity.

Thomas Stephens, the well-known author of the Literature of the Kymry, avers, "that the Welsh or Kymry are the last remnant of the Kimmerioi of Homer and of the Kymry, the Cimbri of Germany." It is possible to cite the authority of two learned Welshmen in favour of the theory that the Gaels preceded the Kymry in the occupation of Britain. Edward Llwyd, the famous author of the *Archæologica Britannica*, who expended five years in travelling among the portions of Great Britain and Ireland where the Celtic languages were spoken, and who is justly regarded as the Father of Welsh Philology, thus writes in his Welsh preface to his book: "Nor was it only North Britain that these Gwydhelians (Gaels) inhabited in the most ancient times, but also England and Wales . . . Our ancestors did from time to time drive them northward . . . From Kintyre, in Scotland, where there are but four leagues of sea, and from the County of Galloway and the Isle of Man, they passed over into Ireland, as they have returned backwards and forwards ever since . . . There are none of the Irish themselves, so far as I know, . . . who maintain that they had possession of England and Wales. And yet, whoever takes notice of a great many of the names of the rivers and mountains throughout the kingdom, will find no reason to doubt that the Irish must have been the inhabitants when those names were impressed upon them, *i.e.*, upon the rivers and mountains." In his *Celtic Britain*, (p. 4,) Professor Rhys, of Oxford, who is himself a Welshman, and a Celtic scholar of large attainments, asserts that the Goidels (or Gaels), were undoubtedly the first Celts to come to Britain, as their geographical position to the west and north of the others would indicate. In connection with the Ogam Inscriptions, which are found in Wales, he remarks in his *Celtic Britain*, (p. 213,) that the Goidels belonged to the first Celtic invasion of Britain, and that some of them passed over into Ireland and made Ireland also Celtic. Some time later there arrived another Celtic people with another Celtic language. "These later invaders," he writes, "called themselves Brittons, and seized on the best portions of Britain, driving the Goidelic Celts before them to the west and north of the Island; and it is the language of these retreating Goidels of Britain that we have in the old Inscriptions and not of Goidelic invaders from Ireland. Their Goidelic speech, which was driven out by the ever-encroaching dialects of the Brythons, was practically the same language as that of the Celts of Ireland, of Man, and of Scotland." As Lhuyd and Professor Rhys give such an unambiguous opinion respecting the earlier presence of the Gaels in Britain, it may fairly be expected that the Topography of Wales will lend strength to the conclusions of those Welsh scholars.

The word *Aber* is of frequent occurrence in the Topography of Wales. It is in all likelihood a compound of *ath*, a ford, and *bior*, water—waterford.

In my previous paper on the Gaelic Topography of Britain, I adverted to the theory which was first advanced by Chalmers and which has as its advocates Dr. MacLauchlan, and Mr. Taylor, the author of *Words and Places,*—that, as Dr. McLauchlan contends, "the Generic *Aber* is in Scottish Topography found uniformly associated with specific terms purely Kymric," and that, as Mr. Taylor contends, "the Cymry held the Lowlands of Scotland as far as the Perthshire hills. The names in the valleys of the Clyde and the Forth are Cymric and not Gaelic." I remarked that Robertson and Skene have successfully refuted the theory in question. It is certainly a singular fact that if the Topography of Strathclyde is Cymric and not Gaelic, there are no *Abers* in the counties of Selkirk, Peebles, Ayr, Renfrew, Lanark, Stirling, Dumbarton and Galloway. Robertson, after examining the theory of which mention has been made, is fully justified apparently in employing this language in his Gaelic Topography of Scotland, (p. 512): "All the great features of nature within Scotland attest to the truth of the Caledonians being the first race; the mountains and the valleys all speak to us in their language —the *Gaelic* and not in *Welsh.* The author has proved beyond all controversy that there is not a mountain to be found in Scotland which bears a Welsh name, not a lake or river." *Aber* is of common occurrence in the names of places that lie along the sea-coast of Wales, *e. g.* :—

Abergeley : the confluence of the white river, *(geal).*
Aberconwy, *aber* and *conabhuinn* : confluence of rivers.
Aberhonnddu, *aber* and *abhuinn*, river ; and *dubh*, black.
Abermaw, *aber* and *baw* : W filthy.
Abermynwy, *aber*, and a root resembling *monadh*, moor.
Abertawy, *aber* and *tabh* : water or ocean.

Aberteifi, *aber* and *tiefi*, akin to *Taff, Taw, Tow*, a root which occurs in Tay, Tagus, Thames.

Aberavon, *aber* and *abhuinn*, river.

The question now arises as to the best and most plausible manner of accounting for the presence of *Aber* in the Topography of Wales and of the Highlands of Scotland; and for its almost entire absence from the Lowlands of Scotland where a Cymric kingdom once existed, as well as from Cornwall, which has many points of resemblance in language and race and tradition with Wales. In the face of the certainty that a large part of Scotland where no *Abers* are found intervenes between Cumberland, which in its very name perpetuates the fact that it was at one time inhabited by Cymry,—and between the Highlands where *Abers* and *Invers* are of constant occurrence, it will be vain to seek for any satisfactory explanation of the presence of so many *Abers* in Scotland in the predominance which the Cymry at one time possessed in the South of that country. Is not the conjecture more reasonable that, as Wales and the Highlands of Scotland resemble each other very closely in their mountainous character, in the ruggedness of their soil, and in the number and strength and rapidity of their streams; and as no other portion of Britain has such an uneven and rugged surface as Wales and the Highlands of Scotland, a similar term should be employed to designate the frequent confluences of streams,—a term which is not found elsewhere, and which, so far as Wales and Scotland are concerned, finds an easy explanation when the concession is made, that it was used by one and the same people in the far-off ages to describe these meetings of streams and rivers, which are common to both countries. The difficulty vanishes when it is granted that *Aber*, which is a Gaelic word, was employed by the observant Gaels of a remote age to represent these confluences which they found in Wales, and which they found in the Highlands of Scotland after they had passed over the comparatively level Lowlands. It is noteworthy that Latham is disposed to regard *Aber* as the *Abor* in the word *Aborigines*, "the locality to which it applied being either the confluence of the rivers Anio and Tiber, or the mouth of the Tiber."

*Cær* or *Cader*, which is the Gaelic *Cathair*, a city or fortified place, enters into many of the Topographical names of Wales, *e. g.:* Cader Idris, Cardigan, Cærnarvon, Cærmarthen, Cardiff, &c. Joyce, in his *Irish Names of Places*, (Vol. I., p. 284-5), states that "in modern nomenclature, the word (*Cathair*) usually takes one of the two forms, *Caher* and *Cahir*, and that there are more than 300 townlands and towns whose names begin with one or the other of these two words,—all in Munster and Connaught . . . *Caher* itself is the name of more than thirty townlands, in several of which the original structures are still standing." Cathair is unmistakably present in such names as these in the Topography of Scotland : Carden, Carriden, Carlin, Carmyle, Carluke, Carlaverock. Carnervon is the name of a place in Aberdeenshire—*Cathair-an-ear-abhuinn :* the city of the East river." The contention of the advocates of the theory, that the Topography of Scotland is largely Cymric, and that *Caer* which occurs in such names as have been already cited, is an illustration of the correctness of the theory,—is altogether untenable. The very fact that *Cathair* enters so largely into the Topography of Ireland and Scotland, clearly indicates that the word is not strictly Cymric, but that it dates from a remote age when Celts, whose language was Gaelic, imposed the names which have come down to our time on similar physical peculiarities in Wales and Scotland and Ireland.

The word *Llan* which means area, yard, church, is frequently found in the Topography of Wales, *e. g. :* Llandaff, Llandeilo, Llanelly, Lampeter, &c. Joyce thus writes, (Vol. I., p. 321) : "*Lann*, in old Irish *land*, means a house or church . . . *Lann* is found in our earliest MSS., among others in those of Zeuss : it occurs also in an ancient charter . . . in the sense of house." The word *lann* occurs also in Gaelic, and has the same meaning that it has in Welsh and Irish. I am disposed to believe that between *lann* and the Gaelic word *lean*, a meadow, a green plain, there is a strong resemblance, if not an identity. Joyce admits that, in its ecclesiastical application, *lann* was borrowed from the Welsh, but contends that "when it means simply *house*, it is no doubt purely Irish and not a loan word." It is clear, therefore, that *lann* is a Gaelic word, and that it does not belong exclusively to the Cymry and to the Topography of Wales.

*Loch* is the term which Scottish and Irish Gaels employ to designate a *lake* or an inland sea, or arms of the sea. The Anglicised form of Loch in Ireland is *Lough*. *Llyn* is the word which occurs in the Topography of Wales to designate a lake, *e. g. :* In Cardiganshire there are Llyn Teifi, Llyn Gynon, Llyn Eiddwen. In the County of Carnarvon there are, among others, Llyn Cwlyd, (*caoilead*, narrowness), Llyn Eigian, (*aigein*. deep), Llyn Llydan, (*leathan*, broad). Llyn is doubtless the purely *Gaelic* word, *linne*, which signifies a pool, lake, gulf. *Linn* enters into such words as Lincoln, Linn, Loch *Linne*, Roslin, *Dublin*. Though a difference obtains between the use which is made of *linne* in the Topography of Wales and the sense which it bears in the Topography of Ireland and Scotland, the word is unquestionably Gaelic, and as much entitled to that parentage as *loch*, or *cnoc*, or *amhuinn*.

The root *moin* or *moine*, a mountain, *moss*, a mossy-place, enters into *mynydd*, the Welsh word for mountain, and into the Gaelic word *monadh*. *Moin* or *monadh* enters largely into the Topography of Scotland and Ireland, *e.g.*, in the former country, Moncrieff, Monimail, Monivaird, &c., and in the latter country, Monalour, Ardmhoin.

*Carn*, the Gaelic word for a heap of stones, raised over the tombs of heroes,—a word which is of common occurrence in Scotland and Ireland, *e. g.*, Cairngorm, Cairndow, Carn, Carnglass, Carnlea, &c., is present in *Carned Llewelyn* and in *Carned Dafydd*, in the County of Carnarvon.

*Maol*, bare, *a precipitous promontory*, *Mull*, *Moyle*, which occurs in such names as the Mull of Kintyre, the Mull of Galloway, Malin Head, Rathmoyle, Lismoyle, Dunmoyle,—is present in *Moel Siabod*, *Moel Hebeg*, in the County of *Carn*arvon, and in *Mael Famman* and *Mael y-Gaer*, in Flintshire. *Drum*, the well-known Gaelic word for a *ridge* or *back*, is in Carnarvonshire. *Kinmel* (*ceann*, a head, and *meall*, a round hillock), is in Denbighshire. *Dun* appears to enter into the first syllable of Denbigh, Dinbych, *Dun*beag, the little dun or fort.

*Arran*, which occurs in *Arran Fowddy*, is the name of an island in Scotland and of several islands on the western coast of Ireland. *Craig y Llyn*, the rock of the pool or lake, is in Glamorganshire.

So far, therefore, as the names of mountains and ridges and hillocks in Wales are concerned, it is evident that Gaelic words are commonly to be found.

The names of various places in Wales disclose their Gaelic origin very readily. *I*, the Gaelic word for island, as in Iona, forms the last syllable of *Anglesey*.

*Maeltraeth*, in the same country, seems to be compounded of *Maol*, smooth or bare ; *traighe*, a beach or shore.

*Penmore* is *ceann*, and *mor*, large.

In *Brecknock*: *breac,* spotted, and *cnoc,* mountain, seem to enter as constituent elements.

*Brynmawr,* (*bryn,* hill; Irish, *bri*; Gaelic, *bruthach,* and *mawr mor,* large), signifies a large hill.

*Crickhowel* seems to be compounded of *creag* and *suil,* an eye. *Bangor* (*Beannchar,* pointed hill or rocks), is also the name of a place in Down, Ireland. CARREG CENNIN, in Caermarthen, is doubtless *Carraig Cheannfhionn,* the white-headed rock. *Pembroke,* (Welsh, *Penfro*), is compounded of *ceann* and *bru,* a country.

The Topography of Wales discloses its Gaelic origin very distinctly in the names of its rivers, *e. g., Taff, Tave, Taw, Towey, Tow, Teifi*: here, are different forms of the same root, which appears also in Tagus, Tay, Thames, and which has the strongest similarity to *Tabh,* an Irish and Gaelic word, signifying *water or ocean.*

Severn: *seimh,* still, and *burn,* water.

Dee, *da, abh*: double water.

Dovy, *dobhaibh*; boisterous.

Cowin, *cumhann*: narrow.

Alyn, *aluinn,* splendid; or *al,* a stone: *abhuinn,* river.

Dwyrid, *Dur,* water; or *duiread,* stubbornness.

Ogmore, *uisge, oice,* water; and *mor,* large.

Verniew, *fearna*: alder tree.

Wye: Welsh, *Guy,* water; *Buidhe,* yellow.

Honddu, *amhainn dubh*: black or dark river.

Conway, Comh, *con-amhainn-aimhne*: coming together of the river.

Seoint, *sinte*: extended.

Gwili, *goil, goileach*: boiling, raging.

Cothi, *cuthaich*: frantic.

Llwchwr, *luachair*: rushes.

Aled, *aillead*: beauty (?)

The citations which have been made from the Topography of Wales will suffice, I trust, to show conclusively, that the names of the Abers, and rivers, and forts, and hills, and lakes of Wales are of Gaelic origin; and that the same Celtic people gave, in the unrecorded ages of the past, the names which the prominent physical features of Wales and Ireland and Scotland have preserved over the centuries, and by which, though at times in the midst of obscurity, those natural features are still wont to be described.

In the preface to his *Grammatica Celtica*, Zeuss (than whom there is no better authority), asserts "that it can by no means be established that there was a community or an identity of language between the British and the Irish, (*inter Britannos et Hibernos*), in the eighth or ninth century, or even at a much earlier date; although it is abundantly manifest that both dialects or languages have begun from one fountain." That statement of Zeuss may be construed legitimately enough in such a manner as to increase the value of the argument which can be drawn from topographical names, in favour of the theory that the Gaels preceded the Cymry in their occupation of Wales as well as of the other portions of the British Isles. May not the argument be fairly advanced, that, as the substratum of the Topography of Wales is distinctly Gaelic, and as Zeuss, as the result of his exhaustive and masterly examination of the oldest forms of the Celtic languages or dialects contends, that long before the eighth or ninth century there was no identity of language between what may be regarded as the Cymry and the Gael,—to the Celts who spoke Gaelic the honour belongs of laying the foundation of the Topography of Wales; for, although the topographical structure has many stones that are of Cymric growth, the stones that form the foundation and on which the entire structure rests, are of purely Gaelic origin, and have an indefeasible kinship with the foundations of similar structures in Scotland and Ireland.

The rapid survey which I have been able to present of the Topography of the Isle of Man and of Wales will, I trust, serve to corroborate the conclusions at which learned philologists such as Llwyd and Rhys arrived from different channels of reasoning and observation, and to strengthen the theory, if not to establish it on honest and satisfactory grounds, that the first powerful stream of Celtic immigration into Britain was Gaelic, and that the same Celts who gave names to Fintry and Bannockburn in Scotland, gave names also to Bantry and Kinsale in Ireland, to Aberavon and Carnarvon in Wales, and to Slieu Mayll and Poolvash in the Isle of Man.

A short discussion followed, in which Mr. Notman, Mr. Shaw, and Mr. Murray took part.

## FOURTEENTH ORDINARY MEETING.

The Fourteenth Ordinary Meeting of the Session 1883-84, was held on Saturday, February 16th, 1884. In the absence of the President and Vice-Presidents, the chair was taken by Dr. Jos. Workman, who, later in the evening, retired on the entrance of the President.

The minutes of last meeting were read and confirmed.

Mr. Henry E. Morphy, B.A., was elected a member.

The following list of donations and exchanges received since last meeting was read :—

1. Journal of the Transactions of the Victoria Institute, to complete a set. Vols. 2, 6, 7, 8, 9, 10, bound, and Part 3, Vol. 15 ; Part 3, Vol. 16.
2. Science, Vol. 3, No. 53, Feb. 8th, 1884.
3. Transactions of the Manchester Geological Society, Part 12, Vol. 17, Sess. 1883–84.
4. Proceedings of the American Antiquarian Society, N. S., Vol. 3, Part 1.
5. Atti della Società Toscana di Scienze Naturali, residente in Pisa, Processi Verbali, Vol. 4, title-pages to do., Vols. 1 and 3.
6. Catalogue of Canadian Plants, Part 1. Polypetalæ, by John Macoun, F.R.S.C.
7. Report of Progress for 1880-81-82, of the Geological and Natural Hist. Survey of Canada. Maps to accompany the above Report.
8. Records of the Geological Survey of India, Vol. 16, Part 4, 1883.

Prof. J. Playfair McMurrich then read a paper on " The Skeleton of the Catfish," which will appear in the next fasciculus of the Proceedings of the Institute.

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## FIFTEENTH ORDINARY MEETING.

The fifteenth Ordinary Meeting of the Session 1883-84 was held on Saturday, February 23rd, 1884, the President in the chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges was read :

1. Science, Vol. 3, No. 54, February 15, 1884.
2. Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. 11, No. 9.
3. Bulletin of the Buffalo Society of Natural Sciences, Vol. 4, No. 4.

4. The Pennsylvania Magazine of History and Biography, Vol. 7, No. 4, December, 1883.
5. Correspondenz-Blatt der deutschen Gesellschaft für Anthropologie, Ethnologie und Urgeschichte, 13 Nos., January, 1883, to January, 1884.
6. The Monthly Weather Review for January, 1884.
7. Journal of the Royal Geological Society of Ireland, Vol. 2, Part 1; Vol. 3, Part 1, 2, 3; Vol. 4, Part 2, 3; Vol. 6, Part 2.
8. The Canadian Entomologist, Vol. 15, No. 12.
9. Journal of the Anthropological Institute of G. B. and Ireland, Vol. 13, No. 3.
10. Proceedings of the Royal Geographical Society, Vol. 6, No. 2, February, 1884.

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Mr. J. Gordon Mouat then read a paper entitled,

## A FEW CANADIAN CLIMATES.

Of the water influences which affect the climate of Canada, that of the Pacific Ocean is by far the most extended and far-reaching. The atmospheric drift of the middle latitudes bears it across the ranges of the Rocky Mountain system and diffuses its ameliorating warmth over the vast plains of the Saskatchewan and Athabasca. The influence of the Atlantic is limited to the few hundred miles over which the eastern surface winds from the sea are drawn inland towards the cyclonic areas advancing from the west. The St. Lawrence valley shows this influence in the winter temperature, which is higher than in the central parts of the continent on similar latitudes, and in a heavier precipitation. The unequal influence of the two oceans tends to throw the meridian of greatest summer heat and winter cold—which, were these influences equal, would lie in the central part of the continent—towards the eastern coast. But here nature has provided a check in the existence of Hudson's Bay and the Great Lakes, which temper the heat of summer and mitigate the winter's cold. It is not, therefore, in the meridian of the Great Lakes that the greatest extremes are found, but westward in the valleys of the Mississippi and Red Rivers.

The influence of the Great Lakes is very marked. In the lake region of the Province of Ontario the mean of the three coldest months varies from nearly 30° Fahr. to a little less than 15°. At similar latitudes in the Mississippi valley, and at almost similar elevation above the sea, the mean temperature of these months varies from 24° to 4°. The winter isothermal of 20° skirts the north shore of Lake Huron on the 46th parallel, descending in the Western States nearly to latitude 41°. The winter mean of 25° has in Ontario an average latitude of 43°, while in the Mississippi valley it reaches as far south as North-Western Missouri in latitude 39°. When the occasional extremes of winter cold are considered, the influence of the Great Lakes is found to be even more marked than in regard to average temperature. The lowest temperature in the past twelve years in Toronto, (lat. 43° 39′) was only −18°·4, Fahr.: Hamilton, (lat. 43°.16′) records −20°.5, and Windsor, (lat. 42° 19′) −19°.5,—while portions of the Niagara and Lake Huron districts show no temperatures lower than 12° below zero. Within shorter periods, not exceeding in any one instance eight years, the following temperatures were recorded at meteorological stations in the Mississippi and Missouri valleys:—

| | |
|---|---|
| Cairo, Ill., lat. 37° 0′ | —16° |
| St. Louis, Mo., lat. 38° 37′ | —21.5 |
| West Leavenworth, Kansas, 39° 20′ | —29.0 |
| Indianapolis, Ind., 39° 47′ | —25.0 |
| Lafayette, Ark | —17.0 |

To instance minimum temperatures in the past eight or nine years at stations further up the Mississippi valley is superfluous. Temperatures 40° below zero have been recorded at places in this valley no further north than the Canadian stations cited. During the present winter temperatures as low as—32° have been recorded in the State of Missouri. The lowest in Toronto has barely exceeded —13°. In the winter of 1874–5, the coldest on record in Ontario, when in Toronto the minimum temperature was—16°, temperatures as low as —39° were reported in Northern Illinois.

In short, the lake region of Ontario has as mild a winter mean as the Mississippi valley two hundred and fifty miles farther south, and eastward of the Rocky Mountains it is only to the south and east of a line drawn from Lake Erie to North-Western Texas that the thermometer does not occasionally fall as low as the lowest ever reached in the milder parts of the Province of Ontario.

It is interesting to notice in connection with the influence of the Great Lakes in modifying the cold of winter that the shore of Lake Michigan, opposite Chicago, has a mean winter temperature nearly four degrees higher than that of the city mentioned, and that while the pear grows with difficulty at Chicago, the much more tender peach grows luxuriantly far northward along the eastern side of Lake Michigan, and over several thousand square miles in the Province of Ontario. The area over which the peach can be grown in this Province is nearly ten thousand square miles. It is even found to succeed on favorable soils and situations at Owen Sound, on the Georgian Bay.

If the winter cold of the Province of Ontario is mitigated by the Great Lakes, so also is the summer heat. The great central plains of the Mississippi and Missouri in summer become so heated that the mean temperature of July in Missouri and Kansas is little less than that of New Orleans in the same month. The influence of the solar rays on these great interior plains is so great that the trade winds of the Atlantic, drawn eastward into the Gulf of Mexico, are deflected northward and, affected by the prevailing eastward drift of the atmosphere, are finally carried, charged with moisture, north-eastward occasionally to the Ohio valley and the borders of the Great Lake region. Far northward, in summer, torrid influences prevail. Temperatures of 110° and upward are experienced in Dakota and Montana, and even further north across the international boundary of 49° in the Canadian valleys of the tributaries of the Missouri. But the Great Lakes interpose a buffer against the easterly drift of the interior heat. The isothermals which in winter trend southward after leaving the lake region, in summer trend north-westerly beyond Lake Michigan. The July isothermal of 74°, which is found in Ontario only in the very warmest localities of the Province, reaches a parallel two hundred miles further north in the great plains of the west. The mean temperature of 70° for the three midsummer months, which in Ontario is found rarely northward of the 43rd parallel, is reached very nearly as far north as the 49th parallel in the North-Western States and Territories. It is not until October that latitude for latitude and altitude for altitude the mean temperatures of Ontario and the Mississippi valley are equalized. The decline in temperature thenceforward till winter has set in is more rapid in the Mississippi valley than in the region of the Great Lakes which, warmed by the summer's heat, delay the advent of winter several weeks after that season is established in the central parts of the continent. The advent of spring in the lake region is also later than in the west, partly owing to the retarding effects of the lake water, which has been chilled by the winter's cold, and partly to the greater distance from the now rapidly heating plains of the Lower Mississippi. The effect of this delay of spring is not disadvantageous, for the occurrence of the last frost damaging to vegetation is very nearly alike in point of time in the lake region and in the central parts of the continent, and in the former districts, vegetation being less advanced when that frost occurs, suffers less from its effects. The general effect of the greater liability of the Mississippi valley to intense frosts in winter, sudden changes and late frosts, is such that north of Tennessee no peach districts are found which compare, in immunity from injury through low temperatures, with the peach belts east of Lake Michigan and in the neighborhood of Lakes Erie, Ontario and Huron.

What is true of the annual and seasonal extremes of the lake region and the Western States, has its parallel in regard to the daily range of temperature. It is only once in many years that Toronto, which is fairly representative in this respect of the lake borders of Ontario, knows a range of forty degrees in any one day. The late Prof. Loomis, discussing the results of two years' records of over one hundred stations scattered over the continent north of the 35th parallel and between the Rocky Mountains and the neighborhood of the Atlantic, states that only in the Province of Ontario had he found stations at which the mercury had not ranged occasionally forty degrees in a single day. At the stations in the Mississippi valley and westward to the Rockies, greater changes than forty degrees were recorded several times in each of the two years ; at several stations twenty to sixty times. Even as far south as Northern Texas sudden changes of remarkable extent are recorded by the American Signal Service. In one instance a fall from 80° to 18° within a few hours is noted ; and on the 7th of September, 1881, on the northern borders of Texas, a sudden lowering of temperature proved fatal to over 300 cattle. The facts given show that in equability of climate the Province of Ontario is one of the most favoured districts in the temperate latitudes of this continent.

While the whole of the lake region of the Province of Ontario as far east as the Ottawa River experiences the modifying influence of the great lakes, the measure of that influence differs greatly according to elevation, and distance and direction from large bodies of lake water. In fact, the lake influence, while rendering the whole region more temperate than any part of the Mississippi Valley to the westward, increases the differences beyond those due to latitude, so that the part of the province south of the 46th parallel presents a much greater variety of climate than any other non-mountainous district of equal area on the continent. Eastward from the Georgian Bay the effect of the great lakes in moderating heat and cold rapidly decreases, and continental conditions rather than semi-insular gradually come to prevail. Lake Ontario not lying in the direction from which the areas of low and high barometer advance on this region, has but a very limited influence. There being no large body of water to the north, such winter anti-cyclones as take a course to the Atlantic to the northward of the great lakes pour their refrigerating northern blasts down over this region.

At Ottawa the summers are hotter than at Toronto, Goderich and many other places a hundred miles or more further to the south, and though the summers over the Ottawa district are shorter than in much of the south-western part of the Province, the mean temperature of July is quite as hot as in most localities in the latter and the maximum temperature very frequently is higher than 95° in the shade; it occasionally exceeds 100° and usually is several degrees hotter than at Toronto, the eastern shore of Lake Huron, and even localities as far south as Lake Erie. The winters of Ottawa on the other hand average as low as 13° Fahr., and are much the same as at Moscow. The average minimum is about 30° below zero. Snow falls deep and the sleighing season is usually four months in length while in parts of south-western and southern Ontario, it is not as many weeks. Though the difference in latitude between Ottawa and Niagara is only about two degrees, the winters of the former place are at least as much colder than those of the latter as the winters of Niagara are colder than those of Memphis in Tennessee, eight degrees still farther south. Yet the sensible cold is not so great as this large excess might suggest; it is usually enjoyable, the atmosphere being dryer and there being more sunshine than in districts more within the influence of the lakes.

The district of Muskoka & Parry Sound, bordering on the Georgian Bay, experiences in greater measure the influence of the Georgian Bay and Lakes Huron and Superior in tempering the heat in summer and the cold in winter of winds from the western semi-circle. This influence is necessarily much more marked in winter; though the elevation of much of the district makes the apparent amelioration less preceptible than it otherwise would be. The summers of Muskoka are cooler than those of any other part of Ontario south of the 47th parallel of latitude. But this tempering of the heat is due in large measure not so much to the influence of the Georgian Bay as to general elevation and the number of small lakes of great depth and coolness. Like the Ottawa Valley, though not to the same degree, the district is open to cold northerly winds in winter blowing outward from such centres of high pressure as move eastward to the Atlantic in high latitudes. Elevation adds to the cold of these north winds, which however are infrequent in some winters. At Huntsville (about lat. 45° 15′) in Eastern Muskoka, the temperature in January 1882 during the passage of almost the only severely cold anti-cyclone of the season, fell under a north wind to a temperature 30° lower than was reached at Toronto, and actually 47° lower than at Windsor, less than three degrees further south and little more than 280 miles distant in a direct line. In severe winters, a large part of the Georgian Bay, encumbered with islands, freezes over and the tempering effect of the lake water is thus greatly diminished.

The winters of the large island of Manitoulin, which approaches the 46th parallel, are milder than those of Muskoka. Of the climate of the north shore of Lake Huron beyond the 46th parallel, the meteorological records are meagre. The district is protected against cold west winds in winter by Lake Superior, but is open to cold blasts from the north-west, north, and north-east. The winter isotherm of 20° skirts the coast; inland the winters are colder. The summers are said to be warmer than those of Muskoka, notwithstanding the higher latitude. Small lakes are less numerous, and are shallow and heat rapidly. Neighbourhood to the great breadth of land between Lake Huron and James' Bay—an area which sometimes becomes intensely heated in summer has probably also some effect on the summers of the district. The heat of the southerly winds is of course greatly tempered by the great length of Lake Huron stretching against them.

At a distance of from 12 to 20 miles north of the north shore of Lake Ontario extends from the Highlands of Grey in peninsular Ontario to the head of the Bay of Quinte, a ridge or watershed attaining at a few places an elevation of nearly one thousand feet above the sea, and doubtless having some effect on the climate of the basin of Lake Ontario. Eastward from the easterly termination of this ridge the land slopes back from the lake far inland to the central heights of the watershed between the Georgian Bay and the Ottawa River. The lake has an elevation of only 234 feet (264 according to American surveys between the Atlantic and Oswego) above the sea. This comparatively low level conduces to raise the temperature of the borders of the lake. The comparatively moderate temperature of winter induced by lake influence and low level, the presence of high land to the north and west, and distance from lake water to the west, render the snowfall of the district lighter than in any other part of the lake region, with the exception of the district immediately north of Lake Erie. Sweeping over these high lands the north-west and westerly winds of winter which in passing over Lake Huron absorb considerable moisture, precipitate most of that moisture, and on regaining the low level of the Ontario basin resume almost their normal dryness. Owing to the comparative narrowness of the lake, and the fact that the winds which blow across it are not common or prevalent winds, the north shore, especially in its westerly portion derives a comparatively small proportion of its rain and snowfall from the lake, and the average annual precipitation is less than in any other part of the lake region with the exception of a limited district immediately north of Lake Erie. Towards the east end of the lake the same influences which make the climate of Ottawa extreme begin more and more to prevail; and the duration of sleighing gradually increases, till at Kingston it is nearly three months in length.

The climate of Toronto fairly represents in kind the characteristics of the north shore. At a low level and protected by the lake against the warm southerly winds, and by Lake Huron and the Georgian Bay from the cold northerly and westerly winds of winter its seasonal and daily range is comparatively small. The summer is cooler than in almost any of the larger towns in Ontario; and few have winters as mild. The mean temperature of January—about 23° for the eight years, 1874–'81, is nearly nine degrees higher than in Montreal, and is higher than in the uplands to the south-west, or than near Chicago, a degree and three-quarters farther south. The average minimum of January is —3°.1, the average minimum of the year —11°.0; the absolutely lowest in the eight years cited, —16°.0; and in the past twenty-five years —18°.4. The latter temperature is not so low as has been recorded within the same period at Louisville, Kentucky, or St. Louis, Missouri. The average duration of sleighing appears to be between three and four weeks; in some winters there has been no sleighing whatever. An examination which I have made of the records of Toronto observatory for the past thirty Christmas days shows that only on four of these holidays, or little more than one in eight, has there been sufficient snow to permit the running of sledges, and on thirteen occasions the ground was bare. The interposition of the lake water against hot winds from southerly points of the compass greatly tends to prevent extremes of heat. The summer of Toronto is cooler than that of Montreal, the Ottawa Valley, and parts of the interior to the north, north-east and west of the city, and as cool as the eastern shore of Lake Huron. The mean temperature of July for the eight year period cited is 69°.01—which is little more than three degrees warmer than Paris, France, over five degrees farther north; and is less than two degrees for the same period warmer than Winnipeg, where though the latitude is higher by 6¼ degrees, full continental influences prevail. The freedom from warm extremes both winter and summer is more noticeable. The average maximum of January is only 46°.25. The absolute maximum (Dec. 31, 1875) of mid-winter in eight years was only 61°, while that of Galt, 56 miles westward and 520 feet higher, was 66°; that of Hamilton, 42 miles distant, but at the west end of the lake, 71°, and that of the Niagara district, 40 miles distant, nearly 80° in the shade. The average maximum of the year is only 91°.5; that of Hamilton is 96°.9, while over the Lake Erie district and over most of the inland parts of the Province as far as the Upper Ottawa, the average maximum is in most localities as high as 95°. The absolute maximum in twenty years past is only 95°.4. At Ottawa and even in Muskoka it has exceeded 100°, while at Hamilton it has reached 106°.3 in the shade. It is interesting to note in passing, that moderate as is the annual maximum at Toronto as compared with other localities in the Province, it is a little higher than at Charleston, South Carolina.

At Toronto, as, more or less, along the shores of the Great Lakes, a lake breeze by day and a land breeze by night, blow during hot, calm weather. These breezes usually do not affect the climate for more than a few miles from the shore. Inland, notwithstanding the increased elevation, the temperature is higher in the day time during the summer months than it is at Toronto.

Hamilton, only forty-two miles distant from Toronto, and only twenty-three minutes further south, has a much warmer climate, and illustrates in an interesting manner several of the peculiar differences due to situation. Like Toronto it is exposed to the northerly winds modified by the Georgian Bay a hundred miles to the northward, but it is in a measure protected from the north-easterly winds by the intervention of Lake Ontario. More important in its bearing on the climate is the fact that the southerly and south-westerly winds which in reaching Toronto, have part of their warmth abstracted by Lake Ontario, reach Hamilton after blowing over a considerable stretch of land. Hence the latter place attains much higher temperatures in all seasons of the year than are reached on the north shore : the mean temperature is also higher. In addition to these causes which tend to increase the daily and seasonal range, the situation of the city on a low plain with a steep escarpment on the south and a range of hills across the bay on the north, tends to the existence of great daily contrasts, for in certain conditions of weather, the heat appears to accumulate in the sheltered "ravine" while in other conditions the heavy cold night air of the upland pours over the "mountain" and displacing the warm air, settles beneath it.

A remarkable instance of the effects of situation in a ravine, cutting through an extended upland, is afforded by the records of Galt on the Grand River. In 1879 the writer had charge of the meteorological station in the valley of that town. On the edge of the plateau to the west, a little more than a mile distant from the ravine station and about 180 feet higher than the later, was a second station in charge of a careful observer, Mr. Alex. Barrie. The thermometers at both stations were protected by the fence and screens approved by the meteorological service and in use at Toronto Observatory, and great care had been exercised to make the conditions of exposure similar. Here while the average daily maximum temperature was about two degrees higher at the valley station than on the plateau, the relative temperatures were sometimes greatly reversed. On Oct. 10th 1879, the maximum at the plateau station was 90°.3, while at the valley station it was but 79°.3, eleven degrees lower. On another date in the same year the difference was still greater, the thermometer at the 9 p.m. reading on the plateau being 79°, when in the valley it was only 65°, or fourteen degrees lower. There being no station at Hamilton, other than in the valley, similar instances there of the inflow of cold air cannot be cited. But the effect of this occasional inflow is seen in the facts that while the mean temperature and monthly maxima at Hamilton are higher than at Toronto, the monthly minima, from July to October, are very nearly the same at both places. The following tables show the average monthly maxima and minima at Hamilton and Toronto over a period of eight years (1874-81) :—

AVERAGE MONTHLY MAXIMA.

| | JAN. | FEB. | MAR. | APR. | MAY. | JUNE. | JULY. | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hamilton. | 49·7 | 50·9 | 58·2 | 72·0 | 89·0 | 91·0 | 93·9 | 94·0 | 90·3 | 81·6 | 64·3 | 54·9 |
| Toronto .. | 46·2 | 44·5 | 50·8 | 66·0 | 83·8 | 86·2 | 89·6 | 87·4 | 84·3 | 71·3 | 57·4 | 48·7 |

AVERAGE MONTHLY MINIMA.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hamilton. | —0·1 | —1·6 | 6·3 | 18·9 | 31·1 | 42·2 | 49·9 | 47·4 | 37·5 | 26·9 | 11·2 | 2·5 |
| Toronto .. | —3·1 | —3·3 | 4·0 | 16·6 | 29·0 | 40·4 | 49·2 | 47·8 | 37·6 | 26·3 | 7·5 | —1·7 |

The average yearly maximum at Hamilton is 96°.9, the average yearly minimum –7°.4; the lowest temperature recorded in the eight years (1874–81) from which these averages are obtained was –20°.5; the highest 100°5. The absolutely highest temperature on record was 106°.3 (July, 1868), a degree of heat which has not been reached at New Orleans, or at Naples or Calcutta, in a period of at least 18 years. The average annual maximum is quite as high as at New Orleans or cities to the eastward along the Gulf of Mexico.

The mean temperature of the different months at Toronto and Hamilton for the eight-year period mentioned is as follows :—

| | JAN. | FEB. | MAR. | APR. | MAY. | JUNE. | JULY. | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toronto .. | 22·7 | 22·2 | 28·7 | 40·2 | 54·2 | 62·6 | 69·0 | 67·8 | 60·3 | 47·6 | 35·1 | 26·4 |
| Hamilton. | 24·4 | 24·6 | 31·1 | 42·5 | 57·7 | 66·0 | 73·3 | 71·4 | 63·9 | 50·3 | 37·1 | 28·4 |

The mean of the year at Toronto is 44°74, and at Hamilton 47°47 or 2°73 higher. The daily range in Toronto is about 13° in January, and nearly 20° in July, while at Hamilton the figures for these months are respectively about 20° and 27°. The average daily maximum of July, at Hamilton, is above 84° in the shade, and not 79° in Toronto. In the warmest month ever recorded in Hamilton (July, 1868 , the mean temperature was 80° with an average daily maximum of 93° in the shade. In Toronto the mean of the same month was 75°.8, with a mean daily maximum of only 85°.4. These contrasts sufficiently illustrate the effect of the different situation of the two cities in regard to the water of Lake Ontario.

Along the south shore of Lake Ontario, eastward to Niagara, the general features of the climate of the belt of land referred to, resemble those of Hamilton, though the thermometer does not fall so low at night as in that city. The summer heats are intense, and temperatures above 70° have even been recorded in mid-winter. The season is, over much of the district, longer than at Hamilton, where the average period between the last fall of the temperature in spring to 32°, and the first descent in autumn to the freezing point, was for three years (1878-80), 186 days. The measure of protection afforded by Lake Ontario from the winds from northerly points of the compass increases, and the mean temperature of winter rises. Lake Erie also affords a measure of protection against the cold which in winters unusually severe in the Western States sometimes accompanies south-westerly winds. At Niagara the mean of winter is several degrees higher than at Hamilton, and nearly as high as at New York, and the average minimum of the year is little, if at all, below zero. The heat and duration of summer and the comparative mildness of winter make the district peculiarly well adapted to fruit growing. The peach-orchard area of the district is very large, and vineyards averaging four to five tons of grapes to the acre are numerous. The sweet potato and the peanut flourish in a degree unsurpassed in any other district in the province. The mulberry grows luxuriantly. The pseudo-papaw, and the tulip tree, *Liriodendron tulipfera*, grow wild in the woods and attain large proportions. At Niagara the writer has found fig-trees heavily laden with fruit, growing in the open air with but little winter protection ; and the soft-shelled almond, though of course but little cultivated, with slight winter protection, produces fruit equal to that of the common almond of commerce.

The north shore of Lake Erie, like the north shore of Lake Ontario, and for similar reasons, is marked by a tendency to the avoidance of great extremes of heat, though owing to latitude and the shallowness, and therefore greater warmth, of the water, the hot extremes of the summer months, and the mean temperature are higher than on the north shore of Ontario. In exceptionally severe winters, ice forms to a greater extent on the bays and indentations of Lake Erie than along the Lake Ontario coast, and though the mean temperature on the north shore of Erie is higher than on the same shore of Ontario, the winter maximum in such seasons is no greater than at Toronto. The snow of winter is light, and usually lies but a short time, even in winters when around Buffalo the depth is great and the sleighing of long duration.

The eastern shore of Lake Huron has a climate differing in several important particulars from the Canadian shores of Lakes Erie and Ontario, and illustrating more than these lakes the peculiar effect of a large body of water interposed against the prevailing westerly winds. The winters are nearly two degrees warmer than at Toronto, and are as mild as those of Hamilton, as free from cold extremes as at Niagara, and from warm extremes as at Toronto, yet the moisture of the lake winds makes the sensible cold appear greater than in the interior or in the Niagara District. Spring is retarded by the lake influence, and the mean of that season at Goderich is no higher than at Toronto; but on the other hand the autumn is several degrees warmer: summer is as cool as at Toronto, and comparatively free from very high temperatures. Goderich, lat. 43° 25′; altitude, 728 feet, has a mean temperature for the year a little higher than Toronto. Zero temperatures, and temperatures above 90° are rare; and the contrast in this respect with the Michigan shore opposite, is very marked. The climate is one of the most equable of the whole lake region, and surpasses in this respect almost every other district in the middle latitudes of the continent. The peach grows far north, and even on the Georgian Bay. Towards the southern part of the district, peach-growing is an important industry. Owing to the moisture of the lake winds, this shore is not so well adapted to the vine as the ordinary or low levels of peninsular Ontario. The rainfall and snowfall are both heavy, for to the rainfall brought by cyclonic areas, there is added the moisture gathered by westerly winds from the lake. The north-westerly winds, normally intensely dry, gather a large amount of moisture from the lake, and in winter when the land is chilled, this moisture is precipitated in snow flurries to a considerable depth. The interior of peninsular Ontario varies greatly in elevation, rising slowly and gradually from Lake Erie; more rapidly from Lake Huron and still more abruptly from the Georgian Bay, up to the

Highlands of Grey, where an elevation of 1,700 feet above the sea is attained. Consequently, considerable differences in climate exist in this interior. On the Highlands of Grey, and on the Lake Huron slope the snowfall is often excessively heavy, and the snow lies several feet in depth, when in some districts of the Province the ground is bare. Sleighing usually lasts for three months or more on the highest levels. Of the annual precipitation of this part of the interior, there are but few records, and these cover but a very short period. There is reason, however, to think that the annual precipitation in some localities, as in Muskoka, exceeds 50 inches, that is, amounts to nearly twice the precipitation of the dryest localities of the Province. The explanation of this heavy precipitation has already been sufficiently indicated.

The winter temperature of the central watershed, owing to great elevation, is cold, averaging in some localities below 20°. The extremes of cold, too, are great, though on these, as on the winter mean, the surrounding lakes exercise a moderating influence, and the temperature usually does not fall so low as at Ottawa or as in the Western States at even lower levels and much lower latitudes.

The difference in mean summer temperature between the lake shore and the highest land of the interior, is not great when the difference in altitude is considered. The mean of July, at the highest points, is about 65° and the maximum heat is about as high as on the Lake Huron shore. The degree of heat attained is due, in a large measure, to the extent of unbroken land to the south and southwest. At Owen Sound on the south shore of the Georgian Bay, so much does this large land area in the direction of the warm winds affect the climate, temperatures as high as 95° have been reported in the month of May. At elevations of 1,000 to 1,200 feet, the mean of summer is nearly as high as at Toronto, and the daily and yearly maxima are higher. The difference from the lake coasts and lower levels is chiefly in the existence of a greater daily and seasonal range on the high land and a shorter period of exemption from early and late frosts. On the long slope towards Lakes Erie and St. Clair, the mean temperature of all seasons gradually rises, and at some distance inland the mean temperature of summer exceeds that of the Erie coast by several degrees, and almost equals that of the very warmest localities of the Province. In extremes of warmth, both summer and winter, the temperatures are higher than in most localities near the lakes. At Galt, lat. 43° 20′, altitude 870 feet, the mercury usually rises to 95°, and has exceeded 100°. London sometimes records a higher July mean than even Hamilton or Windsor. At Zurich, towards Lake Huron, 103° was reported in 1881. Perhaps as forcible an illustration of the tendency of the interior to develope extreme heat as can be given, is in the fact that while in 1881, at Brantford, lat. 43°10′, altitude 720 feet, there were in May 7 days, in July 21 days, in August 16 days, and in September 7 days—51 in all—on which the mercury rose above 90° in the shade, and while the highest temperature was 99°, in Toronto there were but five days, in all, on which a temperature above 90° was reached, and the very highest was only 92°.7. Towards the south-western portion of this inland district, the absence of lake water to the south-west, between the foot of Lake Huron and the head of Lake Erie, fully admits the south-west wind, which is usually warm, and winter temperatures comparatively high are often recorded. An indication of the general climate of this Lake Erie slope is that the peach is grown, on suitable soils, to an elevation of about 1,000 feet above the sea.

In much of the interior of peninsular Ontario, thunder storms are numerous and more severe than on the north shore of Lake Ontario. Tornadoes also occur more frequently, though they are not so violent nor so frequent as in equal areas in Ohio, Indiana and the Central Western States. The snowfall of the Lake Erie slope rapidly diminishes as the distance from Lake Huron increases. North-west winds which near Lake Huron and in the highlands of Grey, bring several inches of snow in a single day are usually snowless over the southern half of the peninsula. At Galt the average duration of sleighing is not more than six weeks; southward and south-westward the period decreases to a few days. The advent of spring is one or two weeks earlier over much of the southern part of the district, than at Toronto, and winter-wheat harvest is almost as much earlier. Harvest usually commences in the beginning of July and has been known to begin in the end of June, as far northeast as Galt, and about the 15th of June a short distance north of Lake Erie.

The climate of Windsor on the Detroit River, lat. 42° 19′, altitude 604 feet, is fairly representative of the climate of the extreme south western part of Ontario. Immediately to the north is Lake St. Clair, and not far beyond that lake, Lake Huron, affording protection from the cold north winds of anti-cyclones passing eastward north of the great lakes. To the south at no great distance is Lake Erie affording only a slight protection against the warmth of the south wind in winter. But against the cold in winter of westerly and north-westerly winds there is no shelter except such as the distant Lakes Michigan and Superior supply, and against the warmth generally, and in some winters the excessive cold, of the south-west wind there is little or no protection. Lake St. Clair is shallow, and in severe winters freezes over, and loses its protective influence, and both it and the very shallow westerly end of Lake Erie become in summer greatly heated, and not only lose the protective influence against extreme heat which lake-water generally exercises, but even at times, and especially in autumn, increase the heat. The extreme south-west has therefore a climate, on the average of the year warmer than almost any other part of the Province, but more variable also than most of peninsular Ontario.

The winter mean is the same as that of Hamilton, but with monthly extremes of heat and cold greater than in that city. The average yearly minimum is about the same as at Toronto. Owing to the great differences in the temperature of different winters in the Western and South-Western States, and the consequently great differences in the temperature of south-westerly winds in different winters, the temperature of the Windsor winters differs very much. In eight years (1874-81) the coldest January was 14°.7 which is lower than any January in the same period at Hamilton or Toronto, or eighty miles northward at Goderich. The warmest January on the other hand was 36°.2, or considerably higher than any at Toronto or Hamilton. December means varied from 18°7 to 38°9 ; March from 26°.6 to 41°.7 ; April from 37°.9 to 54°.2. Though the midsummer months show little difference in their mean temperature in different years, October means ranged from 46°.6 to 58°.9 ; May from 57°.2 to 65°.5, and September from 59°.0 to 72°.2 ; the last higher than any Toronto July in the same period.

The mean of the summer months is almost the same at Windsor as at Hamilton. In autumn, with the exception of the month of October, the two places are alike in mean temperature. It is the temperature of the spring and early summer that makes the mean of the year at Windsor (48°49) one degree warmer than the annual mean at Hamilton. April at Hamilton has a mean of 42°.5 ; at Windsor 45°.25 ; in May the figures are respectively 57°.7 and 60°.8 ; in

June Hamilton averages 66°.0 and Windsor 67°.85. The earlier springs of Windsor are due in part to latitude, in part to greater nearness to the rapidly advancing heat of the south-west, and in part to the fact that easterly winds which prevail in spring reach Hamilton from the deep, winter-chilled lake, and Windsor from the warmer land of Essex and Kent.

The following table shows the mean temperature of each month, the average monthly maxima and average monthly minima at Windsor, for the eight year period (1874-81.)

| | JAN. | FEB. | MAR. | APR. | MAY. | JUNE. | JULY. | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean .... | 24·1 | 24·7 | 32·4 | 45·3 | 60·8 | 67·8 | 73·4 | 71·4 | 63·8 | 51·6 | 37·1 | 28·4 |
| Mean max. | 50·0 | 53·5 | 61·8 | 77·3 | 88·9 | 91·7 | 95·1 | 93·5 | 90·5 | 81·2 | 64·5 | 53 3 |
| Mean min. | —3·0 | —0·6 | 9·4 | 18·8 | 30·0 | 47·3 | 51·4 | 48·3 | 36·8 | 25·0 | 10·4 | 0·0 |

The mean of the year is 48°.49 ; the mean maximum 96°.25, (very nearly the same as at Hamilton) and the mean minimum,—10°.75 or 3°.4 lower than at Hamilton, and almost the same as at Toronto $2\frac{1}{4}$ degrees farther north. The absolutely highest temperature in the eight years referred to was 100°.6 (Sep., 1881) : the absolutely lowest —19°.5.

In the four coldest months the maxima were as follows :—Dec. 68°.3 ; Jan., 66°.9 ; Feb. 63°.4 ; March, 77°.4. The contrast with Toronto goes to show the effect of Lake Ontario in protecting against unseasonable temperatures. There the absolute maxima for those months were Dec., 61°.1 ; Jan., 57°.5 ; Feb., 51°.6 ; March, 58°4. Absence of lake-water to the west renders the precipitation small compared with the adjoining Huron district. The snowfall is light, and the general temperature of winter, and particularly the warm extremes, reduces the average period of sleighing to a few days. The fruits and flora generally are the same as in the Niagara district. The vineyards are very productive, averaging in good soils five tons of grapes, and nearly 700 gallons of wine (first drawing) to the acre—a yield probably unsurpassed either in California or in Europe.

The southernmost part of Ontario and of Canada, Pelee Island, a township of 17 square miles (lat. 41° 40′ to 41° 50′—further south than Rome), has a climate peculiarly interesting. The island lies almost midway between Sandusky, Ohio, 20 miles distant, and Leamington, Ont., and with Kelly's, an Ohioan island, six miles to the southward, and the peninsula of Point Pelee to the northward, marks the dividing line between the very shallow and island-dotted western extremity of Lake Erie, and the larger, deeper and unbroken area of the lake to the eastward. This peculiar position produces remarkable climatic effects. The water to the westward is generally not more than forty feet in depth, and under the hot summer sun becomes so heated that temperatures above 80° are sometimes registered at lake bottom in the habours along the neighbouring coasts. This high temperature not only tends to increase the average heat and length of summer, which here is almost as warm as at Cincinnati, but increases the warmth and length of autumn—which also is as warm and free from frosts as on the Ohio River—and reduces the difference between day and night temperatures to almost tropical smallness. Another effect, a physician on the island informs the writer, is that what corresponds with the nightly land breeze of the lake coasts in hot, calm weather, here blows not from the land, but from the deeper and cooler lake water to the eastward, into the heated western end of the lake. The effects in winter of the surrounding shallow water, vary with the severity of the seasons. In the milder winters the usual effects of water surroundings are experienced in a small daily and seasonal range. In severe winters the shallow archipelago of the western end of Lake Erie is encumbered with ice and sometimes freezes over, and Pelee partakes in greater measure of the continental character of the winter of the neighbouring mainland.

An examination of the records of the meteorological station on the island for a period of three and a half years bears out the deductions which otherwise could be made from the peculiar situation of Pelee.* The figures are interesting. The mean temperature, and mean monthly maxima and minima are as follows :

* The records, which through the courtesy of the Superintendent of the Meteorological Service, were furnished the writer, embrace the period between February 1st, 1879, and August 31st, 1882. The records for May, October and November, 1879, and April and November, 1880, are incomplete or wholly wanting. The mean temperature for these missing months has been approximated by the writer after careful examinatien of the records of Windsor and Sandusky, what is believed to be due allowance having been made for the peculiarities of the Pelee climate. The hours of observation were 7 a.m. and 2 and 9 p.m. The mean temperature is found by adding together the readings at the first two hours, and twice the 9 p.m. reading, and dividing the sum by 4. The maximum and minimum temperatures given are those of the

| | JAN. | FEB. | MAR. | APR. | MAY. | JUNE. | JULY. | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean .... | 26·2 | 27·4 | 32·5 | 41·7 | 59·2 | 67·1 | 73·5 | 72·9 | 66·3 | 56·4 | 38·7 | 29·1 |
| Mean max. | 47·7 | 54·3 | 54·5 | 65·0 | 85·3 | 91·0 | 95·0 | 91·5 | 90·7 | 72·0 | 62·0 | 49·7 |
| Mean min. | 6·7 | 7·0 | 18·7 | 18·7 | 40·3 | 51·3 | 61·5 | 59·7 | 49·5 | 37·5 | 28·0 | 9·0 |

The mean temperature of the year is 49°·25: did the record extend over the eight years which have been used for the averages of Toronto, Hamilton and Windsor, it would probably appear a small fraction of a degree lower.

The coldest January averaged 16°.5, or 0°.7 higher than the same month at Windsor, while the warmest, (34°.8) was 1°.4 colder. The absolutely lowest temperature (—12°) occurred when the west end of the lake was covered with ice and was 5°.4 lower than at Windsor. The occurrence of lower temperatures than at Windsor during the same severe season suggests that the effect of a neighboring area of ice in extremely cold weather, is more favourable to the development of cold than is the vicinity of an unbroken land area, an explanation which may find additional illustration along the eastern side of the Georgian Bay. In mild winters the low extremes are higher at Pelee than at Windsor. In January 1880 the minimum at that town was 19°, while at Pelee it was only 25°. In the other months of the same winter the difference in favour of Pelee was from 4°.5 to 10°.5. The absolutely highest temperatures in the winter months were: Dec. 57°, Jan. 55°, Feb. 63°, March 60°. The extraordinary smallness of the mean daily range in winter is shown by a comparison between the averages of the 7 a.m. and the 2 p.m. readings. The average difference in Dec. is only 2°.2, in Jan. 3°.3, Feb. 6°.4, and March 5°.4. In December 1881 the average temperature was 34°.7, but the 2 p.m. reading was only 36°.1, and the 7 a.m. 34°.5, a total range of only 1°.6, between hours which represent, at this season

hours of observation only, but a careful consideration of the facts as to cloudiness, direction of wind, &c., at the times of their occurrence, and for some time before and after, leads to the conclusion that in many instances they represent within a fraction of a degree the true max. or min., as the case may be, and that in few instances can the highest or lowest temperatures have differed more than one or two degrees from these quantities as taken from hours of observation alone. Where the mean temperature of the month is not derived from the original records no attempt has been made at supplying maximum and minimum, or averages other than for mean temperature. The mean maximum and mean minimum of November is consequently derived from but one month, that of October from only two, those of January, February, April and May from three, and the remaining months of the year from four.

especially, very nearly the extremes of the day. The average daily range in January furnishes an interesting contrast with the range in the same month at Toronto and Hamilton.

April at Pelee is almost as cold as at Toronto, and is more than 3° colder than at Windsor, thirty miles further north. The effect of the cold lake water is shown in the fact that the highest maximum in this month was 82.°9, (April 1881) while in Pelee it was but 68°. Yet the last frost of the season is several weeks later at Windsor than in Pelee, where it occurs about the middle of April. In May, Pelee almost regains the normal temperature of the districts on the neighboring mainland : temperatures above 90° are recorded and frosts are known only in exceptional years.

The summers are hot and steady. In only one June in four years was a lower reading than 50° recorded. In July and August only once in the same period was there a lower reading than 60°. The daily range in summer is much greater than in winter but still not half so great as at most stations on the mainland of Ontario. The range between 7 a.m. and 2 p.m. for June is 8°.4, July 8°.6, Aug. 7°.5. The daily range above the mean temperature is in summer twice as high, as the range below the mean, the nights maintaining an almost even temperature of about 70° in July and August, while the day temperature rises in July to at least 80°. This daily maximum is not so high as that of some parts of the Ottawa Valley, and is much below the daily maximum of Hamilton and Windsor, where however the night temperatures fall considerably lower than at Pelee.

Intensely tropical weather frequently prevails for days together, when, though the mercury does not rise any higher than on the mainland, it does not fall at night below 80°. In the steaming atmosphere of this shallow lake such days must be very oppressive. The following are instances from the records :

| | 7 a.m. | 2 p.m. | 9 p.m. |
|---|---|---|---|
| July.......... | 86° | 96° | 83° |
| Aug.......... | 83° | 95° | 85° |
| Sept .... .... | 82° | 98° | 84° |

September, in regard to heat, is properly a summer month, its mean being higher than that of a Paris July, and little lower than that of a Toronto August. In 1881 the mean was 72°.9, with a minimum temperature of only 58°.

October averages 56°.4, nearly ten degrees warmer than at Toronto, and quite as warm as in the Ohio Valley. November prolongs the balmy, hazy weather which persists here for months, and it is not till about the 12th of the month that the first hoar frost of the season usually occurs on the warmer soils of the island.

In winter sleighing is rare. The rainfall in the warmer months is comparatively light, owing to the high temperature above the shallow surrounding waters checking condensation.

The mean period in which the mercury does not fall to 36°—the average point at which hoar frost here occurs—is nearly seven months in length, or quite as long as at Memphis, Tennessee, and much longer than throughout most of Ohio and Indiana. It extends from April 14th to Nov. 12th. The great length of the season, combined with the long steady heat admits of the full maturing of cotton, which at one Pelee farm visited by the writer, has been grown for many years without any special care either to secure protection or early maturity. Climatic conditions are more favorable to the cultivation of the Catawba grape on Pelee and adjacent islands than in any other part of America. Including the mainland on both sides of the lake, this district is the most famous wine district on the continent, with the exception of a small area in California, where however the yield per acre is not greater than here. On the islands alone, millions of gallons of wine are produced, and the area in vineyards can be greatly extended. The grape crop is never injured by frosts, and conditions in regard to moisture are more favourable to avoidance of loss through mildew than in the Ohio Valley, which formerly was the chief centre on this continent of the production of Catawba wine.

To find European parallels to the various climates of Ontario which have been described, would be no easy task Individual districts will find winter parallels in the Crimea, on the banks of the Danube, and at Berlin on the one hand, and on the other at St. Petersburg, Moscow, Astrachan and in Central Russia. The summers of parts of the Province are paralleled in those of Lisbon, Northern Spain and Italy, Southern France, the lower Danube and Constantinople, or in the cool summers of Paris and Berlin. The Ottawa Valley and the central and inland parts of the Province of Ontario have summers like those of Vienna. Toronto at any season of the year differs but little in temperature from Bucharest. The month of July at Hamilton and Windsor is almost as warm as at Oran, in Algiers, and but little cooler than at Jerusalem, in Syria. In general, it may be said that a line from the Danube through Bucharest to Moscow would furnish parallels to the climates along a line from Windsor north-easterly to Pembroke, on the Ottawa—though the summers of the latter place are warmer than those of Moscow.

By a British standard the summers of much of the Province may be considered long. May in south-western Ontario is warmer than July at Edinburgh. September is warmer than July at London, and warmer than September at Vienna. The vine, maize and sorghum fully mature in most parts of the Province south of the 46th parallel, and in not a few districts yield as abundantly as in any part of America or Europe. The limitations on the cultivation of the vegetals of similar latitudes in Europe is more in the intensity of the winter frosts than in the lack of a sufficiently long or warm summer.

NOTE.

The length and heat of Ontario summers contrasted with those of other places in Canada, and various places in Europe, may be seen by a glance over the following table. The means for Toronto, Hamilton, Windsor and Winnipeg are derived from the annual records of the Canadian Meteorological Service for eight years (1874-81); those for Montreal from same records for six years (1875-80); those for Pelee, from C. M. S. station reports for three and a half years. The averages for European Stations are quoted from Blodgett's "American Climatology," and are for periods, with few exceptions, longer than eight years.

MONTHLY MEANS OF CANADIAN SUMMERS.

| | MAY. | JUNE. | JULY. | AUG. | SEPT. |
|---|---|---|---|---|---|
| | ° | ° | ° | ° | ° |
| Toronto | 54·2 | 62·6 | 69·0 | 67·8 | 60·3 |
| Hamilton | 57·6 | 66·0 | 73·4 | 71·3 | 63·9 |
| Windsor | 60·8 | 67·9 | 73·4 | 71·4 | 63·8 |
| Pelee | 59·2 | 67·1 | 73·5 | 72·9 | 66·3 |
| Montreal, Que. | 55·0 | 65·0 | 69·8 | 68·1 | 59·0 |
| Winnipeg, Man. | 52·9 | 61·8 | 67·3 | 64·1 | 51·9 |

MONTHLY MEANS OF EUROPEAN SUMMERS.

| | MAY. | JUNE. | JULY. | AUG. | SEPT. |
|---|---|---|---|---|---|
| Edinburgh | 50·3 | 56·0 | 58·7 | 56·8 | 53·4 |
| Aberdeen | 52·3 | 56·7 | 58·8 | 58·0 | 54·6 |
| York | 54·5 | 59·2 | 62·0 | 61·1 | 55·7 |
| London | 55·8 | 58·7 | 61·7 | 58·9 | 56·6 |
| Dublin | 54·4 | 60·2 | 61·5 | 61·4 | 56·5 |
| Paris | 58·1 | 62·7 | 65·6 | 65·3 | 60·1 |
| Rochelle | 59·4 | 67·5 | 69·0 | 66·5 | 62·4 |
| Vevay | 58·2 | 64·4 | 68·4 | 64·4 | 59·6 |
| Munich | 57·6 | 62·1 | 64·7 | 64·1 | 58·1 |
| Berlin | 56·5 | 63·3 | 65·8 | 64·4 | 58·4 |
| Konigsberg | 52·0 | 57·4 | 62·6 | 61·7 | 53·6 |
| Vienna | 62·1 | 67·5 | 70·7 | 70·0 | 61·9 |
| Bucharest | 56·3 | 62·5 | 68·1 | 65·2 | 58·3 |

The following members took part in the discussion which followed: The President, Dr. Barclay, Dr. Jos. Workman, Dr. O'Reilly, Mr. John Notman and Mr. David Boyle.

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## SIXTEENTH ORDINARY MEETING.

The Sixteenth Ordinary Meeting of the Session 1883-84 was held on Saturday, March 1st, 1884, the Third Vice-President, Dr. Geo. Kennedy, in the chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges was read:

1. Science, Vol. 3, No. 55, for Feb. 22nd, 1884.
2. Memoirs of the Boston Society of Natural History, Vol. 3, No. 8, on the development of Œcanthus Niveus and its Parasite, Teleas, by Howard Ayres.
3. Harvard University Bulletin, Vol. 3, No. 4, for January, 1884.
4. Historical Collections of the Essex Institute. Vol. 20, Nos. 10, 11, 12, for Oct., Nov. and Dec., 1883.

Dr. P. H. Bryce read a paper entitled, "Some Factors in the Malaria Problem."

The reader of the paper explained that he proposed reading extracts of a Report made upon malaria, prevalent in the lower district of the Grand River, under the direction of the Provincial Board of Health in September last.

After stating briefly the characters of the district regarding the nature of the soil and the underlying geological formations, in which he stated that coniferous strata are overlaid by Erie clays, and that the Saugeen clays overlie these, Dr. Bryce went on to explain how that, since the time of the building of the dams on the river for the purpose of supplying water by a feeder to the Welland Canal, malaria had been very prevalent up to the present. This he showed by the statements of old settlers and medical men, regarding that in past years, and by the tabulated reports of disease made by medical correspondents of the Board during the last year. After explaining the results upon the low-lying flats along the river of the damming back of the waters, the writer stated that there were three distinct elements of the problem, namely, the conditions of the soil, the ground-water and the air. Assuming that the various causes which it has been assumed cause malaria are all much less satisfactory than the germ theory, in which some bacterial organism, e. g., *Bacillus Malariæ*, is supposed to be the immediate cause, Dr. Bryce went into a discussion of how the local physical conditions might favour the free development of these germs, as it is well known that vegetable organic matter in a decaying state forms a favourite *nidus* for the development of bacteria of every kind. This material is largely present in some of the overflowed lands along the river, but free development of organic life in such depends upon the amount of water present in the soil. This necessarily varies with the dryness of the season and with the height of the river-water. This last point introduced the subject of its probable effects upon the ground-water of the low lands along the river. Through the denuded nature of the river-valley, the subsoil water of the neighboring higher lands naturally drain toward the valley along impervious beds of clay, and in some parts along the surface of the underlying rocks. This is seen in some parts in the presence of flowing wells. But, according to Miquel's experiments, it is not enough for the prevalence of germs in the air that they be developed in the soil. It is necessary that the upper layers of soil dry out sufficiently to allow the winds to carry these freely into the air. Further, their free development in the soil depends largely upon the amount of air in the soil, or oxygen. This it is clear must vary with the height of the ground-water, since as the water rises or falls the air must be less or more in the interstices of the soil. Hence, though ground-water conditions the amount of air in the soil, it is after all the oxygen of the air which determines the development of germs. But the next point in this connection is the fact that, as the temperature of the soil varies greatly from that of the contiguous atmosphere, especially during the warm summer weather, it follows that there is a regular circulation of ground air, new oxygen being constantly taken into the soil to supply the conditions of free zymotic development; and further, that this circulation probably serves to some extent as a vehicle for carrying the germs of the soil into the air. Upward currents of air during the day prevent an accumulation of atmospheric particles near the earth, and, on the other hand, the upper colder strata of air descending toward and after sundown, and especially in calm weather, cause accumulations near the earth of germs which have been carried up during the day. Hence, along with the increased humidity, is probably explained why night air is proportionately more malarious than day air. The influence of winds in greatly increasing the number of particles and germs in the air was also discussed and in this way, the writer explained, it was probable that the germs of malaria were laterally disseminated, and how they would tend so to increase each succeeding year as they found new centres of development. Hence it was apparent that forests, both mechanically, by breaking the force of winds, by keeping the air moist, by preventing extreme differences between day and night temperature, and by preventing undue drying out of the soil, would act favourably in preventing the wide-spread prevalence of malaria.

Discussing the matter of the influence of cold in causing malaria, the writer gave a number of selected experiments concerning the rapid decrease of body temperature under different physical surroundings, as temperature, wind and moisture.

He finally showed how drainage and the planting of forest trees would serve to lessen the conditions of soil favourable for the development of *Bacillus Malariæ*, the assumed immediate cause of the disease.

A discussion ensued in which Mr. W. Houston, Prof. J. P. McMurrich, Mr. Livingstone, Dr. Oldright, Mr. J. Notman, Dr. Bryce and the Chairman took part.

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## SEVENTEENTH ORDINARY MEETING.

The Seventeenth Ordinary Meeting of the Session 1883-84 was held on Saturday, March 8th, the President in the chair.

The minutes of last meeting were read and confirmed,

The following list of donations and exchanges was read :

1. Science Record, Vol. 2, No. 4. Feb. 15th, 1884.
2. Science, Vol. 3, No. 56, Feb. 29th, 1884.
3. The Canadian Practitioner for March, 1884.
4. Journal of the Franklin Institute, for March, 1884.
5. Journal of the Royal Microscopical Society, Series 2, Vol. 4, Part 1, for February, 1882.
6. The Canadian Entomologist, Vol. 16, No. 1, January, 1884.
7. Proceedings of the Royal Society of London, Vols. 31, 32, 33, 34, 35, and Part 1, Vol. 36, containing Nos. 206 to 228 inclusive, from March 24th, 1881, to Nov. 30, 1883.

A paper was then read by Mr. Wm. Houston on "Old English Spelling and Pronunciation."

In dealing with the subject, Mr. Houston dwelt for sometime on the changes which have taken place in the pronunciation of English words since Anglo-Saxon, in its various dialects, was the spoken language of the common people of England. The principal authority cited was Mr. A. J. Ellis, who has established by a wide induction from a variety of sources a considerable number of indisputable conclusions, though there are still many points left doubtful. As pronunciation changed, spelling should have changed also, and, as a matter of fact, it did so to some extent before the invention of printing, and to a less extent since; but the growing tendency of modern times is to allow the printers, to whom uniform spelling is a matter of great convenience, to fix the forms of words, not only absolutely but arbitrarily. The reader of the paper cited numerous instances of old spelling from Milton back to Chaucer to show (1) that spelling in Old English was more phonetic, and therefore better than now; (2) that spelling varied with pronunciation in the use of words by the same writer; and (3) that so far from adherence to a uniform system of spelling being regarded as a chief criterion of scholarship, old writers allowed themselves a great degree of latitude in their modes of spelling words. Spenser is an extreme instance of this free and easy view of orthography, for it is not uncommon to find him spelling the same word three or four different ways on the same page. In conclusion, Mr. Houston contended for greater freedom in orthography, not in the interest of diversity, but in the interest of simplicity of spelling.

The following gentleman took part in the discussion which followed: Dr. Workman, Dr. Bryce, Mr. J. Howard Hunter, Mr. D. Boyle, Mr. Murray, Mr. Shaw, Mr. Notman, Mr. Keys, Mr. Livingstone, Mr. Macdougall.

## EIGHTEENTH ORDINARY MEETING.

The Eighteenth Ordinary Meeting of the Session 1883-84 was held on Saturday, March 15th, the Third Vice-President Dr. George Kennedy in the chair.

The minutes of the last meeting were read and confirmed.

The following gentlemen were elected members of the Institute:

T. C. L Armstrong, M. A., LL.B., Henry William Eddis, Esq., and Frank Arnoldi, Esq., Barrister.

The following list of donations and exchanges was read:—

1. Science, Vol. 3, No. 57, March 7, 1884.
2. The Canadian Record of Natural History and Geology, Vol. 1, No. 1, Montreal, 1884.
3. Transactions of the Ottawa Field Naturalists' Club, No. 4.
4. Annual Report of the Library Commissioners and Libarian of the Legislative Library of Nova Scotia, and the Librarian of the Nova Scotia Historical Society for the year 1883.
5. Transactions of the Royal Geological Society of Cornwall, Vol. 10, Part 6.
6. Annuaire de 1884, de la Société des Ingénieurs Civils, 37*e*. Année.
7. Appleton's Literary Bulletin, March, 1884.

PURCHASE.—38 Nos. of the Journal of the Franklin Institute of various years, to complete a set.

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Mr. T. P. Hall, B. A., Fellow of University College, read a paper on "Photography and the Chemical Action of Light," illustrated by diagrams and apparatus.

After reviewing the history of photography, Mr. Hall showed the scientific value of this art, in leading to a more complete knowledge of the nature of radiant energy. The action of different parts of the spectrum upon various substances was explained in connection with wave-lengths and atomic vibrations, and the direction of future advances in photography indicated. The relation between transparency to certain rays and chemical composition, fluorescence, phosphorescence, colour-blindness, and other interesting subjects in this connection were discussed and illustrated. The following is an extract: "To make photographs which shall appear accurate to us we require a compound sensitive to the same rays and in the same relative degree as our eyes are. . . . Since, besides being deaf to an unknown variety of sounds, we are blind to nine-tenths of the light of the spectrum, it becomes a question of interest whether the lower animals are more or less blind than we. From his experiments on ants, Sir John Lubbock concludes that they are nearly or quite blind to red and yellow rays, and sensitive to green, blue, violet and ultra-violet rays. A photograph taken with silver chloride, which is very imperfect to us because the red and yellow rays are not represented, and violet and ultra-violet appear very bright, would therefore to the critical eye of an ant appear quite correct."

Dr. Bryce and Mr. VanderSmissen made remarks on the subject, after the reading of the paper.

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## NINETEENTH ORDINARY MEETING.

The Nineteenth Ordinary Meeting of the Session 1883-84 was held on Saturday, March 22nd, the President in the chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges was read:

1. Selected Papers of the Rensselaer Society of Engineers, Vol. 1, No. 1, January, 1884.
2. Transactions of the Manchester Geological Society, Vol. 17, Part 13.
3. Weather Review for February, 1884.
4. List of Fellows 1884, Royal Microscopical Society.
5. Science, Vol. 3, No. 58, March 14th, 1884.
6. Proceedings of the Royal Geographical Society, Vol. 6, No. 3, March, 1884.

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Mr. W. J. Loudon, B. A., read a paper on the "Radiometer," illustrated by experiments.

The following members made observations on the subject: Mr. H. S. Howland, jun., Mr. Murray, Mr. Macdougall, Mr. McKenzie, Mr. Livingstone and Dr. Bryce.

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## TWENTIETH ORDINARY MEETING

The Twentieth Ordinary Meeting of the Session 1883-84 was held on Saturday, March 29th, the President in the Chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges received since last meeting, was read :

1. Science, Vol. 3, No. 59, March 21, 1884.
2. Life and Work of Darwin, by George Acheson, M. A.
3. Trübner's American, European and Oriental Literary Record, Vol. 4, Nos. 11, 12.
4. Transactions of the Oneida Historical Society at Utica, 1881.
5. Science Record, Vol. 2, No. 5, March 15, 1884.
6. Proceedings and Transactions of the Royal Society of Canada for the years 1882 and 1883. Vol. 1, Montreal, 1883.

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Mr. Henry Brock then read a paper on

## THE UPPER NIAGARA RIVER.

The Border land has long been a theme for novelist and poet, and pen-pictures of the stirring scenes amongst the Grampians, the plateaux and peaks of the Tyrol, and along the vine-clad banks of the Rhine have been depicted with the fervour of enthusiasm by the many lovers of what has tended towards forming the national character of their native land.

The border land of Cánada has been the scene of many a heroic contest. And from Frontenac's struggles against the Mohawk and Iroquois, until the days of Earle's Hill and Limeridge, the Canadian, whether of French or English descent, has proved true to his native land. My intention this evening is to touch upon but a small portion of this interesting subject. Leaving out the country bordering on Memphremagog and Champlain, the noble St. Lawrence, and the clear flowing Detroit and St. Clair, I must content myself if I can bring before you a few reminiscences interesting to the antiquarian or historian of the Niagara Frontier, and particularly that portion of it which is commonly known as the "Upper Niagara River." Commencing at a point where 60 years ago a village hamlet stood with a few hundreds of a population, but where now 200,000 busy people are continuing the struggle for existence in the great city of Buffalo, and flowing in a north-westerly direction from Lake Erie, the Niagara River separates Canada from the United States. On the Canadian side of the river, just opposite Buffalo, are the remains of what was formerly Fort Erie. The fort is entirely dismantled, and is marked only by a few earthen ramparts fast settling down to the ordinary level. It was at this place that the Fenians of '66 crossed, although from the swiftness of the current of the river just below this point, which sweeps on at the rate of 10 miles an hour, and the width of the river, a few ordinary guns in their former embrasures at Fort Erie would prevent any such undisciplined raiders from again attempting to effect a crossing in safety. At present surrounded by the fast growing city, and forming now one of Buffalo's Parks, is the American Fort Porter. This fort is one of the military posts of the United States, forming with Forts Niagara and Detroit, links in that chain of forts, which in the United States extends from Maine to Oregon. It is garrisoned by a detachment of United States infantry, whose services were of great value to the city in the great railroad riots of 1877. Three miles from Black Rock the most northerly suburb of Buffalo is the Island called Grand Island, containing about 80 square miles of land, and forming a Township in Erie County State of New York. Flowing due north through the middle of the Island, is a small creek, called Burnt Ship Creek, emptying itself into the Basin separating Buckhorn Island from Grand. In this Basin the French, in 1759, anchored two small vessels containing the reinforcements which had been sent from Venago to raise the siege of Fort Niagara, if possible, which at that time was beleagured by the British under Sir William Johnson. After landing the men on Isle la Marine, now called Navy Island, they burnt and sunk these ships. Until a few years ago the charred timbers of these vessels were distinctly visible, but now, owing to the gradual filling up of this basin, they have completely disappeared. Some years ago, while fishing in the clear water in company with some American friends, we noticed what we first thought was a sunken log; but American inquisitiveness when once aroused cannot be pacified, save by complete and satisfactory investigation. A grappling hook was obtained and a long rope. By continued exertion we dragged the object on shore, and it was certainly a curiosity. It was evidently a wheel which was used as part of a primitive machine for dragging these small vessels over the portages. The wheel was about 8 feet in diameter, and was, although composed of probably over a hundred distinct parts, made entirely of wood, there not being a particle of iron in its composition. The wood was oak, and although it had been under water for nearly 120 years, was not in the least affected by any kind of rot or decay. Being too cumbrous to transport, it was left on the shore of the Island, and eventually the Philistine propensities of the agricultural natives destroyed this emblem of a departed age. I was fortunate enough the next year to be able to lay hold of some small pieces of the frame work, which I now have in my possession.

Going down the American channel past Tonawanda, with its miles of timber wharves, and directly east of Navy and Grand Islands, we come to Cayuga Island and creek, a mile from whose mouth is the village of La Salle. The name of René Cavelier dit La Salle occupies a place in early Canadian annals second only, if second, to that of Champlain himself. At the mouth of this creek, six miles above the falls, was built the first European craft that ever navigated the waters of the upper lakes, the ill-fated Griffin, whose fate must, like that of many a noble vessel in modern days, be a matter of conjecture, since, after carrying La Salle on his way to the Mississippi, it was never afterwards seen or heard of. The water of this creek, like that of all the streams flowing into the Niagara, is of a dark brown colour, in striking contrast with the clear blue of the river itself. Three miles below Cayuga Creek is Schlosser's Island and landing, pronounced by the degenerate inhabitant of the river Slusher's. Here was one end of the portage round the Falls of which the other end was nine miles below at Lewiston. Here the canoes of the Indian and voyageur once again entered the stream on their voyage from Fort Frontenac to the fur depots at Machilimackinac. The current is very mild along this shore of the river, and until the lower end of Grand Island is reached, when it becomes very rapid, the voyageurs could propel themselves as easily and rapidly as along a placid inland lake. In 1750 the French constructed a stockade and fort at this point which they appropriately called Fort La Portage. It was burnt in 1759 by Chabert Joncaire who was in command of it when the British commenced the glorious campaign against the French, which gave us the "brightest jewel in the British crown." A short time after this the fort was rebuilt by Captain Joseph Schlosser, a German, who had served in the British army throughout the campaign. A few inequalities in the surface of the ground now mark the site of the guardian of the Portage, but some twenty or thirty years ago the outlines and ditches were still quite distinct. A monument of antiquity still stands some yards below the remains of the Fort in the shape of a stone chimney, which was the centre point of the French barracks and storehouses previous to 1759. Several houses have been at different times attached to it and have been burnt or destroyed, but still the chimney remains, solitary, moss-grown and grey, and will remain no doubt until the advancement of civilization and the necessities of commerce will cause its replacement by something more modern. It was at the wharf at Schlosser that the ill-fated steamer Caroline was fastened that night, in '37, when she was cut out by the loyalists from the Canadian shore. The Canadian militia, under Col. Allan McNab's command, at that time investing Navy Island, were in a complete state of ignorance concerning the river. The Falls were a source of great terror to the storming party, and a circuitous route was taken to reach Fort Schlosser that delayed them many hours. At present the hardy inhabitant of either shore safely crosses the river in a small boat or canoe within half a mile of the rapids, and adventurous youths land with impunity even on Goat Island, but in '37 the cutters out of the Caroline were esteemed greater heroes than even those who faced the bullets of the enemy; such is the power of nature compared with even the life-destroying gunpowder. The affair of the Caroline caused much international ill-feeling and was made the subject of much conjecturing and studying of international law. Evidently the same principles and arguments were quoted and cited, but by the opposite parties, when the Alabama claims came before the board of arbitrators at Geneva. Lying to the north-west of Grand Island, and west of Schlosser, is the small Island, formerly Isle la Marine, now Navy Island. The French, in 1759, built some small vessels on this Island, hence its name was literally translated when it came into possession of the English. Although hardly over three miles in circumference it was probably better known and more thought about, at one time of our national existence, than even Toronto itself. Here, in December, 1837, Wm. Lyon Mackenzie established his headquarters and issued his proclamations to the patriots, as the unfortunate rebels called themselves. In fact to this day, on the American side of the river, the trouble of '37 is referred to as the "patriot war." There was great uncertainty as to the number of the insurgents, who certainly had plenty of arms and ammunition. To this day may be seen in the upper rooms of the several farm houses on the Canadian shore the marks of the bullets, while every plowing turns up on Navy Island many a rusty cannon ball. There is still standing and in good repair three miles from the Village of Chippawa, and directly opposite the head of Navy Island, the house in which Captain Usher was shot. Upon the door of this house is painted in white letters "No. 8, 20 men." evidently its billeting capacity. There are yet on the island two log huts or cottages which were occupied by Mr. and Mrs. Mackenzie. Although degraded to agricultural purposes they still seem destined to out-last several more modern structures built near them. There could not have been much peace of mind for any of the Reformers there; Sir Allan McNab, while not exposing his men to too much personal danger, continued to ply the rebels with shot and shell. While Mrs. Mackenzie was attending to some culinary operations one day a shell, plunging through the roof, fell into a barrel of beans which formed part of the stock of provisions, and burst, scattering a week's provender, but fortunately the inmates all escaped. For the greater security of his followers Mackenzie caused an open space to be cut out of the forest in the centre of the island. This is still known by the name of Mackenzie's Field, and is now used as a pasture for cattle. The proximity of the island to the United States, its great capabilities for defence and its commanding the entrance to the Welland River (which river is one of the entrances to the Welland Canal), combine in making it an outpost of great military value in time of war. On Navy Island may be seen many trees and flowers growing wild which cannot be found in any other place nearer than the Southern States; amongst others are the magnolia, sassafras, and several varieties of wild grapes. The apricot and nectarine are also grown and attain great perfection. A mile and a half from the head of Navy Island, on the Canadian side at the mouth of the Welland River, is the Village of Chippawa. It was at one time, before the building of the Welland Canal, a prosperous place. It was the head of navigation and a tramway ran from it to Queenston, the port at the other end of the Portage. But the canal and railway came and Chippawa suffered the common lot and decreased in trade and population in proportion as the larger towns grew. It is one of the oldest settled portions of Canada, John Cummings a U. E. Loyalist having settled there in 1782. It was the scene of several battles in the war of 1812 between the British and Americans. Several buildings are yet standing which were built previously to 1812, and in one of them may be seen a room at that time used as a prison; the rings and staples for securing the prisoners are still there. At the mouth of the Welland River may be seen the outlines of a stockade and fort first constructed in 1812, and afterwards used in 1837. For the purposes of navigation and the security of the harbour, a canal about one hundred yards in length was cut from the southern shore of the Welland River through to the Niagara. The refuse earth was thrown to one side and has several times been mistaken for the ramparts of the old Fort. On making a personal investigation with several of the "oldest inhabitants" last year, we discovered distinct traces of the old Fort, only, however, a few yards from the mistaken ramparts. Chippawa, like Queenston, has fallen into decay, and has been completely outshadowed by the greater attractions at the Falls two miles away.

From Buffalo to the head of Navy Island the river is comparatively deep, averaging from twenty to thirty feet from shore to shore. Across the head of Navy Island the width is about two and a half miles. Opposite Chippewa it commences to narrow, and so on till the Falls are reached; the main, or "Canadian" current, as it is called, does not follow the middle of the river, but pursues a course of its own, running from the foot of Grand Island towards the American shore, past Schlosser's Island in a north-easterly direction, then, instead of following the straight course towards the head of Goat Island, it makes a sweep round the head of Grass Island towards the Canadian shore, almost due west, and skirting the banks just below Chippawa, flows precipitously over the Horse Shoe Fall. In the centre of the river, stretching from about half a mile above the rapids to within half a mile of Navy Island, there is a reef about two miles long and three-quarters of a mile broad. In no place on this reef is the water more than three feet deep, and at times during low water the heads of the larger stones peep above the surface. The water rushes over this reef at a great rate, and the bottom being composed entirely of rock, and the current not allowing any sediment to settle, the reef, on some windy days, to a stranger, looks very much like the commencement of the Rapids. On the American side of the river opposite to Chippawa a canal has been cut for water power; the opening of this canal forms a small harbour called Port Day. Several steam yachts are kept here, and as the channel does not extend along the American shore, these vessels have to strike across towards the Canadian shore before ascending the river. As this is only a few hundred yards above the rapids the sensations of nervous passengers are not to be envied. The country back from the Canadian shore was formerly settled by U. E. Loyalists. At the present time, however, the farms are every day going into the hands of persons of German and American descent, the original settlers flocking to the cities. These new inhabitants of the river front have no sentimental regard for historical remains, and ruthlessly plow up and tear down anything that is not in strict conformity with agricultu al economy. In a very few years all that remains of Forts Erie, Schlosser and Porter will be swept away in "improvements." The relics of 1812 and 1837 will be sought for in vain by the archæologist, but the memory of the deeds that were done, and the devotion of the people who accomplished them, will live forever.

The following members took part in the discussion which followed :—The President, Mr. Murray, Prof. McMurrich, Mr. Livingstone and Dr. Workman.

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## TWENTY-FIRST ORDINARY MEETING.

The Twenty-first Ordinary Meeting of the Session 1883-84 was held on Saturday, April 5th, the Third Vice-President, Dr. George Kennedy, in the chair.

The minutes of last meeting were read and confirmed.

Mr. Chas. Levey, Mechanical Engineer, was elected a member of the Institute.

The following list of donations and exchanges received since last meeting was read :

1. Science, Vol. 3, No. 60, March 28, 1864.
2. Journal of the Franklin Institute for April, 1884.
3. Annual Report of Proceedings of the Belfast Naturalists' Field Club for 1882-83, Series 2, Vol. 2, Part 3.
4. Proceedings of the Academy of Natural Sciences of Philadelphia, Part 1, January to May, 1883, and Part 3, November and December, 1883.
5. Correspondenz-Blatt der Deutschen Gesellschaft für Anthropologie, Ethnologie, and Urgeschichte, 15 Jahrgang, Nos. 2 und 3 Februar und März, 1884.
6. The Canadian Practitioner for April, 1884.
7. Le Courrier de Europe, Semaine Française, for 1884, presented by Mr. Geo. E. Shaw.

Dr. E. A. Meredith and Prof. Galbraith were appointed Auditors of the accounts of the Institute for the year ending March 31st, 1884.

Prof. McMurrich, presented by title, a paper "On the Myology of the Catfish."

Mr. T. McKenzie, B.A., then read an abstract of a paper by A. B. Macallum, M.A., on "The Alimentary System of the Catfish," after which Mr. McKenzie read a paper by himself, on the "Vascular System and Glands of the Catfish."

These papers will appear, together with others on the same general subject, in the concluding fasciculus of the present volume.

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## TWENTY-SECOND ORDINARY MEETING.

The Twenty-second Ordinary Meeting of the Session 1883-84 was held on Saturday, April 12th, the President in the chair.

The minutes of last meeting were read and confirmed.

The following list of donations and exchanges was read:

1. Transactions of the Manchester Geological Society, Vol. 17, part 14, Session 1883-84.
2. Science, Vol. 3, No. 61, for April 4, 1884.
3. (*a*) Records of the Geological Survey of India, Vol. 15, Part 4; Vol. 16, parts 1—3. Vol. 17, part 1.
   (*b*) Memoirs of the Geological Survey of India, Vol. 19, parts 2, 3 and 4.
   (*c*) " of Palaeontologia Indica, Series X., Vol. 2, part 4.
   " " " " X., " 2, " 6.
   " " " " XII., " 4, " 1.
   " " " " XIII., " 1, " 4, Fasciculi 1, 2.
   " " " " XIV., " 1, " 4.
4. Publications of the Oneida Historical Society at Utica, No. 5, January 13, 1880.
   (*a*) Second Annual Address before the Society, by William Tracy, of New York.
   (*b*) Historical Fallacies regarding Colonial New York.
5. Bulletin of the Philosophical Society of Washington, Vol. 6, 1884.
6. (*a*) Fifteenth Annual Report of the American Museum of Natural History (Central Park, New York), March, 1884.
   (*b*) Bulletin of the American Museum of Natural History (Central Park, N. Y.), Vol. 1, No. 5, February 13, 1884.

7. Appleton's Literary Bulletin, No. 4, April, 1884.
8. California State Mining Bureau : Third Annual Report of the State Mineralogist, for the year ending June 1st, 1883.
9. (*a*) Bulletin of the Essex Institute, Vol. 14, January to December, 1882, Nos. 1—12,
   (*b*) Pocket Guide to Salem, Mass., 1883.
   (*c*) Plummer Hall : Its Libraries, its Collections, its Historical Associations.
   (*d*) The North Shore, Massachusetts Bay, 6th Ed., 1883.
10. Anales del Museo Nacional de México, Tomo III., Entrega 5*a*.
11 (*a*) Proceedings of the Literary and Philosophical Society of Liverpool during the 59th Session, 1869–70, No. 24.
   (*b*) Proceedings of the same Society during the 62nd Session, 1872–73, No. 27.
12 (*a*) Transactions of the Cambridge Philosophical Society, Vol. 11, parts 1 and 2 ; Vol. 13, part 3.
   (*b*) Proceedings of the Cambridge Philosophical Society, Vol. 1, 1843–1865, 16 Nos. complete ; Vol. 2, 1866 to 1876, parts 1—17, complete ; Vol. 4, part 6, for 1883.
13. Sitzungsberichte und Abhandlungen der Naturwissenschaftlichen Gesellschaft, "Isis," in Dresden, 1883, Juli bis December.
14. L'Académie Royale de Copenhague, Bulletin pour 1883, No. 2, (Mars–Mai.)
15. (*a*) Annuaire de L'Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique, for 1881, 1882 and 1883 ; 47th to 49th year, Bruxelles, (3 Vols.)
   (*b*) Bulletin de L'Académie Royale de Belgique, 49*me* Année, 2*me* Série 1880, Tome 1 ; 50*me* Année, 3*me* Série, 1881, Tome 1, 2 ; 51*me* Année, 3*me* Série, 1882, Tome 3*me*, et 4*me* ; 52*me* Année, 3*me* Série, 1883, Tome 5*me*, (6 Vols.)

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Dr. E. A. Meredith then read a paper entitled :—

## "COMPULSORY EDUCATION IN CRIME."

The reader of the paper contended that so far as regards the suppression of vice and crime, our Common or County jails were little better than the abominable dens which Howard visited and denounced more than a century ago. Philanthropists, social reformers and Prison Congresses had worked earnestly during the last thirty or forty years, and their labours had in other departments produced good results. In institutions for saving children, such as Homes, Refuges and Industrial Schools, extraordinary progress had been made and in convict prisons for adults an extraordinary revolution had been carried out with equal success, especially in those conducted under the so-called "Crofter" or "Irish" system. The Common Jails alone lagged behind the age, and the reason probably is that they were the only institutions managed by *municipal bodies*, the others being either under the control of the State or of private individuals or societies. The jails have been improved materially, but not morally. The giant evil of Howard's time, the indiscriminate association of the prisoners is still permitted in the great majority of jails on the continent, whether in the United States or Canada. The jails had ceased to be in any sense either *deterrent* or *reformatory;* they are, on the contrary, *attractive* to criminals and to the last degree demoralizing to the inmates. They are nurseries of crime, hotbeds of vice, where criminals are manufactured at the cost of the country. The only remedy for this disgraceful state of things is the introduction of the "Separate System," a system which had been approved by all authorities on the subject, and carried out with marvellous success in many jails in England and on the continent of Europe, and in some few in the United States. The great merit of the separate system is that it stops the corruption and contamination which indiscriminate association of prisoners necessarily produces. In other words it puts an end to the "Compulsory Education in Crime" now going on in all our jails; and more than this, it represses crime, both by its deterrent and reforming influences. Dr. Meredith recommended that the separate system be made obligatory in all jails so soon as these are fitted for it.

In answer to a question by the President, Dr. Meredith explained that "Solitary Confinement" was stricter than "Separate Confinement," which latter meant merely separation from injurious influences, and not from visits of those who may benefit the prisoners. These would be brought together only under supervision.

Mr. B. B. Hughes spoke in high terms of the manner in which the Reformatory at Penetanguishene was conducted.

Mr. Douglas hoped that the Legislature would do something to remedy the evils mentioned in Dr. Meredith's paper.

Mr. Geo. Murray thought that young children should not be sent to the same prison as adults. He would endeavour to sift out the worse juvenile criminals, and he believed a large majority would remain with which we could deal in the way of reformation.

## TWENTY-THIRD ORDINARY MEETING.

The Twenty-third Ordinary Meeting of the Session 1883-84 was held on Saturday, April 19th, the President in the chair.

The minutes of last meeting were read and confirmed.

The Rev. Hugh Johnston, M. A., B. D., was elected a member of the Institute.

The following list of donations and exchanges received since last meeting was read :

1. Memoirs of the Boston Society of Natural History, Vol 3, No. 9, March, 1884.
2. Science, Vol. 3, No. 62, for April 11th, 1884.
3. The Manitoba Gazette, March 31st, and April 5th.
4. Journal of the Asiatic Society of Bengal, Vol. 52, Part 2, Nos. 2, 3, 4, 1883. Proceedings of the Asiatic Society of Bengal, No. 9, November, 1883.
5. The Canadian Entomologist, Vol. 16, No. 2, February, 1884.
6. Proceedings of the Royal Geographical Society, N. S., Vol. 6, No. 4, April, 1884.
7. Atti della Società Toscana di Scienze Naturali, Processi Verbali, Vol. 4, pp. 29–52. Processí Verbalí, Indice del, Vol. 1, pp. 133 to 138.
8. Meteorological Service, Dominion of Canada, Monthly Weather Review, March, 1884.
9. Oneida Historical Society, 1879, Men of Early Rome, by D. E. Wager.

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Capt. Gamble Geddes, A. D. C., then read a paper entitled,

## AN ENTOMOLOGICAL TRIP IN THE ROCKIES.

Mr. President and Gentlemen,

It is with great pleasure that I take advantage of your kind invitation to read a brief paper upon a trip made by me to the Rocky Mountains last summer. As my object in undertaking this long journey was purely " Entomological," I had intended to prepare and read to you a paper upon the genera " Coliadæ" and " Argynnidæ," of our Diurnal Lepidoptera, (two of my favourite families,) but at the request of some of my friends, I am going to give you a rough outline of the entire trip, trusting that I may be enabled to make it of more interest to you, by exhibiting a few of the specimens and relics picked up by the way.

With this short preface and with your kind indulgence, I will begin:

The different points of interest between here and Winnipeg have been so thoroughly discussed by tourists of late years that it is needless for me to refer to my trip until a start is made from Winnipeg on June 9th, 1883.

The main object of this journey, was to make a collection of insects and especially of Rhopaloceres or the day butterflies, the first of the two great divisions into which the Lepidoptera have been divided. The different species of this division all fly by day: they have the antennæ terminated by a knob or club and comprise the Papilionidæ, Pieridœ, Lycœnidæ, Erycinidæ, Litytheadæ, Satyridæ, Hesperidæ, and so on.

The Heteroœres, the greater portion of which fly by night, embrace the Sphingidæ, Bombycidæ, Noctuæ, Geometridæ, &c., &c. In this division the most noticeable feature of distinction is the antennæ, which are of a feather-like appearance and taper to a point at the ends instead of the knob or club that the majority of the diurnals have.

I do not intend to enter into detail with regard to the species which I captured *en route*, but more to give a brief sketch of the trip and the beauty of the country through which I passed, as well as the barren parts.

After leaving Brandon on the 11th June, the next point of interest was Moosomin where we lay over a day, to visit Fort Ellis and Binscarth. The former is an old fort under the charge of Mr. W. J. McLean, a faithful officer of the H. B. C. The party with whom I was travelling were going on to Binscarth, the "stock farm," and property of the Scottish Ontario Co.

As Mr. McLean offered me the hospitality of the Fort, I decided to remain over and make such additions to my collections, as were to be taken in the neighbourhood of Fort Ellis.

I was well rewarded for my pains, as I succeeded in making some rare captures. Fort Ellis is situated 30 miles from the C. P. R. track and about 20 miles from Binscarth.

Here the Blackfeet and the Sioux Indians, (principally the former) were congregated in large numbers around the Fort. Their "tepees" or lodges were thick in every direction, and I had the opportunity of seeing how the Government agents distributed the pork, flour and blankets to those Indians who deserve them.

I was advised to go out with some of the squaws of the Blackfeet tribe, and get some wild turnips, though *why* they are so called, I never could and never will imagine. The root of the plant resembles the bulb of a small tulip, and when the outer skin is removed, the heart of the bulb tastes something like the kernel of an almond and quite as dry. The leaf of the plant reminded me of the lupin (perenniel), but it was too early in the season to take the flower, as a specimen.

The women of the Blackfeet and Sioux seem particularly partial to these roots. Armed with genuine "crow-bars" of *iron*, about four feet in length and from one and a-half inches to 2 inches in diameter, we sallied forth. It was a matter of amazement to me, to see the manner in which the squaws handled these iron bars. On the side of a steep hill they would let themselves down and holding on to a shrub, or the end of a rock with one hand they would with the other hand wield the bar (always pointed at the end) and soon the roots, which were generally about four inches to six inches down in the soil, would be dislodged. I tried to handle one of these bars myself and as I had to use two hands and the combined strength of my two arms to boot, I appeared to cause much merriment to my redskin friends, who looked upon me as a very poor specimen of the human race. I had a chance of purchasing a few samples of the bead-work of the Sioux women, a few articles of which I have brought with me, also one or two of their favourite pipes.

On the 15th June we reached Medicine Hat and the end of the track of the C. P. R., which had just then crossed the Saskatchewan River on a temporary trellis-work bridge. Here we had an opportunity of witnessing the wonderful rapidity with which this road was constructed; the contractors at that time were building from three to five miles a day.

On June 25th we started for Calgarry. On the 27th we reached the Bow River. The mosquitos were terrific. During the night our camp was set on fire by Indians, who hoped to make a stampede with our horses. Luckily, we discovered the grass on fire in two places, in time to put it out with wet blankets, and so saved our property.

The flora between Calgarry and Edmonton (my next halting-place) was simply lovely. The orange and cardinal lilies, or, as the Cree Indians call them, "Wappiconnaisa," the yellow ladies' slippers, anemones, wild rhubarb blossom, 4 feet high, and the plumed head of that lovely flower, Geum Triflorum, made a charming contrast to the innumerable shades of green of the foliage. As one looked into the different "coolies" and "hollows" in the prairie in passing, it appeared to be like a rich carpet of most exquisite workmanship and colouring, but far, far more beautiful.

Upon the 7th July we reached Edmonton, and it became apparent that we were getting much farther to the north, as the days were so long and the nights so very short. I was surprised to hear from the proprietor of the hotel at Edmonton that upon the Sunday previous to our arrival he had put green peas from his own garden upon the table for his guests at dinner. I was not so much surprised however to see what he showed me the same evening we arrived, and that was half a field of beautiful potatoes cut off by the summer frosts and looking as black as ink alongside the other half, which had escaped. It was just as if some one had taken a ruler and drawn a line from one corner of the field to the other, and then painted one half black and the other green. I was very much disgusted with the cold and windy weather that we had at this point. It was impossible to collect butterflies and moths, and I was not at all sorry to start off again for the south.

On July 16th we reached Calgarry on the return trip. Here I met some old friends, and on the 19th July started off for Fort Macleod. This was a very interesting part of the trip, as we stopped at several ranches, amongst them "Oxley Ranche," the property of Mr. Staveley Hill and other English gentlemen, and the ranche of Mr. Stinson at High River. I must not forget to mention that at all the ranches I stopped at on my long journey and at all the posts of the Hudson Bay Co., I received the greatest hospitality, likewise from the N. W. Mounted Police. Whilst amongst the ranches I learned that the cow-boy's whip was called a "Quoit;" the rope for catching horses in "corral" is called a "Mecarte," a "Lariet" being a grass rope for the same purpose. "Chaps" or "chaparellos," are the leather breeches or leggings used for riding, and so on.

On July 24th I spent a rare day of collecting at Pincher Creek, being then the guest of Lieut.-Col. Macleod; also three or four days following I did good work, taking Argynnis Clio, Argynnis Artonis, as well as many rare Coliadæ.

Aug. 1—At the Garnett Ranche, a lovely Ranche in the foot-hills of the Rockies, where the peaks of the mountains tower above one over three sides of the ranche. Here I took many rare insects.

I met Dr. George Dawson, of the Geological Survey of Canada, and his party, at the Garnett Ranche. He had just returned from the Crow's Nest Pass, with specimens of natural history *generally*, but with notes upon the geological formations of the country *in particular*. I took here a new Polyomatus or Chrysophanus called Florus by Mr. W. H. Edwards, of Coalburgh, West Virginia).

Whilst a guest at the Garnett Ranche, I went out with one of the proprietors to get some trout. When I was catching butterflies, he was catching trout, averaging about 1½ lbs. each. He took 17 fine fish in a very short time. Upon the 4th August we reached our camping ground at the Crow's Nest Pass, and a lovely spot it was. Through the kindness of Col. Macleod, I was enabled to take along with me a folding boat made of canvas, with which we explored the lakes near the summit of the mountains known as the "Big Fish Lakes," and judging from the size of the fish taken, the name was very appropriate. I did some rare collecting through this new country, taking the ♀ Hermodur, a species described by Mr. Henry Edwards as a var. of Parnassius Smintheus, also Arg. Chariclea and Arg. Boisduvallii, Chrysophanus Mariposa and Thecla Edwardsii, one solitary specimen. We met large bands of the Stoney Indians throughout this Pass, who were trapping, shooting, and fishing. The Indians supplied us with meat from the mountain sheep or big horn (Ovis Montana), which made a delicious steak when broiled, reminding one both of mutton and venison. The band of Indians who were camping close to us were trapping beaver, and hunting bear and sheep, principally.

Whilst at Big Fish Lake, I saw three fine trout caught (more than once) at one cast, by Mr. Arthur Garnett, one of the most experienced fishermen I have ever met. I may say that our living here was really luxurious, after feeding on fat pork and porridge for a long time, the variety in our fare was most welcome, I can assure you. Let me advise any of you, gentlemen, who ever go for a trip to the Mountains to be well provided with fishing tackle, and lots of it, besides a good rifle, and shot gun as well. These articles are infinitesimally small in comparison with the "prog" you would have to pack your horses with, and with a bag of flour and some bacon you can live well. It is not absolutely necessary to take canned meat and vegetables along with you, as many explorers do, for in this lovely country you are independent, so to speak, with the quantity of fish and game that is always on hand in the neighbourhood.

After reaching the summit of the Mountains here, and returning to my headquarters in camp, we started back to the District of Old Man's River. Upon August 15th, I found myself at the Belly River District, from which place I started for the Koutanai Lakes. All through this beautiful grazing country, I was perfectly delighted with everything I saw.

The ranchers were all busy taking in hay for winter emergencies, although it is seldom required, for the snow is seldom too deep for the cattle to scratch it up to feed on the long grass underneath. The Chenook wind which blows through the mountains from the Pacific Ocean, melts the snow nearly as soon as it makes its appearance, and wheeled vehicles, principally heavy carts and buck boards supply the place of sleighs. From the Muirhead Ranche, I started out for the so-called Koutanai Lakes, where I was successful in capturing many fine butterflies, amongst them *Argynnis Leto*, ♂ and ♀.

The guide who took me up to the Lakes killed two grisly bears whilst I was in this part of the mountains, and I brought the skins back with me as a memento of the trip.

The name of the hills that one meets with on the prairie is " bute " and " cooley " or " lie " is applied to all hollow spots or valleys.

I must warn all who may be disposed to make a summer excursion through the mountains to the British Columbia side, to be well provided with a musquito-net ; I mean by this not only the small nets to wear over one's head and neck whilst riding or driving, but a strong net, capable of being fastened to the tent inside, and covering one's entire body at night time.

It may not be out of place here to relate one or two anecdotes about the extraordinary numbers of musquitos that infest the entire district through which I passed—not forgetting to mention the blackflies, sand-flies, horse-flies or " bull-dogs " as the old settlers call them, and the greatest *torment* of all the flying ants.

I remember one evening after we had pitched our tent for the night, and just about dusk, I set off with one of my fellow-travellers to inspect a curious rock, which was standing upright in the midst of a vast plain, with no other sign of stones or gravel of any kind anywhere near it. Our fire in the camp had driven the musquitos away from the immediate neighbourhood, and for the time I quite forgot the existence of these pests. My friend was wearing a dark blue pea-jacket and walked before me. Fortunately he was provided with a net to cover his face, but I had foolishly left mine behind. As soon as we stirred up the long grass with our feet, the musquitos arose in myriads, and after fighting them off for a short time, I looked ahead at my companion, and I declare I could not tell what colour his coat was, so thickly was his back covered with the insects, I confess that this was too much for me, and I turned and fled to the camp as fast as my legs would carry me in a most ignominious fashion.

In case you have not seen a "smudge" or read of one, I will describe it. A "smudge" is a refuge for horses and cattle that are attacked by flies and mosquitos. A "square" of logs dove-tailed at the four corners, is constructed just high enough to allow a horse standing up to put his head over the topmost log. Inside this square and on the ground you set fire to leaves and grass, and pile on to this wet foliage of plants, and make a heavy suffocating smoke. The horses will run madly towards this smoke from wherever they may be and hold their heads where the smoke is thickest. It is absolutely necessary to build a barricade of logs round these fires, as the horses will burn themselves in the fire often rather than suffer the torment of the flies.

Whilst driving one day to the Koutanai Lakes we had to pass through a cloud of black flying ants. My guide and I were both well covered up, but he had on a light-coloured felt hat which seemed to have some peculiar attraction, for they attacked him vigorously; there was a small opening at the back of his neck between his hat and the top of his coat-collar, and the ants fairly gnawed away that portion of his neck which was exposed. We came across a very intelligent man who acts as guide to exploring parties in the Koutanai District. He lives in a most lonely situation, quite near the mouth of the Koutanai Pass. He is familiarly known as Koutanai Brown, and I would recommend any one going to that solitary neighborhood to patronize this guide. He is a dead shot with a rifle and an excellent fisherman. He makes his living by trading to some extent with the Indians and shooting sheep and bears, himself. We had plenty of bear's meat while with Koutanai Brown. But as it had been dried in the sun, (and not smoked) it was decidedly "odoriferous," and I preferred watching the others enjoy it and partaking of salt pork instead.

I would like to call your attention on the map for a moment to the stretch of country lying between the Red Deer River and Fort Edmonton. Here the shrubs begin to appear as trees, and the trees increase in size as one proceeds north. Very fine timber is to be had in and around Edmonton and all along the banks of the Saskatchewan. Amongst all the farmers we met between Calgarry and Edmonton (with one exception), the opinion expressed as to the quality of the land and the nature of the climate, was unanimous. All agreed in saying that although the winters were severe, yet they could grow such fine crops and so rapidly, that the brief summer was amply long to mature the grain and get it harvested.

In conclusion, I have with me a list of the diurnals taken by me during this tour, and for the benefit of those entomologists who are present, I have looked it over and will call their attention to several of the species which are rare and which I will be glad to point out to them in my cases. I regret that I could not bring my cabinets down here to show my collection to the members of the Institute, but I will only say to those who are interested in this fascinating study, that it will afford me the greatest possible pleasure to look over my cabinets at Government House with them at any time that I may be honoured by a visit.

Thanking you gentlemen, for your kind attention, and trusting that I have not been encroaching too much upon your time, I beg to conclude.

## LIST OF DIURNAL LEPIDOPTERA COLLECTED IN THE NORTH-WEST TERRITORY AND THE ROCKY MOUNTAINS.

1. Papilio Asterias, F. Edmonton.
2. " Troilus, L. Fort Macleod.
3. " Turnus, L. "
4. " Glaucus, L. "
5. " Eurymedon, Bd. Seen but not taken.
6. Parnassius Smintheus, Doubd. Crow's Nest Pass.
7. Dark var. Hermodur, H. Edw. Summit Pass.
8. Pieris Oleracea, Boisd. Kootanai.
9. " Occidentalis, Reak. Pincher Creek.
10. " Protodice, Boisd. Belly River.
11. " Rapæ, L. N. W. T.

12. Anthocaris Olympia, Edw. (v. rare). Summit.
13. " Ausonides, Boisd. Calgarry.
14. Colias Christina, Edw. Red Deer River.
15. " Occidentalis, Scud. (rare). Edmonton.
16. " Edwardsii, Behr. (rare). Edmonton.
17. " Astrea, Edw. (♀ new). Red Deer River.
18. " Alexandra, Edw. (rare) 5,000 ft. elevation Rocky Mountains.
19. " Eurytheme, Boisd. (rare). None taken W. of Moose Jaw.
20. " Hagenii, Edw. Fort Macleod.
21. " " " (diminutive form). Fort Macleod.
22. " Scudderii, Reak. Koutanai.
23. Argynnis Lais, N. S., Edw. Fort Edmonton.
24. " Cybele, F. " "
25. " Baucis, Edw. (not proved new yet). Fort Edmonton.
26. " Coronis, Behr. Belly River.
27. " " (dark varieties). Crow's Nest.
28. " Chariclea, Schneid. Crow's Nest.
29. " Boisduvalii, "
30. " Atlantis, Edw. "
31. " Eurynome, Edw. Belly River.
32. " V. Erinna. Red Deer River.
33. " V. Arge (?), Streck. Calgarry.
34. " Clio, Edw. (v. rare). Crow's Nest.
35. " Monticola, Behr. (v. rare). Summit.
36. " Edwardsii, Reak. (v. rare). Blackfoot Reserve.
37. " Artonis, Edw. (v. rare). Koutanai.
38. " Myrina, Cram. Edmonton.
39. " Aphrodite, F. "
40. Melitæa Nubigena, Behr. Crow's Nest.
41. " Palla (?), Boisd. "
42. " Chalcedon (?), Boisd. Garnett Ranche.
43. " Leanira. " "
44. Limenitis Disippus, Godt. Crow's Nest.
45. " Lorquini, Boisd. "
46. " Arthemis, Drury. N. W. T.
47. Vanessa Milberti, Godt, N. W. T.
48. " Antiopa, L. N. W. T.
49. Pyrameis Atalanta, L. N. W. T.
50. Grapta Satyrus, Edw. Crow's Nest.
51. " Progne, Cram. Fort Macleod.
52. Danais Archippus, F. Common.
53. Chionobas Chryxus, West (v. rare). Summit.
54. " Varuna, Edw. Calgarry.
55. " Uhleri (?), Reak. "
56. Erebia Epipsodea. Butl. Fort Ellis.

57. Satyrus Charon, Edw. Garnett Ranche.
58. " Silvestris, Edw. "
59. " Nephele, Kirby. Rocky Mountains.
60. " V. Boopis, Behr. "
61. " V. Ariana, Boisd. "
62. " V. Olympus, Edw. "
63. Cœnonympha Inornata, Edw. Calgarry and Edmonton.
64. " Ochracea, Edw. " "
65. Phyciodes Carlota, Reak. Brandon.
66. " Tharos, Drury. Edmonton.
67–68. Several varieties from North of Edmonton. Not determined.
69. Thecla Titus, F. Old Man's River.
70. " Edwardsii, Saund. (rare). Summit.
71. Chrysophanus Mariposa, Reak. (v. rare). Summit.
72. " Florus, Edw., Nov. Spec. (v. rare). Garnett's Ranche.
73. " Helloides, Boisd. Oxley Ranche.
74. " Americana, D'Urban. "
75. " Sirius, Edw. (v. rare). Fort Macleod.
76. Pyrgus Tessellata, Scud. Medicine Hat.
77. Amblyscirtes Vialis, Edw. (v. rare). Fort Ellis.
78. Thymelicus Garita, Reak. Fort Ellis.
79. Thanaos Brizo, Boisd. Fort Ellis.
80. Eudamus Pylades, Scud. "
81. Lycæna Anna, Edw. Belly River.
82. " Amyntula, Boisd. Calgarry.
83. " Sæpiolus, Boisd. Crow's Nest.
84. " Rustica. Fort Qu'Appelle.
85. " Pembina, Edw. Crow's Nest.
86. " Afra, Edw. Nov. Spec. Saskatchewan.
87. " Unknown Spec. sent for identification. Garnett Ranche.
88. Pamphila Zabulon, Bd. Lec. Calgarry.
89. " Manataaqua, Scud. (v. rare). Fort Macleod.
90. " Manitoba. Belly River.
91. " Uncas, Edw. "
92. " Cernes, Bd. Lec. Crow's Nest.
93. Argynnis Leto ♀, Behr. Fort Macleod.
94. " Bellona F. Fort Ellis.
95. Lycæna Fulla, Ew.
96. " Melissa Edw. Oxley Ranche.
97. " Neglecta, Edw. Fort Ellis.
98. " Lygdamas, Doubld. Fort Ellis.
99. " Icaroides, Bd. Red Deer River.
100. Pamphila Nevada, Edw. (?) Fort Macleod.
101. " Colorado, Scud. Medicine Hat.
102. " Idaho, Edw. Moose Jaw.

103. Pyciodes Camillus, Edw. Edmonton.
104. " Marcia, Edw. Edmonton.
105. " Nycteis, Doubld. Edmonton.
106. Argynnis Nevadennis, Edw. Calgarry.

The President, Dr. Bryce, Mr. Chas. Levey and Mr. B. B. Hughes took part in the discussion which followed.

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## TWENTY-FOURTH ORDINARY MEETING.

The Twenty-fourth Ordinary Meeting of the Session 1883-84 was held on Saturday, April 26th, 1884, the President in the chair.

The minutes of last meeting were read and confirmed.

The nomination of Office-bearers and Members of Council was made.

A communication was read from Mr. W. Thompson, President elect of Section A of the British Association for the Advancement of Science, giving notice of special discussions in the Section of Mathematical and Physical Science.

The following list of donations and exchanges was read :

1. Journal of the Transactions of the Victoria Institute, Vol. 17, No. 68.
2. List of Members, Council, &c., of the Royal Society of Edinburgh, November, 1883.
3. Science, Vol. 3, No. 63, April 18, 1884.
4. Ninth Annual Report of the Ontario Agricultural College and Experimental Farm for 1883.
5. Report of the Entomological Society of Ontario for 1883.
6. Science Record, Vol. 2, No. 6, April 15, 1884.
7. Report of Speeches at the Annual Dinner of the Institution of Civil Engineers, March 26, 1884.

Mr. Henry S. Howland, jun., then read a paper entitled,

## "THE ART OF ETCHING."

Mr. Howland opened his subject with the following words :

" Very often we, who are engaged in mercantile life, seem to lose sight of the great value of having some interests, some tastes and some pursuits independent of, and in many ways directly opposite in their influence, to our regular business—something to engage our leisure moments, to keep us from becoming too much absorbed in the mere material and hardening act of money-getting, and at the same time by directing our thoughts into a different course, to be a wholesome recreation to our minds and a means of ennobling our hearts.

"Our long and wearisome days of business are usually spent in work without much change, our whole attention directed to practical things the poetical instincts of our natures receiving no culture, and so lacking development, unless quickened into life and activity by some powerful influence. * * *

"Now, while not at all asserting that we should not give to our business the care and attention which it may need, for indeed to make a true success of it, it must be uppermost in our thoughts, but just because of that very thing, because man, by the very constitution of his nature, needs variety and change, or he will develop into a mere machine, or, perchance, his health may fail, he must become interested in something else. And while giving to science and philosophy the tribute of respect and admiration which is their due, I insist that poetry, that painting, that architecture, that music, the fine arts in fact, will appeal to something in man's nature, which science, philosophy, the professions, or branches of mercantile industry, cannot reach. There is a part of man's nature which responds to beauty as to an electric thrill."

Mr. Howland then gave a brief history of the "Art of Etching" as first practiced by Dürer about 1518, with its bright and its dark days, to its decline and comparative obscurity at the commencement of the present century, with its revival about 1860, and gradual growth in popularity to the present day.

The practical part was then carefully described, Mr. Howland illustrating the processes and modes of treatment, with plates and implements used. "Etching really means drawing upon a plate, generally of copper, which has previously been coated with a varnish-like substance called *ground*, with a point which removes the varnish wherever it touches, and then subjecting these exposed parts to the biting of an acid, so as to leave actual hollows in the metal."

Mr. Howland mentioned the names of Haden, Hamerton, Palmer, Whistler, Chattock, Law, Lelanne, Méryon, Jacquemart as being the leading etchers in Europe.

In America Stephen Parish, of Philadelphia, probably stands the highest, and we owe a great deal to such men as Henry Farrer, Thomas Moran, J. T. Bentley, F. S. Church, R. S. Gifford, Wm.

Sartain, J. C. Nicoll, Jas. D. Smillie, K. Van Elten, Walter Shirlaw, J. F. Sabin, F. Diel man, J. F. Cole, E. H. Miller, P. Moran, M. N. Moran, Samuel Coleman, for the work they have given us.

Mr. Howland expressed himself especially indebted to Mr. Stephen Parish, who was very generous in lending him a plate on which he had etched a picture called "An Old Acadian Inn-yard." Mr. R. J. Kimball, of New York, was very kind in sending a plate by Mr. Henry Farrer, President of the "New York Etching Club."

Mr. J. F. Bentley, a Canadian, now living in New York, kindly sent a large artist's proof of his picture called the "South Porch of St. Ouen."

Thanks are due to Mr. Jardine, Secretary of the "Ontario Society of Artists," for his kindness in lending a large collection of etchings. Not only did he volunteer the pictures, but he spent the greater part of an afternoon in hanging them.

Mr. Howland ended his paper with a short description of the beauties of etching, illustrated by a large number of etchings from the time of the invention of the art to the present day, and hoped that, the appreciation and support of this attractive art would go on increasing.

"When the artist by his skill awakens in those who view his pictures feelings or emotions similar to the promptings he had in the conception of his work, he is much nearer true art than when, by careful and minute detail, he gives the conscious feeling of reality. Hence in this particular, etching really seems well adapted for expressing the highest art. Something is given to awaken thought, rather than a passing pleasure only."

After the reading of the paper, the members present were invited to inspect the etchings which Mr. Howland had collected to illustrate his subject.

## THIRTY-FIFTH ANNUAL MEETING.

The Thirty-fifth Annual Meeting was held on Saturday, May 3rd, the Second Vice-President, Mr. George Murray, in the chair.

The Minutes of last Annual Meeting were read and confirmed.

The following list of donations and exchanges received during the preceding week was read :

1. Science, Vol. 3, No. 64, April 25, 1884.
2. Verhandlungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte, Sitzung vom 20 Jan., 10 Feb., 17 Feb., 17 März, 21 April, 19 Mai, 16 Juni, 21 Juli, 20 October, Nov. 17 and 24, Dec. 15, 1883. 12 Numbers.
3. Report of the Canadian Observations of the Transit of Venus, 6 December, 1882.
4. (1) Bulletin of the Natural History Society of New Brunswick, No. 3, 1884.
   (2) Annual Report of New Brunswick Natural History Society. Memorial Sketch of Prof. Ch. Fred. Hartt, by George U. Hay.
5. Bulletin of the Museum of Comparative Zoölogy at Harvard College, Cambridge.
   Vol. 1, Complete.
   " 2, Nos. 2–5.
   " 3, " 3, 6–16.
   " 5, " 1, 7–12, 14–16.
   " 6, complete.
   " 7, Nos. 2–10.
6. Journal of the Franklin Institute for May, 1884.
7. Journal of the Microscopical Society for April, 1884.
8. The Canadian Practitioner for May, 1884.
9. Proceedings of the Worcester Society of Antiquity for 1883, No. 20.

The following gentlemen were elected Honorary Members of the Canadian Institute :

Daniel Wilson, LL.D., Rev. John McCaul, D.D., Prof. Balfour Stewart, (Owen College, Manchester,) and the Abbé Provencher, Cap Rouge, Quebec.

The Hon. Secretary read the Annual Report of the Council as follows :

## ANNUAL REPORT, SESSION 1883–84.

The Council of the Canadian Institute have the honour to lay before the members their Thirty-fifth Annual Report.

The attendance at the weekly meetings has been satisfactory, and a large number of papers have been read. These will compare favorably in average merit with those of any preceding Session. In addition to the regular work of the Institute, a course of three popular public lectures on sanitary subjects was arranged for and delivered in the Library under the joint auspices of the Institute and the Provincial Board of Health. The lecturers were Dr. Oldright, Dr. Cassidy and Dr. Bryce.

The number of members has increased from 225 to 236, and a larger number than heretofore have made use of the reading-room and library. As will be seen by reference to one of the appendices to this report, the number of books and periodicals taken out by members has nearly doubled. The number of Societies with which we exchange publications is now 140. The number of donations and exchanges received has been 800, as against 280 during the preceding year. One hundred and twenty volumes have been bound, and eighty volumes and numbers purchased to complete sets. It is much to be desired that funds should be forthcoming to bind the whole of the 700 volumes that are now awaiting the binder.

A change has been made in the method of publishing the Proceedings, which, it is believed, will have the effect of rendering our transactions more acceptable to our members without rendering them less valuable to other Societies.

The Council having devoted so much attention to the Library, Reading-room, Journal and Exchanges, has not been able to put the collections in the museum in order or increase them. This department, however, has not been altogether neglected. A few valuable skins have been stuffed, and the very handsome offer made by Mr. Brodie to furnish a collection of insects, provided the Institute supplied cases, has been accepted, and a number of cases have been placed at his disposal.

Herewith are submitted appendices, showing (1) the membership, (2) the financial condition of the Institute, which will be found very satisfactory, (3) the number and sources of the donations and exchanges, (4) the number of books and periodicals issued to members, (5) the list of periodicals subscribed for, and (6) the list of periodicals presented to the Institute, with the names of the donors.

All of which is respectfully submitted.

J. M. BUCHAN,
President.

## APPENDIX I.

### MEMBERSHIP.

| | |
|---|---|
| Number of Members, March 31st, 1883 | 225 |
| Withdrawals and Deaths during the past year | 25 |
| | 200 |
| Elected during the Session 1883-84 | 36 |
| Total number of Members, April 1st, 1884 | 236 |
| *Composed of:* | |
| Corresponding Member | 1 |
| Honorary Member | 1 |
| Life Members | 17 |
| Ordinary Members | 217 |
| Total | 236 |

## APPENDIX II.

TREASURER IN ACCOUNT WITH THE CANADIAN INSTITUTE, SESSION OF 1883-4.

| | $ cts. |
|---|---|
| To Summary | |
| " Balance on hand | 689 04 |
| " Annual Subscriptions | 588 00 |
| " Rents | 179 50 |
| " Journals Sold | 17 25 |
| " Interest on Deposits | 17 10 |
| " Freight | 1 20 |
| | $1,492 09 |

| | $ cts. |
|---|---|
| By Summary | |
| " Salaries | 286 47 |
| " Periodicals | 244 34 |
| " Interest on Mortgage | 238 78 |
| " Printing | 222 79 |
| " Fuel | 142 23 |
| " Postage | 78 07 |
| " Express | 34 82 |
| " Gas | 42 19 |
| " Furniture | 32 80 |
| " Stationery | 25 92 |
| " Repairs | 24 39 |
| " Water | 24 00 |
| " Contingencies | 14 30 |
| " Taxes | 9 49 |
| " Cash in Bank | 71 50 |
| | $1,492 09 |

*Assets.*

| | |
|---|---|
| Building | $11,000 00 |
| Warehouse | 720 00 |
| Ground | 2,500 00 |
| Library | 5,500 00 |
| Specimens | 1,200 00 |
| Personal Property | 400 00 |
| | $21,320 00 |

*Liabilities.*

| | |
|---|---|
| Mortgage | $3,411 00 |
| Balance in favour of Institute | 17,909 00 |
| | $21,320 00 |

Examined, compared with vouchers and found correct.

E. A. MEREDITH, } *Auditors.*
J. GALBRAITH, }

14th April, 1884.

## APPENDIX III.

### DONATIONS AND EXCHANGES.

Books and Pamphlets received from—

| April 1, 1882, to April 1, 1883. | | April 1, 1883, to April 1, 1884. | |
|---|---|---|---|
| Canadian | 30 | Canadian | 90 |
| United States | 60 | United States | 300 |
| Great Britain and Ireland | 100 | Great Britain and Ireland | 200 |
| India, and other British Colonies, exclusive of Canada | 20 | India, and other British Colonies, exclusive of Canada | 40 |
| Foreign | 70 | Foreign | 170 |
| Total | 280 | Total | 800 |

The number of Societies with which the Institute exchanges is.. 140

The following are the principal Institutions that have supplied back numbers of their publications to completed sets.

Smithsonian Institution.
Essex Institute.
New York Academy of Sciences.
Academy of Natural Sciences, Philadelphia.
Worcester Society of Antiquity.
Harvard University Library.
Museum of Comparative Zoölogy at Harvard College.
Connecticut Academy of Arts and Sciences.
Historical Society of Pennsylvania.
Peabody Institute, Baltimore.
Entomological Society of Ontario.
Royal Scottish Society of Arts.
Anthropological Institute of Great Britain and Ireland.
Cambridge Philosophical Society.
Leeds Philosophical Society.
Royal Geological Society of Ireland.
Royal Dublin Society.
Royal Colonial Institute.
Royal Geographical Society.
Institution of Civil Engineers, G. B.
The Victoria Institute.
The Linnean Society.
New Zealand Institute.
Naturwissenschaftliche Gesellschaft "Isis," Dresden.
The Literary and Philosophical Society, of Liverpool.

NOTE.—The donations presented by the above, and some others have already been given in detail.

### APPENDIX IV.

The number of books and periodicals issued to members :—

| | | |
|---|---|---|
| (1) | From April 1, 1882, to April 1, 1883 | 450 |
| (2) | " " 1, 1883, " 1, 1884 | 860 |

### APPENDIX V.

List of periodicals subscribed for :—

American Journal of the Medical Sciences.
Athenæum.
Atlantic Monthly.
Blackwood's Magazine.
Brain.
British Quarterly Review.
Builder.
Century Magazine.
Contemporary Review.
Critic.
Edinburgh Review.
English Mechanic.
Fortnightly Review.
Graphic.
Lancet.
London Quarterly Review.
Longman's Magazine.
Macmillan's Magazine.
Mind.
Nature.
Nineteenth Century.
North American Review.
Popular Science Monthly.
Princeton Review.
Punch.
Scientific American.
Scientific American Supplement.
Times, Weekly.
Westminster Review.

To the above have been added for the current year :—

Illustrated London News.
Saturday Review.
English Illustrated Magazine.
Harper's Monthly Magazine.
The Week.

The following were discontinued at the end of 1883 :—

The Builder.
St. James's Gazette.
Critic.
The Medical News.

### APPENDIX VI.

Periodicals presented to the Institute, and the names of the donors :—

*Das Echo*—W. H. VanderSmissen, Esq., M.A.
*Le Temps*, Paris—Dr. C. W. Covernton.
*Spectator*—Prof. Hutton.
*Le Figaro*, for 1883. } Geo. E. Shaw, Esq., B.A.
*Le Courrier de l'Europe, for 1884.* }

On motion of Mr. J. C. Dunlop, seconded by Mr. Alan Macdougall, the Report was adopted.

The following Officers and Members of Council nominated at last meeting were elected for the ensuing year :

President, W. H. Ellis, Esq., M. A., M. B.
First Vice-President, George Murray, Esq.

Second Vice-President, George Kennedy, Esq., M. A,, LL.D.
Third Vice-President, E. A. Meredith, Esq., LL.D.
Treasurer, John Notman, Esq.
Recording Secretary, James Bain, jun., Esq.
Corresponding Secretary, W. H. VanderSmissen, Esq., M. A.
Librarian, George E. Shaw, Esq., B. A.
Curator, David Boyle, Esq.

MEMBERS OF COUNCIL.

James Loudon, Esq., M. A., F. R. S. C.
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Alan Macdougall, Esq., C. C., F. R. S. C.
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On motion of W. H. VanderSmissen, M. A., it was resolved: "That in Section III, Par. 6, of the Regulations, the words "an Editor" * be inserted after the word "Librarian."

It was moved by Mr. Alan Macdougall, and seconded by Mr. B. B. Hughes: "That the thanks of the Institute be presented to Mr. J. M. Buchan, the retiring President, in recognition of his valuable services rendered during the past year." Carried.

It was moved by Mr. Macdougall seconded by Dr. Cassidy: "That the thanks of the Institute be tendered to the retiring members of the Council in recognition of their valuable services during their term of office." Carried.

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* The Rev. Henry Scadding, D.D., was elected Editor at a meeting of Council held on May 31st, 1884,

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## ON THE SKIN AND

## CUTANEOUS SENSE ORGANS OF *AMIURUS*.


BY PROF. R. RAMSAY WRIGHT, TORONTO.



[*Read before the Canadian Institute, January the 12th, 1884.*]


The contribution contained in the following pages to the knowledge of the skin and its sense-organs, in one of the commonest of North American Siluroids (*Amiurus catus*), may be regarded as an extension to this species of the results obtained by various enquirers[1] as to these structures in different European Teleosts. No new facts of great importance are recorded, except in relation to certain structures which are apparently comparable to the nerve-sacs of the Ganoids. The description is chiefly based on sections from skin hardened in chromic acid in the manner employed by Pfitzner[2] in his study of the epidermis in Amphibia. Far from complete as a histological study, the account will serve to indicate the chief gaps which exist in our knowledge of the organs concerned, with regard, *e. g.*, to the development and function of the "clavate" cells, the mode of termination of the nerves in the ordinary epithelium, as well as in the neuro-epithelium of the sense organs, &c. The species will commend itself to American Histologists for the investigation of these questions, not only on account of its ready accessibility and the ease

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[1] Especially *Leydig*.
"Ueber die Hautdecke and Hautsinnesorgane der Fische." Halle, 1879.
[2] Morphol. Jahrb. VI., 475.

with which it may be kept in confinement, but chiefly because the entire absence of scales will allow of the application of various histological methods which it is impossible to carry out after decalcification. With the aid of those methods which have been employed in the study of the more difficult points in the histology of the epidermis of higher forms, the skin of *Amiurus* ought to yield more easily than most other Teleosts, results of great interest and probably of general application to the order.

A vertical section of the skin of the head (Fig. 2), indicates the relationship of the various layers of Epidermis and Corium, the elements of which I shall first describe before discussing the peculiarities of the skin in different regions.

The following different kinds of cells may be detected in the Epidermis :—

*a*. Superficial Cells.
*b*. Polygonal Cells.
*c*. Spindle-shaped Cells.
*d*. Palisade Cells.
*e*. Mucus-Cells.
*f*. Clavate Cells.
*g*. Pigment Cells.
*h*. Non-epithelial Elements.

(*a*) *Superficial Cells.*—The superficial epidermal cells are distinguished by their smaller size and flatter form from the underlying polygonal cells. The nucleus, which is always distinct, measures about 4 $\mu$, the layer of protoplasm outside that rather less than 2 $\mu$, while the whole cell is rarely higher than 8 $\mu$. No special cuticular border exists, but all the protoplasm outside the nucleus appears to be denser than the remainder of the cell-body. Although I find it easy enough to detect pore-canals in the cuticule of *Petromyzon*, I fail to see them in the border of the superficial cells in *Amiurus*. Rather a striation parallel to the surface is to be detected. It is possible that other methods of preparation than hardening in chromic acid may show the existence of such. The superficial cells are not always flat, but often triangular, with the apex projecting beyond the free surface. This gives a somewhat irregular superficial outline. Fig. 1.

(*b*) *Polygonal Cells.*—These hardly differ except in size from the superficial cells. The nuclei are much larger, as much as 8 $\mu$, and the cells proportionately large. In preparations where the elements have been dissociated in Müller's fluid, the cells are much more irregular than they appear in sections; and are further rough with the protoplasmic projections, 'intercellular bridges,' which establish connection with their neighbours. In the lower layers they gradually become somewhat changed in outline until they acquire the form of

*(c) Spindle-shaped Cells.*—These form a considerable part of the thickness of the epidermis. In length they may measure as much as 35 $\mu$, their nuclei, from 8-9 $\mu$, occupying the greater part of the breadth of the cell. They form a transition from the more superficial layers to

*(d) The Palisade Cells*, which, however, may be twice as long, and rest with a broad base on the surface of the corium. Under certain changes produced by reagents, the palisade cells are separated, to some extent, from the corium, being still connected with it by protoplasmic filaments. The appearance is then produced of a space separating the two layers and only traversed by the filaments aforesaid.

*(e) Mucus-Cells.*—These are common to all Pisces, and produce the slime which covers the surface of the skin, and which also invests the cavity of the mouth. They appear to be distributed equally over the skin except where they are interrupted by the presence of the cutaneous sense-organs. Sections which have been stained in Bismarck brown are unquestionably best suited to the study of these, the intracellular net-work taking on a most characteristic and vivid stain. The cells are not confined to the uppermost layer of the epidermis, but are formed by the conversion of ordinary lower polygonal cells, which at first acquire a round outline distinguishing them from their neighbours and gradually become considerably large. Thus, a mucus-cell which has not yet reached the surface but is fully grown, may measure 20-25 $\mu$ in length. As the surface is approached the outline becomes more oval, and when the cell eventually opens by a distinct aperture between the ordinary epidermal cells the oval outline is more elongated. The intracellular network which at first appears to be formed of meshes equally strong in different directions then takes on a different character. Its elements are chiefly disposed longitudinally immediately after the expulsion of the little plug of mucin which also stains in Bismarck brown. Then only is

the nucleus visible, being left behind in the basal part of the cell surrounded by a scanty amount of apparently unaltered protoplasm.

*(f) Clavate Cells.*—These gigantic cells, first described by Leydig as 'Kolbenzellen,' enter very largely into the formation of the epidermis in *Amiurus*, as indeed into that of many fresh-water fishes, such as the eel, burbot, and tench. They have also been examined with care by Pfitzner in the skin of salamander larvæ, and are designated by him 'Leydigsche Schleimzellen.'

It is with some difficulty that one succeeds in getting 'clavate' cells (as they may be termed) isolated. After twenty-four hours in Müller's fluid the other epithelial cells fall readily asunder, but the clavate cells are generally surrounded by a sort of capsule formed of the neighbouring ordinary epidermal cells. These may be in time brushed off, but they invariably leave their trace upon the outer surface of the wall of the clavate cell in the form of a reticular sculpture. When freed from the adherent cells the clavate cells of *Amiurus* are found to vary considerably in their form; the smaller ones are rounded or oval, and this is the case also in young fish, but in adults the proximal end tapers and frequently divides extending down towards the corium, but getting no nearer than the row of palisade cells between which the divided ends frequently dovetail. The clavate cell has a distinct wall, which, like the wall of other epidermal cells, is merely the outermost layer of the protoplasm, acquiring a certain amount of independence with the age of the cell. In small cells and in young forms I find the clavate cells filled with a granular substance which has a certain refractive aspect, and contains one large or two smaller nuclei in various stages of separation from each other. In preparations from adult skin the contents of the clavate cells are very different; vacuolation has set in either at one or both ends of the cell, generally at the proximal end first, and the vacuoles which are occupied by a colourless fluid are separated by a network of protoplasm still in contact with the rest of the granular substance. Also in the neighbourhood of the nucleus does vacuolation take place, resulting in a clear area through which only a few protoplasmic fibres straggle from the nucleus to the granular matter. Vacuolation proceeds till very little of the granular matter is left, but that generally assumes a somewhat crescentic outline at the broad end of the cell, forming a sort of cap—'Käppchen'—to the rest of the contents. By the time this process has advanced so far the granular substance has lost much of its granular appearance, has become more homogeneous, and takes on a slight stain from various reagents (red from picrocarmine) which it formerly refused to do.

The larger clavate cells may attain a length of 100$\mu$, when the nucleus if single may be as much as 25$\mu$ in diameter, while if two be present they are rarely more than half that size. The nucleus is generally vesicular, having a distinct membrane, a single distinct nucleolus and a scanty nuclear network, all of which stain with the ordinary nuclear reagents. In spite of the very favourable size for such purpose, and of the fact that nuclei are present in all stages of division, I have not been able to make out distinct nuclear figures; but when the chromatin is not disposed of as above it appears to be scattered in figures, in which it is impossible to detect any plan. Occasionally four nuclei are met with instead of two, and I have even met with cells containing a greater number, without any indication of subdivision of the cell itself.

There can hardly be any doubt that the clavate cells have an important physiological rôle to play. What that is remains still obscure. They are chiefly developed in those forms where the skin is naked, or the scales rudimentary (*Lota*), and no doubt they are engaged in the secretion of some substance which acts as a protection in lieu of these. Their reaction to various staining fluids indicate that this secretion must be very different from that which is the product of the ordinary mucus-cells which are present everywhere throughout the class. Perhaps Pfitzner's suggestion that the secretion may be poured out into the interepithelial spaces so as to prevent the entry of water may not be very far from the truth. It is certain at least in *Amiurus* that there is no aperture to the clavate cell such as the mucus-cell possesses, and their position indicates that lubrication of the surface is not their function. Occasionally a clavate cell may be seen in sections protruding from the surface (Fig. 2), but such appearances are probably due to a defect in the superficial layers of the epidermis, and to the action of the hardening reagents.

*(g) Interepithelial Pigment-Cells.*—I do not remember to have seen the source of these cells discussed; it is possible that developmentally they may belong to the next group. In young stages the interepithelial pigment is very abundant, forming a continuous network of cells only interrupted by the cutaneous sense organs. In the adult skin the individual cells are more independent, and gen-

erally considerably more branched and possessing more delicate processes than the pigmentary cells of the corium.

*(h) Non-Epithelial Elements.*—Certain small bodies of nuclear appearance are met with frequently in the lower layers of the epidermis surrounded by a scanty protoplasm. In size the nuclei agree fairly well with those of the amoeboid cells of the connective tissue. It is possible, however, that preparation with suitable methods might indicate the existence of interepithelial nerves, a matter which deserves investigation since Pfitzner's[1] discovery of the nerve endings in the epidermis of amphibian larvæ.

The following layers are present in the corium of *Amiurus* which does not appear to present any peculiarities in this respect not met with in other osseous fishes :—

(*a*) The pigmentary or papillary layer.
(*b*) The stratified fibrous layer.
(*c*) The adipose layer, or subcutaneous connective tissue.

*(a) The Pigmentary Layer.*—The palisade cells of the epidermis rest immediately upon a 'basement membrane,' from which in hardened preparations they are readily detached, leaving behind them the membrane with a distinct jagged edge. The teeth of the latter are probably protoplasmic processes serving to connect the cells with the underlying structures similar to the 'intercellular bridges' of protoplasm of the higher cells. In the reticular connective tissue which follows the basement membrane are found the vessels and nerves destined for the supply of the epidermis. The pigment cells which are so abundant here are very different in form from the interepithelial pigment cells (Fig. 1); they are much larger and have short lobate processes rarely connected in the adult with those of neighbouring cells. This layer would not deserve exclusively the name of pigmentary layer in young forms, where I find a second almost equally strong layer below the stratified fibrous layer, which disappears, however, in the adult with the exception of a few scattered cells.

As the papillæ vary much in number in different regions of the body the papillary layer is necessarily modified by its projection into these structures which contain exactly the same elements, and are

[1] Morph. Jahr. VII. 726.

generally conical in form. The palisade cells radiate from the papillæ just as they do from the corium itself, and the result is that where the papillæ are frequent, the interpapillary epidermal cells look as if arranged in pockets between them. (Fig. 2).

(*b*) *The stratified fibrous layer* exhibits the disposition so well known in other osseous fishes—strong parallel bundles penetrated at intervals by vertical fibres.

(*c*) Beneath the above is the *adipose layer*, which differs conspicuously both in thickness and in the character of the tissue in various regions, a difference chiefly due to the mode of arrangement of the fat therein. The adipose layer is separated from the underlying muscles by a membrane formed of bundles chiefly parallel to the surface of the skin.

## THE CHARACTER OF THE SKIN IN DIFFERENT REGIONS.

Apart from the modifications induced by the presence of the cutaneous sense-organs, the skin exhibits characteristic peculiarities in different regions. Thus, on the lips the clavate cells are absent, and the mucus-cells also few in number, the ordinary epidermal cells making up the rather exceptional thickness of the epidermis in this region. It is, perhaps, owing to the great numbers of sense-organs that these peculiar elements of the epidermis are absent, because elsewhere, in the immediate neighbourhood of sense-organs, the same peculiarity is noticeable.

The fibrous layer of the corium in the head is generally much thinner than that on the trunk; on the other hand, the subjacent adipose layer is thicker in the former than in the latter region. The epidermis is somewhat thicker on the sides of the head than on the upper and lower surfaces, while on the trunk the reverse obtains. This is apparently due to a greater number of clavate cells in both cases. Again, in the neighbourhood of the vent and urogenital papilla, the clavate cells are absent, or, at any rate, very sparingly represented.

Important points of difference between the skin on the lateral region of the trunk and that of the head may be gathered from a comparison of Figs. 1 and 2. In the former region the papillæ of the corium are few and scattered, and the clavate cells are generally only in a single layer. In the latter the papillæ are so frequent that the epidermis looks on section as if it were arranged in pockets between them. There the clavate cells are in several layers, and they adapt themselves to the exigencies of their position, confined as they are by the papillæ, so that they lie frequently transversely with their narrow ends extending downwards. (Fig. 2.)

The ventral surface is characterized by the total absence of pigment, which is true of the corium as well as of the epithelium.

## ABNORMAL CONDITION OF THE SKIN.

In two successive Springs I have observed certain tumours of the skin of a somewhat spongy appearance which do not appear to be confined to any particular region of the body but are commonest on the head and in its neighbourhood. I have, however, observed them on various parts of the trunk. It is possible that these are to be seen also at other times of the year, but, as they have only attracted my attention in Spring, I supposed at first that they might be somewhat similar to the 'Perlbildungen' described by Leydig, or comparable to the more extensive epidermal changes which take place at the breeding time in many Cyprinoids. That they are not frequent is sufficient indication that they are not normally recurring structures; and Prof. Leydig informs me that the histological change is not of the same nature as that which characterizes the 'Perlbildung.' Their appearance and the condition of their occurrence appear to me to exclude their being merely a reparative proliferation after a wound, and I have arrived at the opinion that we have in these tumours something similar to Epitheliomata.

If a portion of such a tumour be placed in Müller's fluid over night and the epidermis pencilled away, the slender papillæ stand up from the corium so as to form a sort of pile on its surface. The dissociation of the epidermis takes place much more readily than in normal skin, partly owing to the fact that the superficial layers, especially that bearing the cuticular border, have disappeared, partly owing to infiltration into the interepithelial spaces. The altered papillæ instead of being short, simple and cylindrical, may attain a length of over 1 mm., be much branched, and sometimes flattened and palmately branched. For the nourishment of the increased epidermal surface, the vascular networks of the papillæ are much richer, and an increased number of pigment cells are observable. Although the papillary layer of the corium is thus increased in thickness, the fibrous layer is much thinner than in the neighbouring unaffected parts of the skin. The nature of the cells, which fill up the interpapillary spaces, varies according to the part of skin where the tumour is attached. On the lips, for instance, where there are no clavate cells, the interpapillary spaces are chiefly occupied by spindle-shaped cells, but elsewhere, where clavate cells occur, these also are proliferated, being found in regular nests such as are represented in Fig. 3. Everything indicates rapid division, but no further peculiarity has attracted my attention nor can I furnish any explanation of the appearance of these, no doubt, pathological growths.

## CUTANEOUS SENSE ORGANS.

Within recent years important contributions to the knowledge of the sense organs lodged in the skin of Teleosts have appeared. Following up his earlier researches Leydig[1] has recently described those of *Esox*, *Gasterosteus*, *Acerina* and *Lota*. Solger[2] has studied the organs of the lateral line in various forms, and Bodenstein[3] has given a careful description of those of *Cottus gobio*.

I have not had access to Merkel's work[4] in which[5] a sharp distinction is drawn between two classes of cutaneous sense organs. Those which he terms 'End-knospen,' (end-buds), the 'beaker-shaped sense-organs' of Leydig, are lodged on papillæ of the cutis, and, although freely distributed over the skin and in the mouth cavity of Teleosts, are only found in the latter situation in higher vertebrata, where they reappear as taste-bulbs. To the second class belong the end-organs of the nerves, which are distributed to the lateral line and the 'mucous' canals of the head. Merkel terms this second class 'Nervenhügel,' (nerve-hillocks), and points out their tendency to withdraw themselves for protection from the surface of the integument within more or less completely closed canals, although, primitively, all nerve-hillocks are free and exposed to the surrounding medium (except for a protecting tube of cuticular origin), and in some species such 'free-organs' are alone present. The end-buds, on the other hand, are always flush with the surface, certain of the elements even projecting beyond it, and indeed may be carried beyond the general level of the integument where tactile sensibility is at its highest development, as in the Kentucky blind-fish (*Amblyopsis*), the Indian Cyprinoids recently described by Leydig, and, in fact, in

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[1] *l. c.* p. 22, et seq. [2] Arch. mik. Anat. XVIII., 384. [3] Zeit. wiss. Zool. XXXVII., 121.
[4] "Ueber die Endigungen der sensiblen Nerven in der Haut der Wirbelthiere."
[5] *Vide Wiedersheim* Lehr. der vergl. Anat. S. 358.

the Siluroids, where the barblets, like the pectinated ridges on the head of *Amblyopsis*, are little else than carriers of such end-buds.

F. E. Schulze had already pointed out the difference in form of the sensory cells in these two kinds of end-organs, those of the nerve-hillocks being short and conical in form, while those of the end-buds are long and rod-like. That this difference of form corresponds also to a difference of function has been rendered certain by the study of the nerve supply of the nerve-hillocks, and many facts point to the truth of Mayser's suggestion that we have in the 'mucous' canals of the head and of the lateral line with their contained nerve-hillocks, a low form of auditory organ. In describing further on the origin of the nerves distributed to the mucous canals of the head in *Amiurus*, we shall find further support for Mayser's theory.

This sharp distinction between the two classes of organs does not appear to be recognized by Leydig, who finds that in the pike the organs of the lateral line and the beaker-shaped organs agree essentially in their structure. My observations on *Amiurus* convince me that the neuro-epithelium has a very different character in the two sets of structures in that genus. As I have no new details to offer with regard to the structure of the end-buds, I shall only devote a short space to the description of their situation, number and form.

*(a) End-Buds.*—End-buds are to be found in profusion in *Amiurus*, for tactile sensibility is at its highest development. Not only are they present in great numbers within the cavity of the mouth, on folds of mucous membrane on the gill-arches and on the contractile palate, but the snout and skin of the head, and especially the lips, are thickly covered with them. They diminish in number backwards, and are less frequent on the trunk, as may readily be inferred from their function. They may be most easily studied, however, where they reach their greatest size, and are most closely crowded together, *i.e.*, on the *barblets*, which are solely for the purpose of increasing the functional range of the end-buds, and are little else than modified projections of the skin stiffened by a cartilaginous axis attached to underlying bone, and bearing on each papilla an end-bud. There are eight such barblets in *Amiurus*; the 'nasal' project upwards in front of the posterior nares, and are supplied by a large branch of the *R. ophthalmicus profundus*. The 'maxillary' are the largest and most freely

[1] Zeit. für wiss. Zool. XXXVI., 312.

moveable, being attached to the style-like superior maxillary bones, and indebted for their nervous supply chiefly to the *Rr. maxillares V.*, although they also receive branches from the *Rr. mandibulares.* Attached to the under-surface of the mandible are the four 'mandibular' barblets, supplied by the *Rr. mandibulares V.*

If the tip of one of the barblets of a young specimen be examined in the fresh condition the end buds are visible both from the surface and in profile. From the latter point of view the organ almost invariably appears to have a mouth (owing to the retraction of the central zone of the neuro-epithelium), and this appearance is general also in sections of hardened specimens. Leydig, who has observed this phenomenon, attributes it to contractility on the part of the peripheral zone of cells. From the surface view it is easy to distinguish the two zones of the neuro-epithelium, and likewise in sections which pass transversely to the end-buds. The central cells, which, as distinguished from those of the mantle or periphery, are the sensory elements, occupy the whole length of the end-bud. Difference in form in end-buds from various regions appears to be largely due to the bases of the peripheral cells, which sometimes are considerably swollen round about the nucleus, at others remain slender even there. On the barblets the end-buds are almost cylindrical in form, and are crowded especially towards the tips. In a hardened specimen where the interpapillary epidermis is 200 $\mu$ thick, the cylindrical end bud extends through 120 $\mu$, the papilla occupying the rest of the thickness. The transverse diameter of the end-bud at its mouth is 17 $\mu$, and each end-bud is separated from its neighbour by about twice its width. In young specimens the end-buds are even more crowded, and stand out even more strongly than in the adult from the rest of the barblet, for the interepithelial pigment cells form a complete and close net work in the young, but afterwards become scattered in the adult. The pigment cells do not encroach upon the end-buds whence, apart from their form, their isolation of the latter from the rest of the epidermis.

In other regions the cylindrical form gives place to elongated oval or pyriform shapes. Elsewhere the same length is not attained as in the barblets, although the transverse diameter may be considerably greater.

*(b) Nerve-Hillocks.*

(1). SENSE ORGANS OF THE LATERAL LINE AND OF THE 'MUCOUS' CANALS OF THE HEAD.

The system of cutaneous canals which lodge from place to place the sensory nerve-hillocks was at one time described as the system of 'mucous' canals, owing to the belief that the skin owes its slimy surface to the secretions of these. It is now very well known that the sliminess is due to the mucus-cells described above, and that any mucus which is found in the interior of the canal system has the same sort of relation to the nerve-hillocks as the endolymph in the auditory labyrinth to the *maculæ acusticæ*. The fact that the canal system has a very free communication with the outside, renders it probable that the surrounding medium must penetrate it in such a way as to dilute any mucus present.

The canal system in *Amiurus* possesses the arrangement which is commonest among Teleosts, that is to say the canal of the lateral line is entirely imbedded in the cutis, and opens only from place to place by the pores, while it communicates anteriorly with the more complicated canal system of the head. In other Teleosts the scales of the lateral line are modified in various ways both by the presence of the canal and its pores, but as these are entirely absent in *Amiurus*, the pores are simpler in their structure. It is very much easier to study the apertures of the canal in the fresh condition than in a preserved specimen, owing to the absence of pigment in the immediate neighbourhood of the pores, and to the fact that their edges are somewhat swollen.

All of the lateral pores are similar in character, with the exception of the two terminal pores, which are near the caudal fin, and which open obliquely into a small detached portion of the canal. This is, no doubt, a relic of the interrupted lateral canal seen in other Physostomous forms *e.g. Esox*. Forty pores are present on each side; as the number of pores corresponds to the number of nerve-hillocks (although opening into the canal at some little distance from these), and the spinal nerves are also present in the same number, it is obvious that the sense organs of the lateral line are disposed in a metameric fashion here as in other Teleosts.

The lateral canal corresponds exactly in position to the cleft between the dorsal and ventral divisions of the lateral musculature.

The *R. lateralis vagi* which supplies the sense organs of the canal is not situated in the subcutaneous tissue beneath the canal, but a little distance inwards between the two masses of muscle, a branch being detached to pass outwards to each nerve-hillock. In transverse sections through the canal, it is obvious that it is situated between the epidermis and the stratified fibrous layer of the corium, being lodged in what is elsewhere the pigmentary layer of the corium, although the pigment is practically absent in the neighbourhood of the canal. The epithelium of the canal which is quite low, except where it is transformed into the neuro-epithelium of the nerve-hillock, is continuous at the pores with the surface epithelium of the skin. An exceedingly delicate connective tissue surrounds the epithelium, separating it from the proper wall of the canal, which is formed in the neighbourhood of the pores of a dense connective tissue whose elements are disposed radially to the wall of the canal, but in the neighbourhood of the nerve-hillocks, and indeed for the greater part of the canal between the pores, by a much thinner layer of osseous substance, so disposed as to form a complete tube for the greater part of its course, but less complete towards its ends. No bone corpuscles are present in the osseous wall of the canal, as is also noted by Leydig and Bodenstein for the forms described by them. I am unable to identify the above-mentioned dense connective tissue with cartilage as Bodenstein does, the corpuscles are quite similar to connective tissue corpuscles, and there is no matrix staining in Bismarck brown, as is the case even in cartilage which has a minimum of intercellular substance. Separating the dense wall from the surrounding tissues is again a layer of reticular tissue belonging to that which I have above spoken of as the pigmentary layer of the corium.

The lateral canal of the adult is approximately ·2 mm. in transverse diameter; in young specimens of two inches in length, hardly one-third of that.

To study the course of the mucous canals in the head a series through young forms is most convenient, although approximately the direction of the canals may be seen also from the pores. (Figs. 4, 5, 6.) The pores do not open directly into the canals of the head as they do into that of the lateral line, but by longer or shorter tubes—a circumstance noted also by Bodenstein for *Cottus*—and consequently the direction of the canals can only be approximately determined by the study of the surface.

Within recent years the study of the course of the mucous canals has received an impetus from the discovery of their relation to the morphology of the skull, and accordingly it will be found detailed in Prof. McMurrich's paper on the osteology of this species.

The canals in the head vary considerably in their dimensions; their diameter is on the whole greater, sometimes twice as great as that of the lateral canal, and their walls are different in so far as the protective canal is formed of true osseous substance throughout. Except in respect to the greater size of the nerve-hillocks, the lining epithelium appears to be very similar. A transverse section through a nerve-hillock from a young specimen is represented in Fig. 7. The upper half of the tube is occupied by the ordinary epithelium, which becomes thicker as it approaches the neuro-epithelium, projecting inwards so as to lessen the cavity at this place. Two kinds of cells are to be distinguished in the neuro-epithelium: sensory cells, short and oblong, occupying the inner half of the height of the epithelium, and indifferent cells (Stuetzzellen) occupying the whole height with a basal nucleus. The latter are more frequent at the point of passage into the ordinary epithelium. Fig. 8 represents a section of a *macula acustica* from a fish of the same age, drawn under similar conditions; the resemblance of the two kinds of neuro-epithelia is particularly striking. In Fig. 7 the whole height of the neuro-epithelium is 37 $\mu$, of the sensory cells 15·5 $\mu$; the nuclei of these are 6·5 $\mu$, of the indifferent cells 4·5 $\mu$. The latter stain very densely in carmine, contrasting with those of the sensory cells in this respect. Here and there between the indifferent cells are structures which are possibly nerve fibres in section.

To return to the course of the canals in the head. It will be observed from Fig. 6 that the lateral line rises as it passes forwards towards the posterior upper angle of the gill-cover. Before reaching that a short tube is given off which opens in the skin over the ascending process of the supraclavicle. Directly over the posterior upper angle of the gill-cover is another pore (Figs. 4 and 6) and in front of that another. At the plane of the latter the canals of the two sides communicate by the 'occipital commissure,' which again has two apertures near the middle line. The canal proceeds forwards from this plane, and again opens by a short tube over the articulation of hyomandibular. With Bodenstein I find no communication between the principal canal and that which is lodged in the preoperculum and mandible opening with eight pores on either side. (Figs. 5 and 6).

From the hyomandibular articulation the canal passes forwards and inwards giving off the infraorbital branch which passes through the infraorbital chain of bones and terminates in the adnasal or antorbital bone, which is the most anterior of these. In its course the infraorbital canal first opens directly behind the eye, then by two pores below it and one in front, and finally by two in the same transverse plane behind but lateral to the anterior nasal aperture. The supraorbital canal may be regarded as the continuation of the principal canal ; immediately after giving off the infraorbital branch, a tube is directed backwards which opens behind the first infraorbital pore, but near the middle line. From this point the canal inclines distinctly towards the middle line, opens by a pore in the plane of the eyes, by another medial to the posterior nares, and terminates by two pores which lie in the same sagittal plane over the medial division of the nasal sac. No further communication takes place between the supraorbital and infraorbital canals of the same side, nor do the supraorbital canals of opposite sides meet in the middle line as in *Cottus*. The chief departure from Wiedersheim's diagram (p. 359 *l. c.*) consists in the independence of the mandibular branch, and the absence of an anterior anastomosis of the infra- and supraorbital branches—features which are common to *Amiurus* and *Cottus*. On the other hand, *Cottus* differs from *Amiurus* in possessing one median and two lateral pores in the occipital commissure, and in the supraorbital branches meeting each other in the middle line before they give off a single backwardly-directed tube in place of the two noted above.

### (2). Accessory Lateral Organs.

In various Teleosts the lateral line is not an uninterrupted canal as in *Amiurus*, but may be regularly interrupted as in *Esox*, two or more uncanaliculated scales separating those which are canaliculated. "As if in compensation, however," says Leydig[1], "additional scattered canaliculated scales are present above and below the lateral line, to a certain extent accessory or rudimentary lateral lines, as

[1] *l. c.* p. 33.

they have also been named." Such a condition does not occur in *Amiurus*; but other accessory protected nerve-hillocks are present, of which I can find no mention in the literature of the subject, unless they prove to be structures similar to those described by Leydig in the pike and burbot. He says of the former: "In addition to those 'lateral organs' which are present along the principal and accessory lateral lines they are distributed also elsewhere. On the trunk they are arranged in rows transverse to the long axis of the body. Each row may be composed of six to ten hillocks. In such spots the pigment of the skin only approaches so as to form a sort of boundary line, and the slime cells are likewise absent, so that the row of sense-hillocks has something of an isolated character, although not situated within a furrowed scale."

"To give approximately the number of transverse rows of sense-hillocks is impossible, as I have not succeeded in recognizing them with the loup on the unwounded skin. Horizontal sections and microscopical investigations will be necessary to determine their number and arrangement."

"On the skin of the head, *e. g.*, the region of the cheeks, beaker-shaped organs of the usual size are to be found, as well as others which are not inferior in size to the nerve-hillocks of the lateral lines, so that it is indifferent what name we give them."

"It is worthy of remark that the beaker-shaped organs of the pike and the organs of the lateral line on the trunk agree essentially in their structure."

Of *Lota*, Leydig says (p. 39): "In the head region the pores of the mucous canals are also present, but more numerous, and although for the most part restricted to the course of the mucous canals, they are also to be found in spots far from any mucous canal. The same is the case on the trunk. If all of these points are actually pores of the system of mucous canals, the principal tubes of these must send off long branches in the corium to open in this manner. It is probable, however, that the structures indicated are nothing but large beaker-shaped organs."

As has been remarked above, Leydig does not sufficiently distinguish in the above passage and elsewhere between 'beaker-shaped organs' and 'nerve-hillocks.'

*Amiurus* possesses certain structures which I am inclined to believe are comparable to the scattered nerve-hillocks described by Leydig in the pike, but perhaps more closely resemble the structures which, in *Lota*, communicate with the outside by scattered pores. The structures to which I refer open by slit-like apertures very different in character from the ordinary pores. It is only in the fresh skin that they can be readily detected, and then it is owing to the deficiency of pigment in the wall of the slit similar to that which occurs in the mouth of the pore, that they stand off from the rest of the skin. In size they vary considerably. Some are larger, others much shorter than the pores, but all of them are very much narrower. The most easily recognized are those which form a sort of accessory lateral line stretching obliquely downwards and backwards from the upper angle of the gill-slit. They are accompanied and probably supplied by a distinct branch of the *Ramus lateralis vagi*, which runs along the line of junction of the lateral and ventral musculature, but another very distinct row is to be found almost parallel to the praeopercular mucous canal, running down over the *M. adductor mandibulæ.* Both of these are indicated by the dotted lines on Fig. 6. Again, in front of the dorsal fin similar slits occur, several very distinct behind the occipital pores, others less so, disposed transversely to the long axis of the body.

I have no preparations of the adult skin which pass through these structures, but in a series through a young fish of two inches in length, made for a different purpose, I find certain detached flask-like sacs traceable through three or four sections, which communicate freely with the outside by apertures which are, no doubt, the above-mentioned slits. These sacs appear to be irregularly scattered, at any rate, as Leydig observes in relation to the pike it would be a work of some labour to map them out, but although often far removed in the trunk from the lateral canals, they appear to be always grouped near these in the head. They are especially numerous in the neighbourhood of the nerve-hillocks, and are thus found especially on the snout, below the eyes, on the cheeks and in the occipital region. I recognize the same structures also in the much younger forms whence Fig. 7 is taken, and as well in the one series as in the other, the difference between these sacs and the end-buds is very striking. Although the central-cells of the end-bud may be retracted, as noted above, so as to form a little recess in the mouth of the 'beaker,' the whole organ does not extend down to the corium but is lodged on a papilla extending half-way up through the epidermis, the end-bud consequently corresponding in length only to the other half. Otherwise with the sacs in question: the corium is hardly disturbed by their presence: the bases of the epithelial cells which form the fundus of the sac resting on it at the same level as the ordinary palisade cells do. In preparations where the epidermis is 110 $\mu$ thick. the cavity of the sac is 80 $\mu$ deep, 18 $\mu$ wide in the expanded fundus, and 6 $\mu$ in the narrow neck. Whether the aperture of the sac, which widens somewhat from the neck, be much larger than it is broad (*i.e.*, slit-like), in the stage in question, I am unable to say, from the vertical sections at my disposal, but I am inclined to think not. The walls of the sac vary in thickness from without inwards; in the aperture the ordinary surface epidermal cells are found, but the neck is bounded by cells, which are oval in outline where they look into the cavity, (the long axis being disposed transversely to the long axis of the sac), while their flattened opposite ends converge downwards towards the corium, being imbricated round the cells of the fundus like the scales of a bulb. The fundus is occupied by a nerve-hillock, the neuro-epithelium of which is quite similar to that in the ordinary canals, although, perhaps, only three or four of the short sensory-cells may be counted in one section. In my sections the hairs and bristles have not been preserved; different methods of preparation would, of course, be necessary to determine further the histological peculiarities of the sacs both in the young and adult. All the cells that look into the sac, except those of the neuro-epithelium, have a distinct cuticular border, which is directly continuous with that of the superficial epidermal cells. In still younger stages than that described the cavity of the sac communicates much more freely with the outside, and the characteristic flask-like shape has not yet been assumed.

I have not studied the cutaneous 'nerve-sacs,' first discovered by Leydig, which replace ordinary free nerve-hillocks on the head in Ganoids, nor can I refer to Merkel's work in which these are accurately described, but from the account (based on Merkel's) which Wiedersheim furnishes of these,[1] I am inclined to believe that we have here small 'nerve-sacs' of a similar character. It will be observed, if the above description be compared with that which I translate from Wiedersheim, that the agreement between the struc-

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[1] L. c., p. 361.

tures in question is close. "They are small, hardly over 1 mm. in size, and are especially numerous on the under surface of the snout, round the eyes, and on the occipital and opercular regions. In the form of the histological elements they recall the ampullæ of the Selachians more than the nerve-hillocks of the Teleosts. The epidermis of the skin is folded into a minute sac, in the interior of which the stratified pavement epithelium gives place to a single layer of cylindrical epithelium with a distinct cuticle. Between the cylindrical cells are found the hair-bearing sensory cells, shaped like those of the Teleosts, but closer together, as well as shorter and more pointed. Below each sac is a subcutaneous cavity filled with gelatinous substance."

# THE OSTEOLOGY OF *AMIURUS CATUS* (L.) GILL.

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[*Read before the Canadian Institute, February the 16th, 1884.*]

Numerous statements regarding the osteology of the Siluroids have appeared from time to time in various works, such as the text-books of Stannius, Huxley, Claus, Wiedersheim, etc., and in many scattered papers, but, as far as I can discover, no complete study has been made of any one form. In the following pages I desire to recount the results of a detailed study of the various osteological elements of our common Canadian Siluroid, *Amiurus catus* (L.) Gill. The description of the various portions of the skeleton will be accompanied by some notes on the development of certain bones, as far as it has been possible to trace them, and a few remarks of a comparative nature.

## I.—THE CRANIUM.

Viewed as a whole the cranium is extensively flattened, tapering from behind forwards in depth, so that a vertical longitudinal section would present a triangular aspect. Posteriorly are seen the five processes characteristic of the Teleostean skull, those of the pterotics, epiotics, and the median elongated supraoccipital spine. No well defined orbit is present, the postorbital process of the sphenotic being exceedingly small. A well marked antorbital process is, however, present, and in front of this at the anterior extremity of the skull two more lateral processes are formed by ossification of the lateral expansions of the ethmoid cartilage. On the upper surface of the skull are two median fontanelles; the anterior is the broadest, and is bounded by the frontals behind, and slightly by the mesethmoid in front; the posterior, which is long, tapering posteriorly, is bounded in front by the frontals, and posteriorly separates the supraoccipital into two halves, nearly as far back as the posterior surface of the skull. In accordance with the flattening of the skull, the canal for the orbital muscles is exceedingly rudimentary, and very little cartilage remains in the skull, the anterior portion of the ethmoidal cartilage alone remaining unossified.

1. Supraoccipital.

This is the largest of all the occipital bones, but enters only very slightly into the boundary of the foramen magnum. Looking at it from above (Pl. II., Fig. 1, SO), it would appear to be divided into two portions, owing to the continuation backwards of the posterior fontanelle. Posteriorly, on either side of the fontanelle, it presents many minute foramina, belonging to the system of the mucous canals. Behind the posterior plane of the skull the bone is prolonged into a long spine, from the under surface of which a triangular ridge (Pl. II., Fig. 2, SO) projects downwards and bifurcating above the foramen magnum is continued downwards on the exoccipital. On the posterior surface, on either side of this ridge, is seen a foramen, which, from the inner surface, opens into a canal formed by the union of two others. Of these the superior and larger is occupied by the *ramus lateralis trigemini*, the lower, separated from former by a small spicule, by the ascending branch of the first spinal nerve. Below this latter opening is a third, leading into a canal which traverses the substance of the bone, running downwards and outwards, and containing in the living state the *canalis semicircularis posterior*. The supraoccipital articulates anteriorly with the *frontals*; laterally with *postfrontals*, *pterotics*, *epiotics* and *supraclavicle*; below with the *epiotics*, and *ex-occipitals*.

2. Exoccipitals (Pl. II., Fig. 2, ExO).

Occupying the remainder of the boundary of the *foramen magnum* are the *exoccipitals*; each of which forms the three sides of a cube open above, in front, and on the inner side. A ledge of bone projects from the lower part of each bone inwards, meeting in the middle line, and forming the floor of the *foramen magnum*, and the roof of the *sinus impar*. The ridge of bone extending downwards from the lower surface of the supraoccipital spine is continued downwards on these bones, forming the lateral walls of the *foramen magnum*. On the outer surface are two foramina; the anterior small one gives passage to the *nervus glossopharyngeus*, and the posterior large one to the *N. vagus*. On the posterior surface is another foramen, small, situated on a line with the inwardly projecting ledges, and giving passage to the first spinal nerve. The inner surface of the bone is smooth. The exoccipitals do not unite into a close articulation with neighbouring bones, but are merely placed in apposition, the outlines of the bones not being indented but perfectly smooth. They are in relation above with the *supraoccipital, epiotics*, and *pterotics*: in front with the *prootics*; and below with the *basioccipital.*

3. Basioccipital (Pl. II., Fig. 2, BO).

The Basioccipital is shut out by the exoccipitals from contributing to the formation of the *foramen magnum.* Its posterior face is deeply concave; below is a nutrient foramen; the upper surface forms the floor of the *sinus impar;* and the body of the bone is deeply hollowed for the reception of the *sacculus* of either side. It extends forwards, becoming smaller and thinner anteriorly, where it articulates with the posterior edge of the basisphenoid. Its articulations are as follows:—Above and at the side with the *exoccipitals*, and *prootics*; below with the *parasphenoid*: in front with the *basisphenoid*; behind with the body of the first vertebra; and laterally with the horizontal limb of the *supraclavicular.*

4. Epiotics (Pl. II., Fig. 1, EpO).

These bones, one on either side, form the postero-lateral angles of the skull. Each has an irregularly spherical triangular shape, affixed by the base, the apex forming the projecting angle. Internally the bone supports part of the posterior and longitudinal semicircular canals, the former passing in a deep groove on its posterior wall, the latter lying on the horizontal floor. The anterior upper edge of the bone is deeply channelled, the cavity communicating with a similar one in the substance of the pterotic. The articulations of the *epiotics* are with the *supraoccipital, exoccipital, pterotic*, and *supraclavicular.*

5. Pterotics (Pl. II., Figs. 1 and 2, PtO).

Form the postero-external angles of the skull. Each is an ossification around the arch of the horizontal semicircular canal. The posterior upper edge shows a wide opening extending some distance into the cavity of the bone, apparently separating the upper portion of the bone into two lamellæ. The groove mentioned above as occurring on the epiotic, and also one on the outer edge of the horizontal portion of the supraoccipital, are parts of the same cavity. In a skull from which all accessory parts have been removed, it opens by a comparatively wide opening at the base of the ridge, which extends upwards upon the bone to unite with the similar ridge on the supraoccipital spine. This opening is almost closed in the natural condition by the supraclavicle, a small opening only being left. The cavity is apparently quite shut off from any communication with the brain-cavity, and contains only fatty tissue. On the upper surface of the pterotic, on the projecting posterior portion, are several foramina—the openings of a mucous canal, which passes forwards in an osseous canal, running along the outer edge of the bone. The smooth surface formed by pterotic, exoccipitals and epiotic lodges the utriculus. The pterotic articulates with the *supraoccipital* above; the *epiotics*, and *supraclavicular* behind; the *exoccipitals*, and *prootics* below; and in front with the *sphenotic*.

6. Prootics, (Pl. II. Fig. 2, *PrO.*)

Lie on each side immediately in front of the *exoccipitals*. Each is a somewhat quadrate bone, extending to the middle line below, where it articulates with the fellow of the opposite side, thus entering into the formation of the base as well as the walls of the skull. The middle portion of its inner surface is crossed by a ridge, notched outwardly, in which notch the anterior or sagittal semi-circular canal passes to the *recessus utriculi*. Near the posterior edge is another smaller ridge, round the outer extremity of which the same canal turns in passing forwards from the *utriculus*. Between these two ridges is a smooth hollow, with a very thin wall, which lodges the *recessus utriculi*. Below the prootics, where they meet in the middle line below and between them and the anterior portion of the basioccipital above, and the parasphenoid below, is a small cavity. This is the almost aborted rudiment of the canal for the orbital muscles, which is largely developed in many fishes, but absent or very rudimentary in *Silurus*, *Amiurus*, *Gadus*, *Lophius*, &c. The middle of the anterior edge of the prootic is notched variously in different individuals, sometimes possessing a single notch, at other times there being two more or less separated by an intervening osseous spicule. These notches are closed in front by the posterior edge of the alisphenoid, and through the foramina thus formed the fifth and seventh cranial nerves (*trigeminus* and *facialis*) make their exit from the cranial cavity. The prootics articulate with the *exoccipitals* and *basioccipital* behind ; above with the *pterotics* and *sphenotics* ; internally with the fellow of the opposite side ; anteriorly with the *alisphenoids* and *basisphenoid* ; and below with the *parasphenoid.*

7. Sphenotics, (Pl. II. Figs. 1 & 2, *SpO.*)

Or postfrontals, present a flat surface on the roof of the skull, but send down a vertical longitudinal plate of considerable thickness, which is grooved deeply posteriorly. the arch of the anterior semi-circular canal being contained in the groove. On examining the bone from above, there may be seen below the surface a channel, a continuation of that already mentioned as traversing the pterotic, and containing a mucous canal. About the middle of its course on the sphenotic is an opening for a mucous pore, with which usually opens also a canal passing from the cranial cavity and giving exit to a dorsal branch of the *trigeminus*, though it occasionally opens separately. From the same point another channel in the bone passes inwards, opening by a pore on the line of articulation between the *postfrontal* and *frontal.* This also contains a mucous canal. On the under surface, near the external edge, is a longitudinal groove continued from pterotic which is the articular surface for the hyomand. The vertical portion of the bone forms the superior boundary of the foramen for the *trigeminus* and *facialis*, and is not continued forwards to the anterior extremity of the bone, which is there formed solely of a horizontal plate. The sphenotic articulates with the *supraoccipital* and *pterotic* posteriorly ; below with the *prootic ;* in front with the *alisphenoid ;* and above and internally with the *frontal.*

8. Parasphenoid, (Pl. II. Fig. 2, *PaS.*)

This bone, lying at the base of the skull, extends from the basioccipital, which it slightly overlaps, to the vomer anteriorly, by which it is overlapped. About the junction of the anterior two-thirds with the posterior third it expands somewhat, extending upwards to articulate with prootic. Behind it forms the floor of the small rudiment of the canal for the orbital muscles, and its expanded portion is firmly anchylosed with the superjacent bone, the basisphenoid. The parasphenoid lies below the *basioccipital* behind, and also passing forwards, the *prootic*, *basisphenoid*, *orbitosphenoid* and *ectethmoid*.

9. BASISPHENOID.

Does not appear as a distinct bone in the skull of *Amiurus* but is anchylosed with the subjacent parasphenoid, the line of demarcation between the two being more or less distinct however. It is a flattened impair bone, presenting no especial features for examination. It forms the lower boundary of the foramen for *trigeminus* and *facialis* behind, and partly of the foramen for *opticus* in front, and articulates behind with the *prootic* : externally with the *alisphenoid* : in front with the *orbitosphenoid* ; and below with the *parasphenoid*.

10. ALISPHENOID, (Pl. II. Fig. 2, *AS*.)

A rather small bone, lying on either side between the foramina, of which it forms the anterior and posterior boundaries, respectively. These foramina are that for the *trigeminus* and *facial* behind, and that for the *opticus* in front. The bone is very roughened and ridged on its external face for the attachment of muscles, and above this roughened portion is a hollow in which lies the anterior portion of the hyomandibular. The inner surface is smooth. From the posterior edge a spicule of bone passes backwards in those individuals, in which the foramen for passage of the 5th and 7th nerves is divided completely, which spicule unites with a similar one from the prootic. Immediately in front of posterior edge is a small foramen for exit of the *ciliary* trunk of the 5th nerve. On the inner side, immediately above the inferior process, which articulates with the basisphenoid, are two foramina, one above the other. The inferior of these is the larger, and opens into a canal, pursuing a course more or less oblique in different individuals to the exterior. It gives passage to the deep branch of *R. ophthalmicus trigemini*. The smaller one lies at the extremity of a longitudinal groove, and opens into the interior of the bone like other similar foramina which perhaps, have a nutritive function. Each alisphenoid articulates above with the *sphenotic* and *frontal* ; behind with the *prootic* ; below with the *basisphenoid* : and in front with the *orbitosphenoid*.

11. FRONTALS, (Pl. II. Figs 1 & 2, *Fr*.)

Are flat plate-like bones, with a small ridge projecting downwards from the middle of the under surface. They are separated from each other along nearly the whole of their length, entering into the formation of the anterior and posterior fontanelles, their articulation being only at a small surface about their middle point. The mucous canals, which run in the pterotics and sphenotics continue their forward course in these bones, which present many foramina or mucous pores. On the upper surface one of these is especially noticeable, situated on a level with the anterior extremity of the articular surface on each side. Below, on the inner side of the vertical ridge, is a small foramen which is for the exit of a small dorsal branch of the *trigeminus*. On the outer side of the ridge are a varying number of foramina, varying even on opposite sides of the same skull both as to size and number. In front of these a groove runs forward to a foramen in the very front of the bone, opening into the nasal capsule and giving passage to the *opthalmic* branch of the fifth which exits from the skull through the alisphenoid. The frontals articulate internally with the fellow of the opposite side ; below with the *alisphenoids, orbitosphenoids* and *ectethmoids ;* behind with the *sphenotics* and *supraoccipitals*.

12. ORBITOSPHENOID. (Pl. II. Fig. 2. *Os.*)

A single bone forming the base and walls of the skull, the cavity of which is contracted in this region, expanding both in front and behind. It forms a passage or canal in which lie the olfactory nerves. Immediately above the horizontal portion the bone is notched deeply anteriorly and posteriorly. These notches are made foramina by the articulating bones. Through the anterior one a vein passes, through the posterior, the *optic* nerve. The *orbitosphenoid* articulates in front with the *ectethmoids* and *mesethmoids ;* above with the *frontals ;* behind with the *alisphenoids* and *basisphenoid ;* and below with the *parasphenoid*.

13. MESETHMOID, (Pl. II. Figs. 1 & 2, *MEth.)*

Forms the anterior boundary of the skull, and enters into the formation of the floor and the roof of the anterior portion which contains the olfactory nerves. It is the median ossification of the ethmoid cartilage of the young fish, and is one of the two bones in which the ossification of the cartilage is not completed in the adult, the inner surface of the bone being lined with it. In front it is notched, and spreads out into two horn-like processes which articulate below with the premaxillæ. Its posterior articular surfaces, both above and below, are very much indented, split up, in fact, into a number of very long osseous spicules, as in the parasphenoid and vomer, which fit in between corresponding spicules in the bones with which it articulates. Its articulations are :—behind with the *orbitosphenoid*, *frontals* and *parasphenoid* ; below with the *parasphenoid*, *vomer* and *premaxillæ* ; laterally with the *ectethmoids*.

14. Ectethmoids, (Pl. II., Figs. 1 & 2, *EEth* ; Fig. 2, *Pfr.*)

Are the lateral ossifications of the ethmoidal cartilage. They are very deeply grooved on the inner surface for the *olfactory* nerves, opening anteriorly by a large foramen, through which the nerves pass to the olfactory organ. Laterally the bone is produced into a strong slightly curved process, the *antorbital process*, and below this is a roughened surface for articulation with the posterior extremity of the palatine. The lower and posterior surface of the antorbital process presents one or two foramina through one of which a branch from the deep branch of *R. ophthalmicus trigemini* passes. The upper surface of the bone is irregular, and presents many foramina connected with the mucous canal system. The ectethmoids articulate with the *mesethmoid* interiorly ; the *frontals* and *orbitosphenoids* behind ; the *vomer* below, and the *palatine* externally. Their upper surfaces also come into relation with two membrane bones, the *nasal* and the *adnasal*, on each side, and the extremity of the antorbital process is in relation to the anterior ossicle of the *infraorbital chain*.

15. Vomer, (Pl. II., Fig. 2, *Vo.*)

Is a nail-shaped bone, *i.e.*, very much expanded in front, and abruptly narrowed and tapering toward the posterior extremity. It lies below the *mesethmoid* and anterior portion of the *parasphenoid*, with which it interdigitates.

Certain membrane bones, developed in connection with the mucous canal system, may also be described as belonging to the cranium ; these are the *infra-orbitals*, the *nasals*, and the *adnasals*.

16. Infra-orbitals.

Extending from the frontals downwards behind the orbit, and below it bending and running forwards to the ectethmoid, is a chain of bones lying in the dense fascia which covers the *adductor mandibulæ* muscle. The first or superior is an almost square bone, the second long and slightly curved, lying directly behind the eye. It is followed by the third, almost straight and shorter than the second; the fourth, fifth and sixth are straight rod-like bones, longer than the first or third, the sixth being the shortest of the three. All are traversed by a channel in which lies a mucous canal, more or fewer possessing an opening by which the canal communicates with the exterior.

17. ADNASAL, Pl. II., Fig. 1, *An.*)

A small bone on either side, lying at the base of maxillary tentacle in the fascia covering the nasal region. It is really a continuation forwards of the infraorbital chain, containing the same mucous canal, which opens by a pore on its surface. The bone is slightly triangular, with curved edges, the apex being directed forwards.

18. NASALS, (Pl. II., Fig. 1. *Na.*)

Are small bones in *Amiurus*, lying on either side between the *adnasal* and the *mesethmoid*. They are oblong in shape, and are traversed by a channel for a mucous canal which opens by a pore on the outer edge of the bone.

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On comparison with other Teleostean crania, the almost entire absence of cartilage is a very noticeable feature. Ossification has progressed so far in every part that it has replaced the original cartilage entirely, except in the mes- and ectethmoid. Since the cartilaginous stage precedes in the ontogeny the osseous stage, one must conclude that a form whose skull is completely ossified is phylogenetically older than one whose skull contains a considerable amount of cartilage, and, therefore, *Amiurus* and the *Siluroids* in general form a highly specialized group, which indeed other points in their anatomy also show. The absence of a canal for the orbital muscles would also appear to characterize only highly specialized types. It is found in forms in which much of the original cartilage persists, but in this form only a rudiment of it is present, indicating its presence in the ancestral forms of the *Siluroids*. Vrolik[1] mentions a fact in connection with the absence of the canal which receives confirmation in *Amiurus*, namely, that when such is the case, the petrosum (*prootic*) is not pierced by the facial and trigeminus (*Gadus*, *Silurus* and *Lophius*).

[1] *Vrolik.*—Studien uber die Verknocherung u. d. Knochen des Schädels d. *Teleostei.* Niederand. Arch. f. Zool.—Bd. I., 1873.

As regards the various bones of the skull, they differ in no very essential points from those of *Silurus glanis*, which have been described in general terms and for comparative purposes only by Vrolik. All the bones usually found in Teleostean crania are present with the exceptions of the opisthotic, intercalare, and parietals. The principal features are the presence of a well-ossified and large mesethmoid; the orbitosphenoid forming three sides of a canal for the olfactorius, thereby separating widely the eyes and acting as an interorbital septum; the meeting of the prootics at the base of the skull; and the absence of teeth in the vomer, a point of some importance, since certain closely related forms are provided with vomerine teeth.

Certain points in the development of the cranial bones merit a detailed description. In a young *Amiurus*, about 20 mm. in length, it was to be noticed that wherever a mucous canal appeared in transverse section a ring of bone surrounded and protected it, (Pl. II., Fig. 8, MC), so that each of these canals in the cranium was surrounded by an osseous tube. The bone was apparently deposited in membrane, and was evidently formed solely for the protection of the mucous canal. In certain cases a bone, usually perforated for the emission of a branch from the canal to a pore, became formed by a lateral extension of this osseous tube into the adjacent connective tissue. Instances of such bones are the infraorbital chain, the adnasals and nasals. The adnasals in reality, then, as was stated above, belong to the same group as the bones of the infraorbital chain, and may be described as the anterior ossicle of that chain, since it is formed in the same manner, and is traversed by the same canal. Sagemehl[1] proposes to name it the antorbital, but, since its function is not only to protect the enclosed mucous canal but also to protect the nasal region to which it stands in the same relation as does the nasal, I prefer the name employed.

In the majority of cases, however, the osseous tube does not remain distinct but fuses with the subjacent bone, whether formed in membrane or perichondrally. In the case of the frontals, for instance, the mucous canal bone unites with the underlying bone formed in membrane, and in the sphenotic and pterotic (Fig. 8) a similar union occurs with the perichondral bone with which the ossification of the

[1]*Sagemehl.*—Beiträge zur vergl. Anat. der Fische. Das Cranium von *Amia Calva. L.*, Morph. Jahrb. Bd. IX., 2nd Heft. 1883.

cartilage of those regions commences. As regards the former it must be noted that there is apparently a portion (the thin ledge-like portion overlapping the anterior portion of hyomandibular) which is formed entirely by membrane. These two bones, then, are partly formed perichondrally, and partly from bone originating in membrane, and, accordingly, objections to the pterotic being considered equivalent to the other otic bones on account of its possessing a mucous canal, are groundless, since the pterotic and sphenotic are in reality cartilage bones for the protection of semi-circular canals, the union of the membrane bone being secondary, and probably for the purpose of increasing the strength of the protective tube of the mucous canal. Schmid-Monnard[1] has recently pointed out the part played by the mucous canal in the formation of the pterotic, but does not seem to have noticed it in the case of the sphenotic.

Sagemehl[2] also points out that the sphenotic postfrontal) and also the prefrontal (ectethmoid) in *Amia* possess a membranous element, but does not recognize in the sphenotic that the membrane bone really belongs to the mucous canal. As regards the ectethmoid in *Amiurus*, it is truly perichondral, for the mucous canal which lies above it does not unite with it, but is separated from it by connective tissue.

As regards the other bones, the prootics, epiotics, alisphenoids, and basisphenoid, are entirely perichondral in their formation; the supraoccipital is partly perichondral and partly formed from a superficial plate of membrane bone, which unites with the subjacent perichondral; the orbitosphenoid is mainly perichondral, but the cartilaginous orbitosphenoids do not meet in the middle line, but leave a space at the base of the skull bridged over by membrane continuous with the perichondrium, from which the median basal portion of the bone is developed. The ex-occipital, too, is mainly perichondral, the two ledges which roof in the sinus impar being, however, membranous in their origin.

The basioccipital, however, presents several points for consideration in its development. In the young stage above mentioned, at the median line at the base of the skull is the notochord, surrounded with some osseous tissue apparently developed from its sheath, as in the vertebræ. The lower angles of this ossification are continuous

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[1] *Schmid-Monnard.*—Die Histogenese des Knochens der Teleostier. Zeit. f. wiss Zool Bd. XXXIX., 1883.

[2] *Loc. cit.*

with a thin layer of bone extending across and becoming continuous with the outer perichondral layer of the exoccipital. This thin layer forms the floor of the cavity for the sacculus, and contains no cartilage, so that the basioccipital at this stage is destitute of cartilage, and is composed of membrane bone in this (anterior) region. More posteriorly, however, behind the exit of the vagus and behind the cavity for the sacculus, the cartilage, continuous with that of the exoccipital, comes down towards the middle line as far as the chorda, which is still surrounded by bone. In an older stage (about 38 mm. in length) the cartilage present around the chorda and on the floor of the cavity for the sacculus is very noticeable. Opposite the exit of the glossopharyngeal, where no cartilage was to be seen in the younger stage, a large plate of it is present at floor of the sacculus-fossa, bearing upon its upper (inner) surface a mass of trabecular bone representing the ossification around the notochord in the younger stage. So opposite the foramen for the vagus (where no cartilage is present in the younger stage) the chorda has much diminished in size, and cartilage is to be seen at its sides below, separated from it by a layer of bone. Still more posteriorly the cartilage has the same relations as in the younger stage.

It is thus seen that the older stage presents cartilage where in the younger stage only bone is present, apparently reversing the fact that the older the form the less the amount of cartilage present. How is this to be explained? In the young stage the sacculus occupies the place of the cartilage, being so large in comparison to the size of the skull that there is room only for a thin layer of bone at the floor of the fossa, and a thin investment round the chorda. Later, however, the cranium grows more rapidly than the auditory apparatus, and then the cartilage always present posteriorly grows forward, and, by the ossification of its perichondrium, contributes largely to the formation of the basioccipital.

The vomer and parasphenoid are formed in membrane and show no signs of teeth.

Objections have been made by certain German authors to the application of the terms proötic, epiotic, etc., to the bones developed in the cartilaginous ear-capsule. Vrolik[1] bases his objection to the terms on the fact that other bones, for instance, the supra-, ex-

[1] *Vrolik.*—Studien über die Verknocherung u. d. Knochen des Schädels der Teleostei. Niederlandisches Archiv für Zoologie, Bd. I. 1873.

and basioccipital, also enter into the protection of the auditory apparatus, and that in *Salmo* (the only instance apparently observed by him) the epiotic does not contain the exterior semicircular canal. The cartilage in which the occipital bones develop did not originally form part of the auditory case, the passage of the semicircular canal through the exoccipital and supraoccipital being secondary, as the hollowing out of the basioccipital for the sacculus certainly is, so that the names applied to these parts more truly indicate their origin. Parker's paper on the skull of the salmon,[1] published later in the same year, states that, contrary to Vrolik's opinion, the epiotic *does* arise in connection with a semicircular canal, and shows also that a similar relation occurs in the pterotic, sphenotic, and opisthotic.

In the *Selachii* the auditory capsule is at first quite distinct from the rest of the skull, with which it eventually fuses, and throughout life remains without connection with the cranial cavity except by the foramen for the auditory nerve. It lies at the sides of the skull, but does not extend back to the occipital region. In young Teleosts the cartilaginous capsule does not extend back as far as the occipital region, lying still at the sides. Now all bones formed in this cartilaginous capsule are certainly entitled to be referred to the "otica" group. The anterior portion of this capsule is ossified as the proötic (petrosum), a tract of osteoblasts outside the ampulla of the anterior semicircular canal gives origin to the sphenotic (postfrontal), the pterotic (squamosal) arises over the ampulla and arch of the external canal, the epiotic (occipital externum) over the arch of the posterior canal, and the opisthotic (intercalare) over the ampulla of the same canal. All these bones lie in the region occupied by the cartilaginous auditory capsule, all are mainly what may be called cartilage bones,[2] and all hold a more or less definite relation to the included auditory apparatus.

*The terms proötic, sphenotic, pterotic, epiotic and opisthotic, applied respectively to the bones known to German authors as the petrosum, postfrontal, squamosal, occipitale externum, and intercalare, are preferable, as indicating the true relations of these ossifications.*

Sagemehl in his paper on *Amia*[3] makes many ingenious and

[1] *W. K. Parker.*—The structure and development of the skull in the Salmon. Phil. Trans., 1873.

[2] Gegenbaur's objections to the pterotic (Ub. das Kopfskelet von Alepocephalus rostratus (Risso). Morph. Jahrb, Bd. IV., suppl., 1878,) have been shown above to be groundless.

[3] *Ante cit.*

valuable suggestions. His paper coming to hand after the previous descriptive portion had been written, explains the homology of the cavity described as occurring in the upper surfaces of the pterotic, supraoccipital, and epiotic. He shows that a similar cavity, which he terms the *temporal cavity*, occurs in *Amia* between the bones and the primordial cartilage, is widely open behind, and contains a portion of the lateral musculature. In all probability the cavity in *Amiurus* is a rudiment of this temporal cavity of *Amia*, the original contents of which have vanished, their place being taken by fat and blood-vessels.

The same author suggests that the occipital segment of the Teleosts has fused with it a certain number of vertebræ. He bases his assertions on the presence of such vertebræ, partially fused, in *Amia*, *Polypterus*, *Protopterus* and *Lepidosteus*. If such be the case, there is no trace of such a coalescence in *Amiurus*. A nerve certainly does pass out from the exoccipital behind the vagus, but in all its relations it is a spinal nerve, passing through the arch of the preceding vertebra, as do the succeeding nerves. The occipital segment is certainly composed of many segments, one corresponding to each branchial branch of the vagus and to the glossopharyngeal, but beyond these there is no indication of any further segments in the basioccipital of *Amiurus*.

## II.—PALATO-QUADRATE AND MANDIBULAR APPARATUS.

Under this head will be included a description of the maxillary and palatine apparatus, as well as of the chain of bones constituting the first postoral arcade, or, according to views expressed elsewhere,[1] the third cranial arcade, the trabeculæ cranii being considered as representing the first arch, and the palatine as the second.

1. THE PREMAXILLÆ, (Pl. II., Fig. 1, *Pmx.*)

Each is a small, somewhat arched bone, supporting five or six rows of teeth. They meet in the middle line, but are not united by suture. The upper surface of each bone rests on the under surface of the *mesethmoid*, and at the outer extremity each articulates with the *maxilla*.

2. THE MAXILLÆ, (Pl. II., Fig. 1, *Mx.*)

Depart very widely from the typical form. They are very much elongated rods, projecting at right angles to the sides of the skull,

[1] On the Osteology and Development of Syngnathus Peckianus, (Storer). Quart. Journ. Micr. Sci., N. S., Vol. XXIII., 1883.

but are capable of considerable movement, so that they may lie almost parallel to the longitudinal axis. At the base the bone forms a complete sheath for the cartilage which supports the maxillary tentacle, but this sheath is complete only for a short distance, the cartilage lying in a groove in the posterior (inner) surface of the bone. At the base are two processes, a smaller posterior dorsal and a larger anterior ventral. The latter has a fascia firmly attached to it in such a way that, when the anterior extremity of the palatine is pushed forward, it draws the same fascia, and by the tension thus produced the maxilla is abducted or pushed away from the sides of the skull. The bones possess no teeth. They have in relation to them the *premaxillæ* in front and below; the *palatines* behind; and the *adnasals* on the inner side.

3. THE PALATINE, (Pl. II., Fig. 1, *Pa.*)

Each palatine is a short, rod-shaped bone, extending antero-posteriorly, parallel with the long axis of the skull. The anterior extremity abuts upon the maxilla, and the posterior lies in front and outside of No. 4, and below the antorbital process of the *ectethmoid.*

4. (Pl. II., Figs. 1 & 4).

This is a small almost round scale-like bone, lying behind and within the posterior extremity of the palatine. It is developed in the fascia of the anterior fibres of the *adductor arcûs palatini* muscle, and cannot be referred to the pterygoid series of bones. In a specimen of the very closely related *Amiurus nigricans*, (LeS) Gill, it was quite absent.

5. METAPTERYGOID, (Pl. II., Fig. 1, *Mpt.*)

Is an almost square bone, lying directly behind No. 4. It is flattened, and its upper posterior border is somewhat concave, aiding in the formation of the notch for the passage of the trigeminus to the superficial muscles. The anterior superior angle is attached by ligament to the *orbitosphenoids.* The bone articulates in front with No. 4; behind with the *hyomandibular*, and below with the *quadrate.*

6. THE QUADRATE, (Pl. II., Fig. 1, *Qu.*)

Furnishes the articular surface for the mandible. It is triangular in shape, thicker behind and below, the upper portion being squamose. In a deep fossa, on the upper and posterior portion of the bone, lies the cartilaginous *symplectic*, in a perfectly dried skull, the fossa being empty and an interspace occurring between the quadrate and the hyomandibular. The posterior border of the quadrate is contained in a groove on the *preoperculum* ; behind and above it articulates with the *hyomandibular* ; and above and in front with the *metapterygoid*.

7. THE MANDIBLE, (Pl. II., Fig. 1, *Mn.*)

Consists of two portions, one on either side, united in the median line in front by ligament. Each portion again consists of four parts. These are as follows :—

(*a*) The *dentary*, constituting the anterior two-thirds of the bone and bearing numerous teeth. It is broader in front than behind, the teeth being arranged correspondingly, there being 5-6 rows anteriorly, tapering off to two rows posteriorly. The bone increases in height posteriorly, and is grooved on the inner surface for the reception of Meckel's cartilage and the articulare. The under surface presents six pores, openings for branches of the mucous canal which runs in this portion of the bone.

(*b*) The *articulare* forming the posterior high portion of the bone, and presenting the articular surface for the quadrate. It encloses Meckel's cartilage posteriorly.

(*c*) *Meckel's cartilage*, the remains of the primordial cartilaginous mandible. It consists of a rod of cartilage lying on the inner surfaces of the dentary and articulare, its posterior portion being included within the latter.

(*d*) The *angulare*, fused completely with the articulare, being merely indicated as a small triangular nodule below the articular surface.

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The great size of the intermaxillaries and the limitation of the teeth to them, as far as concerns the upper jaw, are points worthy of notice. This is, of course, due to the specialization of the maxillæ for another purpose ; with the decrease in size of the latter was an increase of the former. The intermaxillæ belong to that class of bones which are formed by the fusion of cement-plates of teeth. At first they are represented by a thin lamella of bone-bearing teeth, but by means of osteoblasts the ossification extends into the superjacent tissue in the form of trabeculæ which are, in their histological details, similar to the cement plates.

The maxillæ are specialized for the support of the long maxillary tentacles. Instead of developing parallel to the axis of the skull, they extend outwards at right angles to it, their antero-posterior extent being very much diminished. They have, in fact, lost all the usual relations to the gape. That they do not possess teeth is not remarkable, since even in *Esox* they are toothless, though probably their origin was similar to that of the intermaxillæ, *i.e.*, the union of cement plates. The fact of their being moved by a special muscle lying below the *adductor mandibulæ*, instead of by the upper layer of that muscle, and also their relation to a nerve arising from the trigeminus before its division into the superior and inferior branches, which seemed to indicate for them an angular nature, gave rise to a passing idea that they might not really be homologous with the maxillæ of other Teleosts, and I was inclined for a time to compare them to the supramaxillaries described by Gegenbaur as occurring in *Alepocephalus* and *Clupea*[1]. These peculiarities, however, do not properly belong to the bones but to the tentacle, and, since the relations of the bones are the same as those of the maxillæ of other Teleosts, and their mode of development similar, there seem to be no reasons for departing from the usual idea that they are homologous with the maxillæ of other osseous fishes.

The palatine bears no teeth. The first trace of bone is formed by the perichondral investment of the ethmo-palatine cartilage, this osseous layer having similar histological characters to the cement plates, there being evidently a close relation between these two forms of bone.

The true pterygoids are all so-called cartilage bones, and therefore the bone described as No. 4 cannot belong to the series. Its true relations have already been indicated. The presence of only one pterygoid is, however, a peculiar feature. In the youngest stage which I was able to study, ossification had just commenced, and by means of sections[2] it was seen that the anterior portion of the metapterygoid contained no cartilage, there being thus, apparently, an interval between the anterior extremity of the pterygo-quadrate

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[1] *Loc. cit.*

[2] I must testify to the good results obtained by the use of a saturated watery solution of Bismarck Brown. Not only are cartilage and bone admirably differentiated, but also muscle, nerve, glandular tissue, etc.

and the posterior extremity of the ethmo-palatine cartilages. Whether this is really so my specimens do not allow of absolute certainty, but make it a strong probability. Somewhat further back the cartilage is seen and may be traced unbroken back to the quadrate. The metapterygoid of *Amiurus* combines to a certain extent the relations of the ectopterygoid and entopterygoid, as well as that of the metapterygoid of other Teleosts, but, since it is in direct relation to the quadrate, and performs the usual function of a buttress to the hyomandibular, I have preferred the last named term for it.

The development of the dentary suggests some important thoughts. In a 20 mm. stage, (Fig. 9) Meckel's cartilage *Mck*) is present in its entirety. On its upper surface is a layer of tooth-bearing bone, in which the individual cement plates (*cp*) are still to a large extent recognizable. At the sides and below is a layer of perichondral bone (*pc*), the cement plate bone passing into it without any line of demarcation. In fact both varieties are identical, not only in their histological features, but also in their origin. Below the cartilage is a mucous canal (*MC*) enclosed in its osseous tube, which is united with the perichondral bone of the lower surface. In a 38 mm. stage the cartilage has almost disappeared, its place being occupied by trabeculæ of bone, osteoblasts lying in the interspaces. The mucous bone has become quite united with these trabeculæ, and it is impossible to distinguish it. We have then in the dentary portion of the mandible what may be termed three different varieties of bone—cement-bone, perichondral-bone (with which may be included the trabeculæ), and mucous-canal bone. All three, however, pass into each other, and are indistinguishable in structure and origin. The old division into primary and secondary ossification should be done away with since both varieties are in reality similar.

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## III.—THE HYOMANDIBULAR, HYOID, AND OPERCULAR APPARATUS.

The bones constituting these parts belong to a single arch, the second post-oral, and are in relation to the seventh nerve.

### 1. The Hyomandibular, (Pl. II., Fig. 1, *Hmd.*)

Is a large almost quadrate bone, forming the upper part of the arch. It articulates above by a somewhat arched surface with the *sphenotic* and *pterotic*, and from the anterior angle of this surface a process passes forward and upward to touch upon the *alisphenoid*. Upon the inner surface of the bone, not far from the base of this process, is a foramen leading into a canal which traverses the hyomandibular from above downwards and backwards, opening on its posterior surface a little above the posterior inferior angle. This canal contains the *R. hyoideo-mandibularis facialis*. On the outer surface is a flattened ridge overlying this canal, immediately behind which is the articular knob for the operculum, and extending forward at right angle to it is a ridge for the attachment of muscles. The hyomandibular articulates above with the *pterotic*, *sphenotic*, and *alisphenoid*; in front with the *metapterygoid*, and slightly with the *quadrate*; below with the *symplectic* cartilage and the *preoperculum*; and behind with the *operculum*.

2. The Symplectic

Element does not appear to ossify. It is represented by a cartilage contained partly within the hyomandibular and partly within the quadrate, and filling up the space between these two bones.

3. The Hyoid

May be described as consisting of five portions, as follows :—

(*a*) The *interhyal* is represented by a small knob at the extremity of the arch which is connected by ligament to the inter- and preoperculum, the hyoid thus being fixed at its upper extremities without articulation with the symplectic.

(*b*) The *epihyal* is the upper triangular portion of the arch, separated from the succeeding portion by a deep notch above and below, and by a usually well marked articulation.

(*c*) The *ceratohyal* is the longest portion of the arch; broad and flat above, it becomes contracted towards its anterior extremity and again expands for articulation with the hypohyals. Both the ceratohyal and epihyal bear branchiostegal rays on their lower borders.

(*d*) The *hypohyal* is united with its fellow of the opposite side by ligament. The bone so denominated in *Amiurus* is not simple, but has usually connected with it one or two accessory nodular bones, the number frequently varying on opposite sides in the same individual.

(*e*) The *urohyal* is an impair bone extending back from the junction of the hypohyals. Anteriorly it is partly divided into two rounded portions, from the extremities of each of which a ligament passes forward uniting it to the hypohyal. Behind is a thin flattened plate, bearing on its upper surface a high longitudinal keel which bifurcates anteriorly, each division continuing its way upon the anterior round portion, diminishing as it passes forward. Upon the upper surface of the flattened portion, and separated from each other by the median keel, are the two *hyo-clavicular* muscles.

4. THE BRANCHIOSTEGAL RAYS,

According to Jordan[1], the typical number of branchiostegal rays for *Amiurus* is nine, varying, however, from eight to eleven. The variation seems to occur even individuals, there being, for instance, sometimes nine on one side and eight on the other. In *Amiurus catus* the usual number was eight. They arise from the posterior (inferior) borders of the epihyals and ceratohyals, which possess notches for their articulation. The inner ones are short and rounded, but the outer (superior) ones are more or less flattened, the last two being quite flat and applied to the under surface of the operculum. In fact I would prefer to state the number of the rays at seven, considering the upper one as the suboperculum.

5. THE PREOPERCULUM Pl. II., Fig. 1, *PrOp.*)

Is more or less firmly united with the hyomandibular and quadrate. It is broader at the lower part than above, and is grooved on its anterior border for the reception of the lower part of the hyomandibular, the symplectic, and the quadrate. It is a continuation of the longitudinal flattened ridge of the hyomandibular and contains a mucous-canal, foramina upon its surface being for the exit of branches to the pores. Behind and below it rests upon the *operculum* and *interoperculum*.

6. THE OPERCULUM (Pl. II., Fig. 1, *Op.*)

Is a triangular scale-like bone, articulating with the knob on the hyomandibular. Its apex is in relation to the *interoperculum*.

7. THE INTEROPERCULUM (Pl. II., Fig. 1, *IOp.*)

Is a short, stout bone, lying between the apex of the operculum and the posterior extremity of the mandible, with which it is united

[1] *Jordan.*—Manual of N. Amer. Vertebrates, Chicago, 1876.

by ligament. It is also firmly united by ligament to the upper portion of the *epihyal*.

8. THE SUBOPERCULUM,

As above indicated, is seen in the uppermost branchiostegal ray, which occupies exactly the position of the suboperculum in other Teleosts.

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The large anterior extension of the hyomandibular, whereby the metapterygoid is thrust forwards, is a characteristic feature. On examining a young stage it is seen that this extension is not an ossification originally represented by cartilage, but is a growth forwards of the perichondral bone of the hyomandibular cartilage into the membrane lying in front. This appears to have been originally due to the relations of the *R. hyoideo-mandibularis N. facialis*, the growth being later on carried still more forwards for the attachment of muscles. This has resulted in the hyomandibular usurping the position of the metapterygoid, and its functions as regards the origin of the *musc. adductor mandibulæ*, the longitudinal ridge usually being in the metapterygoid.

The relations and origin of the opercular bones at one time aroused much discussion; some light is apparently thrown upon these points by *Amiurus*, but, before enunciating any theory, it may be well to state briefly the ideas of earlier authors.

The earlier writers, such as Geoffroy Saint-Hilaire and Spix, were inclined to consider the opercular bones as comparable to the auditory ossicles of the mammalia. Thus the former terms the preoperculum, the 'tympanal,' the operculum, the 'stapéal,' the suboperculum, the 'malléal,' and the interoperculum, the 'inceal;' while, according to Spix, the same bones are respectively, leaving out the suboperculum, the 'marteau,' the 'enclume,' and the 'étrier.' Cuvier[1] denies these relationships, saying "—— plus on examinera les pièces operculaires, plus on se convaincra que ni leurs connexions entre elles et avec les autres os, ni les muscles qui les mettent en mouvement, ne présentent le moindre rapport avec les osselets dont il s'agit." Neither deBlainville or Agassiz believed in the auditory theory, the former believing the opercular bones to belong to the

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[1] *Cuvier et Valenciennes.*—Hist. nat. des Poissons. Paris, 1828.

subcutaneous system, and the latter to the system of the branchiostegal rays. Hollard[1] sums up his observations thus, " En d'autres termes et pour nous résumer, il résulte pour nous de cette étude que le battant operculaire des Poissons se divise, quant à sa signification anatomique, entre le squelette normal et un squelette supplémentaire et cutané ; que l'interopercule appartient au premier, comme naissant et se développant dans le premier arc viscéral ; qu'il occupe la même place que l'enclume des mammifères ; qu'enfin l'opercule et le sous-opercule, loin de lui faire suite, loin de pouvoir être assimilés aux autres osselets de l'ouïe ou à vrais appendices, sortent des limites du névro-squelette, non, comme le voulait Cuvier, à titre de piéces sans analogues mais en se rattachant au développement si général et si considérable des expansions tégumentaires des Poissons." Owen[2] does not commit himself definitely either way, considering them merely appendages to the " tympano-mandibular arch," but however implies a certain amount of credence in the auditory theory, by referring them to the mandibular rather than to the hyoid arcade. Lastly, Gegenbaur[3] suggests that the interoperculum was originally a part, not of the hyoid skeleton, but of the mandibular.

It is now a recognized fact that the homologues of the auditory ossicles are not to be looked for in the opercular bones, and we have remaining the theories that they are a subcutaneous system, a part of the branchiostegal system, and that the interoperculum is a part of the mandibular arcade. In *Amiurus* they seem to belong to the branchiostegal system, with the exception of the preoperculum. This is formed round a mucous canal, and is one of what may be called the mucous canal series, to which also the infraorbital ossicles belong. Functionally it is not one of the opercular bones but protects the included mucous canal. The suboperculum is properly a bone lying below the lower edge of the operculum. This is the position it holds *Esox*, also in *Salmo*, but in the latter case it is increased in size, and projects largely from under the operculum. In both these forms also it lies on the inner side of the interoperculum. In *Amiurus*, what is usually considered the upper branchiostegal ray bears exactly the same relations. Shortly behind its attachment to the epihyal,

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[1] *Hollard.*- De la signification de l'appareil operculaire des Poissons. Ann. des Sci. Nat., 1864.

[2] *Owen.*—On the anatomy of the vertebrates. Vol. I., London, 1866.

[3] *Loc. cit.*

it lies on the inner surface of the interoperculum, and its outer portion lies below and slightly behind the operculum. Accordingly as above stated, it may be considered as equivalent to the suboperculum of other Teleosts. The operculum and interoperculum seem to have been originally a single ray, which dividing transversely, gave rise to the two bones. They are directly in apposition in *Amiurus*, the lower extremity of the operculum being of the same size as the upper (posterior) extremity of the interoperculum. With regard to the attachment of the latter to the articulare, it may be stated that it is just as firmly attached to the epihyal, which, however, it overlaps, and it is possible that it may, as Gegenbaur suggests, be the only remaining ray of the mandibular arch. However, be that as it may, it is evidently an appendage of a visceral arch, and as such, is homologous with a branchiostegal ray.

My conclusions as to the homologies of the opercular bones are as follows :—*The preoperculum is developed around a mucous canal and does not belong to the same category as the other bones. The suboperculum is a modified branchiostegal ray, and the operculum and interoperculum correspond to another ray which has become divided transversely.*

## IV.—THE BRANCHIAL APPARATUS.

This consists of five arches, each arch consisting of a number of bones, the upper portion of each being bent at an acute angle, so as to lie in a plane almost parallel to that of the lower portion. In other words, the lower portions of the arches lie on the floor of the pharynx, the upper portion in its roof. In a typical arch five portions are present. Below in the middle line, extending between the arch and its successor, is an impair bone, the *copula*. Opposite the anterior end of the copula is a usually short portion —the *hypobranchial*, on the outer side of which lies the *ceratobranchial*, usually the largest of the branchial elements. Between the last-named portion and its successor, the *epibranchial*, the bend occurs, so that the extremity of the arch, formed by a usually small *pharyngo-branchial*, lies near the median line of the roof of the pharynx.

In *Amiurus* (Pl. II. Fig. 3) all the arches do not possess the typical number of bones. Only two copulæ are present, *i. e.*, those between the 1st and 2nd ($cp_1$), and 2nd and 3rd arches ($cp_2$) ; between the 3rd and 4th a cartilage ($cp_{3\text{-}4}$) is present, with the posterior extremity of which the ceratobranchial of the 5th arch articulates, and which probably represents the conjoined copulæ of the 3rd and 4th and 4th and 5th arches. Similarly osseous hypobranchials are not present in all the arches. The 1st and 2nd possess them ($Hbr_1$ and $Hbr_2$) in the form of their round bones, but in the 3rd and 4th ($Hbr_3$ and $Hbr_4$) they remain cartilaginous, and in the 5th appear to be wanting. Ceratobranchials ($Cbr_{1-5}$) are present in all the arches; they are long slightly curved bones, grooved on the under surface for the reception of the branchial vessels and nerves, and carry the majority of the gill-leaflets. The ceratohyal of the 5th arch ($Cbr_5$) however, departs from the normal type. It is flattened from side to side, is not grooved below, has no branchial leaflets, but bears on its upper edge an oval plate of bone possessing a large number of teeth; this is usually known as the *hypopharyngeal* (*PhI*). The epibranchials (Fig. 4, $Ebr_{1-4}$) also bear gill-leaflets to a certain extent, at least those of the 1st and 2nd arches do. These resemble slightly the ceratobranchials, but do not possess so deep a groove on the under surface, being flattened. From near the middle of the posterior border of the 3rd epibranchial a strong process (*pro*) passes backwards, inwards and upwards, serving for the attachment of muscles. The 4th epibranchial ($Ebr_4$) is very broad towards its inner extremities, while the 5th is wanting. The pharyngobranchials are rudimentary also. The 1st is wanting or represented only by cartilage; the 2nd ($Pbr_2$) acts as a copula between 2nd and 3rd epibranchials; the 3rd ($Pbr_3$) has a similar relation to the 3rd and 4th epibranchials; while the 4th and 5th are wanting. Thus none of the elements of the upper moiety of the 5th arch are present. Lying on the under surface, and attached to the 3rd pharyngobranchial and the inner extremities of the 3rd and 4th epibranchials, is a round osseous disc bearing numerous teeth—the *epipharyngeal* (*PhS*). To the anterior edges of the cerato- and epibranchial, and to both the anterior and posterior edges of some, are attached a number of small rays equivalent to the branchiostegal rays of the hyoid arch. These are readily removed from the arches along with the soft parts.

The only points to be noticed here in connection with the branchial arches are the relations of the epi- and hypopharyngeals. These bones are not inherent parts of the branchial arches, as is frequently supposed, but have become secondarily united to them. This is indicated by the fact that they do not belong to the same arches; the hypopharyngeal being attached to the 5th arch, while the epipharyngeal is in relation to the 3rd and 4th arches. A stronger proof of this fact, however, is afforded by a study of the development of these bones. They are then seen to be originally quite distinct from the adjacent cartilaginous branchial arches, and to be formed by the union of the cement-plates of the teeth which they bear, and by a subsequent formation of osseous trabeculæ by osteoblasts. Their morphological significance is not hard to determine. They represent the remains of the *dermal denticles* which originally lined the mucous membrane of the buccal and branchial cavities, and which are still to be seen in those situations in certain *Selaclii*[1].

## V.—THE SPINAL COLUMN.

With regard to this portion of the skeleton, the greatest interest centres round the first four vertebræ and their arches, which have become very much modified in accordance with the development of a series of ossicles within the auditory apparatus and the air-bladder. These anterior vertebræ being thus intimately connected with the auditory sense-organ, will, with greater appropriateness be described in detail in the portion of this work, by Professor Wright, referring to that structure. It will be necessary, however, to denote here briefly the modifications undergone. The body of the *first vertebra* is fully formed, but its transverse processes are rudimentary, while its dorsal arch forms the *stapes* of either side, and a pair of intercrural cartilages present in front of it, are converted into the *claustra.* The body of the *second vertebra* has entirely disappeared, and become fused with the third, the fusion being indicated by two nutritive foramina at the base of the conjoined vertebræ. Its transverse process is wanting, and its dorsal arch becomes converted into the rudimentary *incus.* The body of the *third* fuses with the second and fourth; its dorsal arch is normal, and its spine is represented by the anteriorly directed process, which, arising from the broad flat plate mentioned below, extends forwards and articulates with the supraoccipital and exoccipitals; and its transverse process is transformed into the *malleus.* The *fourth vertebra* is fused with the third and fifth; its transverse process is the broad plate extending out on either side in this region, and its dorsal arch is the backwardly pro-

[1] *O. Hertwig* Ueber das Zahnsystem der Amphibien. Arch. für mikr. Anat. Bd. XI. supplement 1874. See also Jenaische Zeitsch. Bd. VIII. 1874.

jecting process from that plate. The *fifth* is of the normal type, all its parts being present, but its body is united anteriorly with that of the fourth. The bodies of the 2nd-5th are deeply grooved below for the reception of the aorta.

The bodies of the succeeding vertebræ as far back as the commencement of the tail fin are all similar in appearance. They are of the usual piscine amphicœlous type, but they are very much flattened at the centre of their length from above downwards, and a strong longitudinal ridge extends along the lateral surface of each, increasing the appearance of flattening. In the adult the bodies, as well as the arches, are thoroughly ossified, no notachord remaining in the centre of the bodies. In a stage incompletely ossified it may be seen that the notachord is contracted very much vertebrally, expanding rather suddenly as one approaches either extremity of the body, and resuming its full uncontracted size. The lateral ridge seems to be formed by an extension of the ossification into the adherent connective tissue along the lateral line of the column. On the upper and lower surfaces of each centrum, on either side of the middle line, is a ridge, so that viewed laterally the vertebræ do not appear extraordinarily flattened. Posteriorly in each vertebra, *i. e.*, between the attachment of successive arches, these ridges increase in height, thus forming a protection for the spinal cord or aorta between the arches.

The arches are completely ossified, and are firmly anchylosed with the bodies. They unite with the anterior portions of the bodies above and below, enclosing in either case the spinal cord or the aorta. In the more anterior dorsal arches the anterior elevations of the dorsal longitudinal ridges of the centra articulate with the posterior border of the preceding arches, but posteriorly no such articulations obtain. All the dorsal arches, and the hæmal arches also in the tail region, are surmounted with long backwardly directed spinous processes ; those of the 5th-9th dorsal vertebræ inclusive being bifid for the reception of the interspinalia of the dorsal fin. The majority of the vertebræ of the trunk region have their lower arches projecting at right angles from the centrum, forming the transverse processes ; with the 6th-14th of these ribs (ossifications of intermuscular septa) articulate, the upper surfaces of their proximal portions being in contact with the under surface of the distal extremities of the transverse processes. The last two vertebræ of the trunk bear no ribs. The hæmal arches of the last extend almost directly downwards, parallel to each other, and are connected about the middle of their length by a transverse bridge, above which runs the aorta. The first tail vertebra has the hæmal arches firmly united below, but somewhat broadened so as to separate, as it were, the trunk and tail regions. The remaining hæmal arches are exactly similar in appearance to the neural arches of their vertebræ, possessing long spinous processes, certain of which assist in supporting the interspinalia of the anal fin. There is then in *Amiurus* a gradual passage from the transverse processes of the trunk region to the hæmal arches of the tail, and thus a strong argument in opposition to the view that the hæmal arches of the tail represent the transverse processes *plus* the ribs of the trunk.

The typical features are present in all the vertebræ posteriorly until one comes to the region of the *caudal fin* (Pl. II., fig. 5). Here some modifications occur. The neural and hæmal processes of the sixth vertebra (counting from the tail) are the first that are in relation to the caudal fin rays. They do not, however, suffer any modification, and are firmly coalesced with the centrum. So with the arches of the fifth. The spinous process of the lower arch of the fourth ($H_4$) is somewhat expanded, and that of the third ($H_3$) still more so, while that of the second ($H_2$) forms a very broad plate, from the anterior border of which a thin plate extends to the posterior edge of the third arch. The dorsal arches ($N_{6\text{-}2}$) of these vertebræ present no modifications.

The last vertebra is, however, specially interesting. Its upper arches, instead of projecting upwards and backwards, are directly perpendicular to the axis of their centrum. The spinous process ($N_1$) is not coalesced with their upper extremities, but forms a distinct piece connected with them by ligament. The lower arch ($H_1$) is fused with a small lateral process projecting from the lower portion of the body, and expands to a broad plate in apposition with the preceding and succeeding arch. The body is somewhat modified also, wanting the lateral longitudinal ridge and the fossæ above and below it, so characteristic of the other vertebræ.

The notochord extends upwardly and backwards from the last vertebra almost at an angle of 45°. No further trace of centra are to be perceived nor of dorsal arches, but the presence of several coalesced vertebræ in this terminal filament seems to be indicated by the presence of several hæmal arches. Of these there are in all six, the four lying immediately below the terminal filament of the notochord being separated from the other two by a distinct interval, corresponding to the longitudinal axis of the body. The lowest (*A*) (*i.e.*, the one posterior to that of the last vertebral centrum) is fused with the posterior inferior portion of the last vertebral centrum, and bears at its base a slight lateral ridge. It expands very much towards its extremity. being the broadest of all these fin-bearing arches. The next four (*B*, *C*, *D* & *E*) arise from the posterior surface of the last centrum, being fused with it. They are triangular in shape, expanding posteriorly, and diminishing in size from below upwards. The last (*F*) (*i.e.*, that immediately below the notochord) is small, and partly enclosed by the lateral bones enclosing the notochord. It seems to arise from these structures near their base.

We have thus six hæmal arches which are well developed, and specially modified for the purpose of supporting the rays of the caudal fin, the centra and upper arches corresponding to them having become aborted, or perhaps the centra are represented by the last body, several having fused to form it. Lotz[1] has investigated the structure of these vertebræ in Cyprinoids and other fishes, and in the former there appears to be an arrangement very similar to that of *Amiurus*. The specialization however does not seem to have progressed quite so far. In *Barbus* the third or second vertebra bears two dorsal arches. The spinous process of the last dorsal arch is similar to that of *Amiurus*, Lotz naming the free spinous process a 'falsche Dorn,' believing it to be either a part of the true spinous process or a free fin-bearer. I prefer the former hypothesis. The three lower arches, which have no distinct vertebræ, are fused with the last centrum, as in *Amiurus*, but the upper four are independent. It would appear from this that the last vertebral centrum really consists of three fused centra, those of the four upper hæmal arches having become aborted, the fusion of these arches with the last centrum in *Amiurus* being secondary. All these lower arches are tipped with cartilage, but there are no intervening cartilaginous pieces as in *Barbus*.

Extending back from the posterior superior angles of the last centrum on either side of the notochord filament are two bones (*NS*)

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[1] *Lotz.*—Ueber den Bau der Schwanzwirbelsaule der Salmoniden, Cyprinoiden, Percoiden und Cataphracten. Zeit. f. wiss. Zool. XIV., 1864

fused with the centrum below and protecting the terminal filament. Lotz terms these the 'grosse Deckstücke,' and believes them to be 'Bogenstücke des letzten Wirbels.' With this homology I cannot agree, for two reasons. Firstly, the spinal chord does not stand in the same relation to these bones as to the arches of the other vertebræ; it does not pass between them but lies in front (above) them in the groove which they form; posteriorly the rudiment of the nervous tract is partly enclosed, but this arises from the upward growth of the bone posteriorly, and does not correspond to a passage between two arches. Secondly, these bones are not preformed in cartilage, as their development shows, but are formed in membrane, thus belonging to a different category to the arches, which are all preformed in cartilage. These two facts appear to me to dispose of the 'Bogenstücke' theory, and the question arises as to what is their true homology. They seem to correspond both in development and relations to the dorsal longitudinal ridges of the vertebræ. They are direct continuations of these ridges which protect but do not surround the central nervous system, and are developed by an ossification of membrane.

To recapitulate, then, the homologies of the modified ventral parts of these posterior vertebræ: *The free spinous process of the second vertebra is the true spinous process of the arch of that centrum. The last centrum consists of three coalesced vertebræ, the upper arches of which have disappeared. The four succeeding centra and their upper arches have become aborted, leaving only the hæmal arches to represent them. The protecting bones on either side of the terminal filament of the chorda are continuations of the dorsal longitudinal ridges of the vertebræ, and have no relations with the arches.*

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## VI.—THE DORSAL FIN.

The dorsal fin adheres, to a certain extent, to the type of the impaired fins, consisting of fin-rays ossified in membrane, supported by interspinalia, which are preformed in cartilage, but the anterior rays and their interspinalia are modified for the formation of an organ of defence capable of fixation in an erected condition.

Anteriorly there is a small ossification lying in front of the large plate for the support of the defensive spine, united to it by ligament only and situated immediately below the skin. The plate with which it articulates extends backwards as far as the posterior surface of the defensive ray, which it supports. It is of a triangular shape, broader behind than in front, and perforated by three foramina. The two anterior are small, and situated one on either side of the middle line, giving passage to the muscles which erect the small modified ray lying in front of the defensive spine. The third is large, but is divided into two parts by the extremity of the interspinal which supports the small modified ray just mentioned.

This is shaped like an inverted U or a horse-shoe, and rests astride of the extremity of the corresponding interspinal, the two limbs passing down on either side through the large posterior foramen. When erected it slides down over the anterior surface of the interspinal, and the limbs then come into apposition with the preceding expanded interspinal, so that it cannot be depressed until it is drawn upwards again to its original position. The fixation is due to this arrangement, the defensive ray being attached by a strong ligamentous band to the extremity of this modified ray. The interspinal of this horse-shoe ray is partly enclosed by the backwardly projecting and strong spinous process of the fourth vertebra, and additional strength is given by its union, by means of a thin osseous plate, to the succeeding interspinal. Its extremity is smooth and is divided by a slight transverse ridge into two parts, the posterior of which is a continuation of the osseous plate between it and the succeeding interspinal, originally formed in membrane, and, secondarily, united to the bone developed round the cartilaginous interspinal.

The succeeding ray is the defensive one. It is completely osseous, slightly curved, and terminates in a sharp point. Its base is expanded and presents three processes—two lateral, which rest on either side on the horizontal plate already described, and a ventral one which fits into a slight depression immediately behind the extremity of the interspinal of the preceding ray. Immediately above this ventral process is a perforation, which, when the ray is erected, receives the extremity of the preceding interspinal, and above this perforation is a rough surface for the attachment of the ligament by which the ray is united to the preceding one. The interspinal corresponding to this ray is situated in the cleft extremity of the spinous process of the fifth vertebra, and is united with the preceding interspinal by the thin plate already described; above it expands and unites with the horizontal plate forming the surface on which the lateral processes of its ray rests.

The succeeding rays and their interspinalia are not modified. The latter, five in number, lie below in the cleft extremities of the spinous processes of the 6th-10th vertebræ. The rays are slightly expanded and osseous below, but towards the extremities are horny, transversely striated, and branch dichotomously.

A study of the development of these bones throws light on their homologies. The horizontal plate which supports the defensive ray, and the anterior prolongation of it, are formed in membrane (Fig. 10, *hp*). The small ossicle lying in front of it is represented at an early stage by a rod of cartilage, (*Isp.*1), lying almost in the longitudinal axis of the body. The small ∩-shaped bone is also developed in membrane, the bone on which it rests being partly formed in cartilage, (*Isp.*2) and partly (*i.e.*, the posterior part) in membrane. The defensive ray and its successors are formed in membrane, and its interspinal (*Isp.*3) and its successors are preformed in cartilage. These, then, being the facts, one must refer all those bones which are preformed in cartilage to the category of interspinals, and all those formed in membrane to that of rays. Accordingly, the anterior bone, which is united by ligament to the horizontal supporting plate, is the first interspinal, which early (even while completely cartilaginous) has lost its typical position, and the horizontal supporting plate, the anterior portion of it at any rate, is to be considered the ray corresponding to it. The interspinal enclosed within the strong fourth spinous process is then the 2nd, the small ossicle which it supports being the 2nd ray. This second interspinal has a certain amount of membrane united to it ; the lateral flanges which give a *point d'appui* for the limbs of the 2nd ray, the thin plate uniting it with the 3rd interspinal, and the portion of its extremity behind the slight groove (in reality a continuation of the thin plate), being of this nature. The third interspinal is also formed partly of cartilage and partly of membrane-bone, the portion of the horizontal plate in which the 3rd ray rests probably belonging to the membranous portion of the 3rd interspinal, which has coalesced with the modified 1st ray.

The parts of the dorsal fin may be tabulated as follows :—

| | |
|---|---|
| 1st Interspinal .......... | Ossicle in front of horizontal plate. |
| 1st Ray ................. | Anterior part of horizontal plate. |
| 2nd Interspinal .......... | Only slightly modified. |
| 2nd Ray ................. | The ∩-shaped bone. |
| 3rd Interspinal ........ | Slightly modified ; upper portion forms the broad surface for support of 3rd ray. |
| 3rd Ray ................. | The defensive spine. |

The succeeding interspinalia and rays are normal.

## VII.—THE ANAL FIN.

The anal fin is constructed on the normal type, consisting of 21-22 rays, osseous at the base, but horny a slight distance outward. The interspinalia are completely osseous, and are not quite regular in their arrangement to the hæmal processes of the vertebræ, two interspinalia occurring at irregular intervals in the space between two processes.

## VIII.—THE CAUDAL FIN.

The caudal fin is also normal. The rays here are also osseous at the base. Those in the centre are shorter than those above and below, and a few short rays run forwards a short distance above and below upon the body.

The adipose fin, containing no osseous skeleton, belongs more properly to the tegumentary system.

## IX.—THE PECTORAL ARCH AND FIN.

The pectoral arch in *Amiurus* has undergone much modification, and has many points of difference from the arches of such forms as *Salmo* and *Esox*. It consists of two principal divisions, termed by Gegenbaur the *primary* and *secondary shoulder-girdles*. In the majority of the Teleosts the latter is much the larger, the former forming as it were a mere appendage to it. In *Amiurus* this is not exactly the case, for the primary girdle, or at any rate an extension of it, forms a large part of the pectoral arch. All parts of the arch are completely ossified, and considerable modifications are present in relation to the peculiar articulation of the fin ray.

The secondary shoulder-girdle consists of two pieces. The upper or *supraclavicula* (Fig. 1 *SCl*) is a T-shaped bone, of which the upper portion of the transverse limb articulates with the pterotic and epiotic, and almost occludes the opening of the temporal fossa, while the extremity of the vertical limb articulates with the side of the basioccipital, and a process on its ventral surface near its junction with the transverse limb articulates with the stout transverse process of the fourth vertebra. The upper portion of the lower division of the secondary girdle lies in the deep groove between this process and the extremity of the lower portion of the transverse limb.

The lower piece consists of two portions coalesced, which may be denominated the *mesoclavicula* (Fig. 6 *MCl*) and *infraclavicula* (*ICl*), no trace of the constituent parts, however, persisting. Above are three processes. The anterior (*ap*) which projects directly upwards, fits into the deep groove mentioned above; the median (*mp*) projecting backwards and upwards, lies behind the lower portion of the transverse limb of the supraclavicula, and prevents excessive downward and backward motion of the arch; and the inferior (*ip*), which projects directly backwards, lies quite free immediately below the the skin, its outer surface being roughened by minute tooth-like tubercles. The axis of this portion is almost directly vertical, below, however, the bone curves inwards, becomes horizontal, and is united by ligament with its fellow of the opposite side. The upper surface of this portion, which is thin, is smooth. The under surface presents several points for examination. Just below the base of the inferior process mentioned above is a deep semi-circular groove (*sg*), in which the correspondingly shaped basal process of the first fin-ray runs. The ridge which bounds this on the outside is continued downwards and then inwardly on the under surface, and with a corresponding though slighter parallel ridge forms a groove. With the posterior ridge the anterior edge of the coracoid (*cor*) articulates—a broad process (*br*) extending across to the anterior ridge near its outer extremity, and thus forming in this region a canal. By the expanded outer and posterior portion of the coracoid overlapping the under surface of the coalesced meso- and infraclavicula in that region, and not further inwards, another canal is formed, which unites with the one already described, both containing parts of the same muscle. No *post-clavicula* is present.

The two pieces, *coracoid* (*cor*) and *scapula* (*sc*), of which the primary girdle is originally formed have also become quite coalesced.

The foramen (*for*), however, which usually occurs between them, is still present and indicates that while the scapular portion is very small the coracoid has reached a very great degree of development, meeting with its fellow in the middle line, and being united to it by sutural union. This coracoid has been described (by Huxley for instance) as the clavicle, but this must be a mistake, for in a well macerated skeleton, this portion separates perfectly from the portion in front, the clavicle, showing that these two are not the same. If the extension of the coracoid, towards the middle line, seen, for instance, in the *Gadidæ*, be continued still farther, the arrangement which obtains in *Amiurus* will result. The upper surface of these coalesced bones presents no point worthy of special notice, but on the ventral surface of the outer portion the following points may be noticed. First of all there is the bridge-like process (*br*) which extends over to the anterior ridge on the under surface of the *infra-clavicula*, and at its base a high ridge (*r*) is to be seen which diminishes rapidly as it passes inwards, and is soon lost. Slightly exterior to this is a small rod-like process (*rp*), which articulates with the inner basalia of the fin, and from its base a fine spicule of bone (*sp*) passes transversely across to the posterior margin, its anterior portion giving an articular surface to certain of the *radialia*. This spicule forms an arch through which a muscle runs and just below its anterior point of attachment is the foramen between the scapular and coracoid portions.

From the arrangement of the articulations of the fin, and from general characters, I am inclined to refer to the scapula, the thin triangular portion, which is well marked off, and whose limit on the exterior edge would be a line drawn from the base of the rod-like process for the inner basale. The spicule-like arch belongs probably to the coracoid portion.

The fin consists of two principal rows of elements. The proximal row consists of three elements, two osseous and one cartilaginous. The posterior element (the fin being erected) is osseous, a rather slender rod tipped with cartilage at either end. Proximally it does not reach the pectoral arch, a small cartilage intervening. This is Huxley's[1] *metapterygial basale*. The next element, proceeding

[1] *Huxley.*—Anatomy of the Vertebrates. London, 1871.

anteriorly, is similar in appearance, but stouter. Distally, like the basale, it supports the fin rays, but proximally it articulates with the upper surface of the anterior extremity of the spicule-like bridge. Between the distal ends of this, which is a *radial* and the *basale*, is a small cartilage, embraced by the fin-rays. The next element, anteriorly, is a large cartilaginous nodule, articulating with the extremity of the rod-like process of the coracoid, and supporting the fin rays. It probably represents another radial. Huxley's *mesopterygial basale* is here, as is usual, ossified with the anterior fin ray.

Concerning the majority of these structures nothing need be said but that they are on the same plan as the rays of the unpaired fins. The most anterior ray (fig. 7), however, requires special mention. It is completely ossified, terminates in a sharp point, and has the posterior edge serrated. By special arrangements it can be firmly fixed in the erect position, and can only be depressed by rotation through an angle of 90° ; it is therefore an important weapon for defence or offence. These arrangements are as follows :—From the upper surface of the base (the original mesopterygial basale) a high semi-circular ridge (*sr*) arises, and the proximal extremity terminates in two processes (*tps* and *tpi*), including a deep groove between them. When the fin is erected the semi-circular ridge runs into the semi-circular groove (fig. 7 *sg*) at the base of the inferior process of the mesoclavicula, and at the same time the outer edge of the coracoid is received into the groove between the two terminal processes. Movement directly forward or directly backward is now effectually prevented, and flexion can only be accomplished by rotation, when the ridge slips out of its groove, and the outer edge of the coracoid out of its groove.

The terms applied to the different parts of the pectoral arch have varied much at different periods. The following table will illustrate this :

| Terms here Employed. | Bakker. | Geoffroy. | Cuvier. | Stannius. | Owen. | Huxley. | Gegenbaur. |
|---|---|---|---|---|---|---|---|
| Scapula. | | Humerus. | Cubitus. | Ossa Carpi. | Radius. | Scapula. | Scapula. |
| Coracoid. | | | Radius. | | Ulna. | Coracoid. | Coracoid. |
| Supra-clavicula | Omoplate. | Omolite. | Surscapulaire. | Omolita. | Suprascapula. | Post-temporal. | Supra-clavicles. |
| Meso-clavicula. | Acromion. | Omoplate. | Scapulaire. | Scapula. | Scapula. | Supra-clavicula. | |
| Supra-clavicula | Cœnosteon | Clavicula. | Humerus. | Clavicle. | Coracoid. | Clavicle. | Clavicle. |
| Post-clavicula. | | | (Coracoideum.) | | Rib. | Post-clavicula. | Accessory piece. |

## X.—PELVIC ARCH AND FIN.

The pelvic arch consists of two similar pieces united in the middle line. The anterior part of each piece is very thin, and is produced into a point at the outer angle. The posterior edge is rounded, and gives articulating surfaces for the rays of the ventral fin—eight in number. Posteriorly in the middle line there is a horse-shoe shaped cartilage, the concavity of which is directed backwards, the two limbs of which give attachment to portions of the infracarinales muscles. Cristæ for the attachment of muscles traverse the thin portion, and the posterior border is edged with cartilage. According to Davidoff[1] these bones are not homologous with the pelvis of the Elasmobranchs, but correspond to the metapterygial basalia much enlarged. The pelvis of *Amiurus* corresponds very closely to the description of that of *Barbus fluviatilis* given by the same author, the horse-shoe shaped cartilage representing the stout posterior process as in that form.

The reduction of the radialia which characterises the Teleosts when compared with Elasmobranchs and Ganoids is here carried to its greatest extreme, these structures being entirely absent. The fin-rays have the usual character.

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Having now described the structure of the various parts composing the skeleton of this Siluroid, it remains to point out one or two generalizations with regard to it. In the first place its relation to the Cyprinoids is close, as evidenced by the modifications of the anterior and the tail vertebræ, and also by the relations of the auditory apparatus.

Secondly, there is evidence that the Siluroids have branched off at a very early period from the primordial Teleosts. This is shown, as has been already stated, by the almost complete ossification of the skull, and also by the extent of the specialization of the various parts. The canal for the orbital muscles has almost disappeared, showing that *Amiurus* has passed through a stage in which it possessed a complete canal, a stage in which the Cyprinoids still remain. The perfectness of the arrangements for the fixation of the

[1] *Davidoff*.—Beiträge zur vergl. Anat. d. hinteren Gliedmasse d. Fische. Morph. Jarhb. VI. 1880.

anterior ray of the pectoral fin also points to the lapse of a considerable period of time, during which small successive changes have been wrought, and the extent of the modifications of the dorsal fin for the same purpose point to the same conclusion. Other evidences of a similar nature are to be seen in the absence of any neural arches corresponding with the hæmal processes which support the rays of the caudal fin, and in the complete abortion of the radialia of the ventral fin.

All these latter points are, however, subordinate to the first in determining the relative position of *Amiurus*. Since the course of development, as is shown both by the ontological history of any form, and by the study of the various vertebrate groups, leads from a purely cartilaginous to a purely osseous skeleton, the amount of cartilage present in the skeleton of any fish is in indirect relation to the extent of its development. This character is necessarily less subject to the modification of external conditions than other parts, so that even though certain of these may undergo great specialization, yet if a considerable amount of cartilage be present in the skeleton, the form under consideration must be considered as standing comparatively low in the group. The Lophobranchiates, for instance, have undergone modifications, even more striking than those of *Amiurus*, but since the relative amount of cartilage in the skull is greater, and the parts modified may all be readily influenced by the conditions of existence, the members of this group must be placed lower among the Teleosts than *Amiurus*.

In conclusion, a few words concerning the process of ossification. From what has already been said in this paper, it will be seen that what may be termed several modes of ossification are present. We have, in the first place, the deposition of the bone in general connective tissue, forming certain of the 'Deckknochen,' and the bones around the mucous canals; we have, secondly, cement-bone, as in the premaxillæ and dentary; and we have, thirdly, perichondral bone, as in the prootic, palatine, etc. It has also been shown that all these forms of bone formation pass into one another perfectly, no dividing line marking the termination of one form and the commencement of another. Not only, however, do they thus pass into one another, but they also replace each other. This is very evident in the case of the frontal, maxillæ, vomer, parasphenoid and mucous canal bones. At one time these bones were probably formed by the union of the cement plates, as has been shown by Hertwig,[1] but in the process of time, by a shortening of their developmental history, the bone came to be deposited directly in membrane, without any previous tooth-formation. The same thing may happen with certain perichondral bones, as, for instance, the palatine and the branchial arches. These in some Teleosts are formed from cement-bone, but in *Amiurus* are developed perichondrally, a shortening of the development again taking place.

But not only are these different varieties of bone identical in their histological features, and not only are they able to replace each other, but they also are identical in their histogenesis. In all osteoblasts are present (either transformed cartilage or connective tissue cells) and secrete the calcareous matter which is deposited in an organic non-cartilaginous substance. This is very evident in the case of the 'Deck-knochen' and mucous-canal bones. It is also the case with cement bones which are formed of osseous trabeculæ deposited in membrane by means of osteoblasts, the cement plates of the teeth themselves arising, "theils direct als Abscheidung einer zelligen Anlage (cement membran), theils durch Verknöcherung des den Zahn ungebenden Bindegewebes[2];" so that the formation of the subsequent osseous trabeculæ is merely a continuation of the original process which formed the individual cement plates. And again, with regard to the perichondral bone the same thing may be shown to obtain. With the growth of the bone secreted by the osteoblasts there is a concomitant absorption of the cartilage, the cartilage cells probably being partially transformed into osteoblasts, by whose agency new trabeculæ are formed occupying the place of the lately absorbed cartilage, there being no deposition of the calcareous matter in the cartilaginous matrix. This is what occurs in centripetal perichondral bone[3]. The processes in centrifugal perichondral bone are similar to those to be seen in the formation of cement-bone.

In the dentary portion of the mandible there is a combination of the cement process with the centrifugal perichondral process, in which union of processes is seen the close relationship between perichondral and cement-bone. For exactly the same process goes on as in the premaxillæ and the palatines. The osteoblasts which have given rise to one individual cement plate carry on their work of bone

[1] *O. Hertwig—loc. cit.* [2] *O. Hertwig—loc. cit.* [3] See *Schmid-Monnard—loc. cit.*

formation, producing osseous trabeculæ which replace the cartilage as it becomes absorbed, so that one might justly term the dentary a cement bone.

It has now been shown that membrane-bone, cement-bone, and perichondral bone can replace each other, that they are identical in their histological characters, and also that they are identical in their mode of formation. A comparison of the upper portions of the premaxillæ with the frontals shows that the process of bone formation is in both cases the same, and similarly a comparison of the dentary with the palatine or prootic shows that the centripetal perichondral method can start and be in relation with cement bone just as well as centrifugal perichondral bone ; for in the prootic, palatine, etc., a layer of bone is first deposited outside the cartilage and by the formation of trabeculæ in connection with this, and extending out into the surrounding connective-tissue, the bone grows in thickness. There can be no good reason, then, on histogenetic grounds, for the separation of these varieties into different groups.

The Gegenbaurian distinction of bones into primary and secondary[1] is now proved to be imperfect, and consequently also Vrolik's[2] classification of bone formation into *perichonrostotisch* and *enchondrostotisch.* Walther[3] from his observations on the pike, classifies the various kinds of bone thus :—

| | |
|---|---|
| Hautknochen | 1. Cementknochen (primäre Deckknochen).<br>2. Bindegewebsknochen (secundäre Deckknochen).<br>3. Perichondralknochen (centrifugal wachsend). |
| Knorpelknochen | 1. Perichondral (centripetal wachsend).<br>2. Enchondral (Bildung von Knochenkernen). |

Göldi, again, in a very recent paper, objects to Walther's distinction between centrifugal and centripetal perichondral bones and classifies thus :—

| | |
|---|---|
| I. Hautknochen | 1. Cementknochen.<br>2. Bindegewebsknochen. |
| II. Perichondrale Knochen | 1. Exo-perichondral (centrifugal wachsend.)<br>2. Endo-perichondral (centripetal wachsend), |

and refers to a third group endrochondral bones, *i. e.*, those formed from a centre of ossification in the centre of the cartilage.

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[1] *Gegenbaur*—Elements of comparative anatomy.

[2] *Vrolik—loc. cit.*

[3] *Walther* —Die Entw. d. Deckknochen am Kopf-skelet des Hechtes (*Esox lucius*). Jen. Zeit. Bd. XVI., 1882.

It is a question whether from the facts of development one is entitled to lay such stress upon the presence of cartilage, and thus to separate so distinctly the perichondral from the membrane bones. I should prefer to have two classes of bone-formation (I.) that in which the calcareous matter is first deposited in the centre of the cartilage, and (II.) that in which it is not. In the first class enchondral bone would be placed and in the second the other four. But since such classification should indicate the ontogeny of the bone as well as its histogenesis, since the preformation of a bone in cartilage is of great use in determining its homologies, the second class should be subdivided. My classification would then be as follows :—

I. Bones developing from ossificatory centre in the cartilage.
  1. Endochondral bone.

II. Bones which do not develope from ossificatory centre in the cartilage.
  A. Bones preformed in cartilage :
    1. Exoperichondral (centrifugal).
    2. Endo-perichondral (centripetal).
    3. Cement bones which replace cartilage.
  B. Bones not preformed in cartilage :
    1. Membrane bones.
    2. Cement bones which do not replace cartilage.

*Guelph, February 25th, 1884.*

# THE MYOLOGY OF *AMIURUS CATUS* (L.) GILL.

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[*Read before the Canadian Institute, April the 5th, 1884.*]

The group of the physostomous fishes shows many structural divergences from the common type, and in the osseous and muscular systems this fact is especially noticeable. In no large group do we find the structure identical throughout the various members, but variations occur sometimes in one, sometimes in another particular, according to the natural conditions under which the animal exists. The osseous and muscular systems being so closely related, one would naturally expect to find great modifications of the one accompanied by equal modifications of the other, the extraordinary development of a muscle causing an extraordinary development of the parts to which it is attached, and, *vice versa*, the modification of a bone for any special purpose being accompanied by a suitable modification of the attached muscles.

Vetter[1] has given a detailed account of the myology of the head and arches of *Cyprinus*, *Barbus*, *Esox* and *Perca*; Cuvier[2] before him a complete account of the musculature of *Perca*; and similarly Owen[3] and Stannius.[4] In the succeeding pages I propose giving an account of the myology of *Amiurus catus*, a Siluroid, and comparing it with that of other members of the Physostomi, with the object of showing the coördinate modifications of parts and of deducing probable homologies. I may state here that I am indebted to Prof. R. Ramsay Wright for information regarding the innervation of the various muscles, he having studied this subject, so necessary in discussing homologies, in connection with the nervous system of *Amiurus*. In connection with the muscles of the head and arches, in drawing com-

[1] *Vetter*—Untersuchungen zür vergl. Anat. der Kiemen, und Kiefer-Muskeln der Fische. Th. II., Jen. Zeit. Bd. xii.

[2] *Cuvier et Valenciennes*—Hist. Nat. des Poissons, Paris, 1828.

[3] *Owen*—On the Anatomy of Vertebrates, Vol. I., London, 1866.

[4] *Stannius*—Handbuch der Zootomie, Bd. I.

parison with other forms when no authority is given for statements regarding these, it may be assumed that they are drawn from Vetter's paper.

I shall divide the various muscles into the following groups, according to their present relations :—

I.—Mandibular Muscles.
II.—Muscles of the Palatine arch.
III.—Opercular Muscles.
IV.—Muscles of the Hyoid arch.
V.—Muscles of the Branchial arches.
VI.—The Trunk Musculature.
VII.—Muscles of the Pectoral arch and fin.
VIII.—Muscles of the Pelvic arch and fin.
IX.—Muscles of the Dorsal fin.
X.—Muscles of the Anal fin.
XI.—Muscles of the Caudal fin.

## I.—MANDIBULAR MUSCLES.

In removing the integument from the side of the skull, one exposes a strong fascia, attached above to the frontal and supraoccipital bones, and covering the large *adductor mandibulæ*. Behind, it is attached to the descending ridge of the supraoccipital, and thence passes to the posterior border of the hyomandibular, preoperculum, and quadrate, whence it is continued on to the mandible. In front it contains behind the eye the chain of infraorbital bones. Passing below the eye, it passes forward and is attached to the antorbital process, continuing on over the nasal region, and containing the nasal and adnasal bones, to be finally inserted into the premaxillæ. On removing this fascia one exposes the

1. Adductor Mandibulæ, (No. 20, Cuv.; *Retractor oris*, Owen; *M. Masseter*, Ag.) (Pl. III., Fig. 1, AM.)

This is a broad thick muscle, which fills up the depression on the side of the skull. It arises from a semicircular ridge commencing anteriorly and above on the outer edge of the ectethmoid, extending thence along the frontal and supraoccipital. The muscle covers the sphenotic and pterotic, from the edges of which fibres also originate. Descending posteriorly, the line of origin passes along the posterior edge of the hyomandibular and preoperculum, and thence to the quadrate. Certain fibres also take origin from the surface of the hyomandibular and from the transverse ridge on that bone. These fibres are at first distinct from the main muscle but soon unite with it. The lower fibres pass obliquely forward, and are inserted directly into the posterior edge of the process of the articulare, uniting partly with the remaining fibres. These converge towards the inner surface of the mandible, uniting to form a tendon on the inner surface of the muscle which is inserted into the longitudinal ridge on inner surface of articulare and the inner surface of the dentary, Meckel's cartilage receiving also some fibres.

*Innervation.*—It is supplied by the *trigeminus.* The deeper portions are supplied by a branch arising from the upper lateral strand of the trigeminus before its division into the superior and inferior maxillary branches. The superficial portions are innervated by a branch arising just behind this.

*Action.*—The *add. mand.* raises the jaw after it has been depressed by the *geniohyoid*, and is therefore the opponent of that muscle.

In most Teleostei the *add. mand.* consists of three portions, of which the upper passes to the maxilla, the others to the mandible. In *Esox*, an arrangement more related to that occurring in *Amiurus* obtains. The superficial portion is wanting, but the other two portions are distinct. Of these the upper, arising from the upper part of the semicircular ridge and inserted into the inner surface of the articulare and Meckel's cartilage, corresponds to the upper portions of the muscle in *Amiurus* ; while the deeper one, arising from the metapterygoid and lower part of the semicircular ridge and inserted into Meckel's cartilage, a tendon uniting with that of the upper portion, corresponds with the lower portion of the muscle in *Amiurus* plus that arising from the transverse ridge and surface of the hyomandibular which here usurps the position of the metapterygoid, the slight difference in the insertion being no greater than that which obtains in *Esox* and *Barbus* in the deeper portions, which in these forms are clearly homologous. From the position of the muscle one may conclude that it is an angular structure, *i.e.*, belonging equally to the upper and lower moieties of the first post-oral arch, and this conclusion is confirmed by the innervation, the supplying branches leaving the trunk of the trigeminus before its division into the superior and inferior maxillary branches. Since the maxilla is a splint-bone belonging to the upper half of this arch, one would suppose that originally it received a portion of the muscle, and that the arrangement now seen in *Cyprinus*, *Barbus*, and *Perca*, is the older one, that of *Esox* and *Amiurus* being the later modification.

2. Adductor Tentaculi.—(Pl. III., Fig. 1, and 2, AT.)

On cutting through the insertion of the *add. mand.* and reflecting it, a muscle is exposed which is apparently characteristic of the Siluroids. It arises from the outer surface of the metapterygoid, its upper portion being covered by the *lev. arcûs palatini.* It runs forward beneath the *add. mand.*, forming the inferior boundary of the orbit and being crossed by the fifth nerve. Anteriorly it becomes tendinous, the tendon near its insertion dividing into two slips, between which the nerve supplying the tentacle passes. One of these slips is inserted into the upper, the other into the lower border of the base of the maxilla, which encloses the proximal portion of the tentacle.

*Innervation.*—It is supplied by a branch of the same nerve that supplies the deeper portions of the *add. mand.*

*Action.*—It draws the tentacle backwards towards the middle line, opposing the anterior portion of the *add. arcûs palatini.*

The position and innervation of this muscle leads to the conclusion that it is a part of the *add. mand.* which has been separated off for a particular purpose. It does not, however, compare with any of the three parts of that muscle in *Barbus* or *Perca*, nor even with the fourth part, which is sometimes present, as in *Cyprinus*, since this is formed by a division of the superficial portion. Since the osseous support of the long tentacle is the maxilla, this muscle bears a certain amount of analogy to the superficial portion of the *add. mand.*, but it cannot be its homologue. The relation of the maxilla to the tentacle was probably secondary, and since the power of moving the tentacle would always have been an advantage it is probable that originally the muscle was inserted into the tentacular cartilage, its insertion into the maxilla only occurring after that bone had commenced to be a support and had enclosed the base of the tentacle. There are two theories which will account for the presence of this muscle. (1) It may be a new structure evolved for a particular purpose, or (2), it may be the representative of a muscle present in ancestral forms but which has disappeared in all the *Teleostei* hitherto examined. If the latter is the correct explanation, one should be able to point to homologous muscles in the lower forms. Can this be done? As to the Ganoids, to which one would naturally turn, I have not been able to consult any account of their musculature, with the exception of Vetter's description of *Acipenser*, in which, apparently, no homologue is present.[1] In the Elasmobranchs[2] however, there are muscles with a certain amount of similarity. In *Chimæra* the *lev. anguli oris* consists of two portions, of which the posterior arises principally from the lower border of the orbit, is inserted into the inner surface of the posterior inferior labial cartilage, and is innervated by twigs from the *R. maxillaris inferior trigemini.* The *Plagiostomi* present a muscle even more analogous. It is absent in *Heptanchus*, in *Acanthias*, but strong in *Scyllium*, and arises from the under surface of the orbital regions of the skull. It passes forwards and is united by connective tissue to the posterior superior labial cartilage, union occurring also with the *add. mand.* It is innervated by a twig of the second branch of the *trigeminus*, which runs over the muscle into the integument of the upper lip. Vetter terms this muscle the *lev. labii superioris.*

The difference between this muscle and the *add. tent.* may possibly be explained by the presence of the membrane bones in the Teleostean skull, but nevertheless it seems that the first hypothesis is to be preferred. As I have already shown in a preceding paper, the Siluroids must have branched off very early from the original stem of the Teleosts, and have undergone much specialization. The presence of the tentacle itself is a great specialization, and since it would be of advantage to the fish that this should be capable of voluntary movement, there would be a tendency for a separation of certain fibres of the *add. mand.* for this purpose, which tendency would in the course of time result in the production of a perfectly distinct muscle. The innervation points very strongly to this theory, and the adaptation of the anterior fibres of the *add. arcûs palatini* to act as an *abductor tentaculi* also accords with it.

3. Musculus Intermandibularis, (No. 21, Cuv.) (Fig. 3, Im.)

This muscle is seen on removing the integument from the under surface of the head. It lies immediately behind the symphysis of the mandible, running transversely from one ramus to the other.

1 *Vetter—Loc. cit.*

2 *Vetter*—Untersch. zür vergl. Anat der Kiemen-und Kiefer-Muskeln der Fische. Th. I., Jen. Zeit. Bd. viii.

*Innervation.*—A branch from an anastomosis of *R. maxillaris inf. trigemini* and *R. hyoideo-mandibularis facialis.*

*Action.*—Prevents the separation of the rami of the mandibles whether from pressure within or from the action of the *lev. arcûs palatini.*

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## II.—MUSCLES OF THE PALATINE ARCH.

1. Levator Arcûs Palatini, (No. 24, Cuv.; *Lev. suspensorii,* Stan.; *Lev. tympani,* Ow.) (Figs. 1 & 2, LAP).

This is exposed on cutting through the upper and posterior portions of the insertion of the *add. mand.,* and reflecting it. The muscle may be described as consisting of two parts. The *anterior* portion is triangular and thick, and arises from the posterior border of the antorbital process and from the inferior surface and the edge of the ectethmoid and frontal. Its fibres arching over the orbit and passing below the *add. mand.,* unite to a tendon, which is inserted into the extremity of the transverse ridge of the hyomandibular. The *posterior* part is quadrangular and thin, and arises from the edge of the sphenotic. Those fibres arising from the rudimentary postorbital process are at first tendinous but soon become muscular, and, along with the more anterior ones, pass directly downwards to be inserted along the whole upper surface of the transverse ridge on the hyomandibular, a few fibres passing to the surface of the bone above the ridge.

*Innervation.*—It is supplied by a branch from an independent strand of the *trigeminus* which accompanies the *R. maxillaris sup.*

*Action.*—It raises the palatine arch. The anterior triangular portion will also pull it forwards.

This muscle is very similar in its relations to that of *Esox,* but differs slightly from that of other forms. The innervation differs also slightly, Vetter describing it in the forms he studied as being by a branch from the *R. maxillaris inferior.* Here, however, the independent strand must be equivalent to this branch, since like it it also supplies the *dilatator operculi.* The great differentiation which the trigeminus shows accounts for these slight dissimilarities.

2. Adductor Arcûs Palatini, (No. 22, Cuv.; *Constrictor,* Stan.; *Depressor tympani,* Ow.)

This consists of two distinct parrs. The posterior portion is exposed by removing the branchial and lower part of the hyoid apparatus and so exposing the under surface of the skull. It is covered below by a dense fascia, in the anterior prolongation of which is the bone denominated No. 4. This *posterior portion* arises from the edges and the ascending process of the parasphenoid, and from the contiguous surface of the prootic. The fibres pass directly outwards and are inserted into the inner surface of the metapterygoid and anterior portion of the hyomandibular. The *anterior portion* may best be seen on the outer surface of the skull, after removing *add. mand.* and *lev. arc. pal.*. It arises from the parasphenoid, orbitosphenoid and upper surface of No. 4, which is developed in the fascia covering its inner surface. It passes outwards and is inserted into the inner surface of the posterior half of the palatine.

*Innervation.*—Both muscles are supplied by a special branch of the facial—the *R. musc. add. arcûs palatini.*

*Action.*—The posterior portion depresses or adducts the palatine arch after it has been raised or abducted by the *lev. arc. pal.* The anterior portion acts directly on the posterior extremity of the palatine, and indirectly through it on the tentacle. By pulling the posterior extremity of the palatine inwards it forces its anterior extremity outwards. To this is attached a portion of the dense fascia which covers the antorbital process and adjacent parts, fibres of which are also inserted into the base of the maxilla. When, therefore, the muscle acts, the fascia is rendered tense, and by the arrangement of the osseous parts acts on the maxilla, drawing the tentacle forwards. This anterior portion acts therefore as the opponent of the *add. tent.*

The muscle in *Esox* corresponds to the posterior portion in *Amiurus*, the anterior portion being apparently wanting. In *Cyprinus*, however, the origin is continued forward on the orbitosphenoid, and is more like what has been described. In neither of these forms, however, do any fibres pass to the palatine, being wholly confined to the metapterygoid and entopterygoid, and extending in *Perca* back to the hyomandibular. At first sight the anterior portion does not seem to have any relation to the posterior, since, from its lying on the outer (upper) surface of No. 4, it seems to belong rather to the outer surface of the skull than the inner. But, when the relations of that bone are considered, it is at once evident that this anterior portion is a special modification of the anterior fibres of a muscle similar to that of the Cyprinoids.

3. ADDUCTOR HYOMANDIBULARIS, (No. 26, Cuv. in part; *Depressor suspensiorii*, Stan.; *Depressor operculi*, Ow., in part.)

This muscle is very closely related to the *add. operculi*, lying immediately in front of it and partly overlapped by it. It arises from the lower surface of the pterotic, and passes downwards, outwards and forwards, to be inserted into the hyomandibular immediately above the opercular process.

*Innervation.—Ramus opercularis facialis.*

*Action.*—It aids the *add. arc. pal.*

The relations of this muscle correspond almost exactly with those of the corresponding muscle in *Perca*. In *Esox*, however, it is merely a part of the *add. arc. pal.*, while in the Cyprinoids it has a much greater origin and insertion than in any of the other forms.

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## III.—OPERCULAR MUSCLES.

1. LEVATOR OPERCULI, (No. 25, Cuv.) (Figs. 1 & 2, LOp.)

The levator of the operculum is exposed by removing the integument from the side of the head and stripping off the posterior continuation of the fascia covering the *add. mand.* This posterior continuation is not directly continuous with the anterior portion, but takes origin from the posterior edge of hyomandibular and preoperculum, and is attached above to the edge of the pterotic and below to the upper surface of the operculum, being posteriorly continuous with the fascia covering the trunk musculature. The muscle arises from the posterior edge of the ridge on the hyomandibular, and from the edge of the pterotic. Its fibres are directed downwards and slightly backwards, and are inserted into the whole upper border of the operculum.

*Innervation.—R. opercularis facialis.*

*Action.*—It pulls the operculum upwards and slightly forwards, helping the dilatator.

2. DILATATOR OPERCULI, (No. 25, Cuv., anterior part; *Lev. operculi*, ant. part, Ow.) (Fig. 2, Dil. Op.)

This muscle lies immediately below and behind the *lev. arc. pal.*, and is closely related to it. The anterior part forms a very strong tendon, which arises by muscular fibres from the under surface of the frontal and ectethmoid above the orbit and below the first portion of *lev. arc. pal.* The tendon passes obliquely backwards and is inserted into the anterior and upper surfaces of the process by which the operculum articulates with the hyomandibular. The origin of the muscle is continued backwards on the ventral surfaces of the frontal and sphenotic, a few fibres arising from the latter behind the postorbital process, and posteriorly a few take origin from the surface of the hyomandibular and from the ridge on its posterior superior angle. The majority of these fibres unite with the strong tendon, only those which arise from the hyomandibular being inserted directly into the opercular knob.

*Innervation.*—It is innervated by a branch of the nerve which supplies the superficial portion of *add. mand.*, *i. e.*, a branch from the *trigeminus* arising behind the branch for the deep portion of *add. mand.* and *add. tent.*

*Action.*—Raises the operculum, and swings it outwards on its articulation with the hyomandibular.

In *Esox* this muscle is weak and does not extend forwards beyond the posterior extremity of the articulation of the hyomandibular with the pterotic. In *Perca* it reaches the sphenotic, but in none does it extend as far as in *Amiurus.* In other Teleosts the innervation is from twigs from the branch of *R. max. inf. trigemini*, which supplies the *lev. arc. pal.*, while here the innervation would indicate a closer relationship with the *add. mand.*

3. Adductor Operculi, (No. 26, Cuv.; *Depressor operculi*, Stan. et Ow.)

This may be seen by cutting through the insertion of the *levator operculi* and reflecting it, or better, by the dissection required for exposing the *add. arc. pal.* and *add. hyomand.* It arises from the inferior surface of the pterotic, and is inserted into the posterior edge of the upper border and the upper part of the inner surface of the operculum.

*Innervation.*—*Ramus opercularis facialis.*

*Action.*—Approximates the operculum to the side of head, and is therefore the opponent of *lev.* and *dil. operculi.*

## IV.—MUSCLES OF THE HYOID ARCH.

1. GENIOHYOIDEUS, (No. 27, Cuv.) (Fig. 3, GH).

This muscle which runs along the inner side of the ramus of the mandible, may be exposed by removing the integument from the lower surface of the skull and turning back the *intermandibularis* which covers its insertion. It arises from the posterior portion of the lower (ventral) and outer surfaces of the ceratohyal, and also from the epihyal at the bases of the upper branchiostegal rays. It passes forwards as a thick muscle, inclining slightly inwards towards its fellow of the opposite side, the inner fibres being inserted into a median aponeurosis between the two, no interdigitation occurring. The greater bulk of the muscle inclines outwards, and is inserted into the posterior surface of the anterior part of the ramus of the mandible, being partly covered by the intermandibularis. Crossing the anterior portion of the muscle obliquely are two tendinous bands, (Fig. 3, ti, ti[1]), to which are attached the cartilaginous supports of the tentacles of the under surface.

*Innervation.—R. hyoideo-mandibularis facialis.*

*Action.*—According as the hyoid or mandibular arches are fixed this muscle acts in different ways. If the hyoid is fixed by the *hyoclavicularis* it acts on the mandible, depressing it. This is its usual action. If, however, the mandible is fixed by the powerful *add. mand.*, it raises the hyoid arch and through it the operculum, thus aiding the *lev.* and *dil. operc.* Through the tendons which pass across it, it is the means by which the tentacles resting on these tendons move, but the range of motion thus imparted is very small.

The simplicity of this muscle contrasts somewhat with what occurs in *Esox*, and agrees more closely with the arrangement in *Barbus.* In *Cyprinus* the origin is similar, and in *Barbus* the muscles of either side do not interdigitate as they appear to do in other fishes. In *Esox* and *Cyprinus* a median enlargement of the muscle occurs. The tendinous bands are of course peculiar to the Siluroids.

2. HYOHYOIDEUS, (Nos. 28 and 29, Cuv. ; *Lev.* and *Dep. branchiostegarum*, Ow.)

This is exposed by the dissection required for the preceding with the removal of the integument from the branchiostegal rays. It may be considered as being composed of two portions, of which the posterior belongs essentially to the branchiostegal rays. This portion (Fig. 3, Hh[1]) arises from the inner surfaces of the operculum and interoperculum, extending from them to the dorsal border of the first branchiostegal ray Thence it passes below that ray to the dorsal border of the second, and so on to the most internal ray, becoming narrower as it nears the median line, and having its central fibres better developed than the lateral ones. From the last ray the muscle extends upwards and forwards, and is inserted into the aponeurosis which separates it from its fellow.

The anterior portion (Fig. 3, Hh[2]), arises from the upper border and surface of the ceratohyal and hypohyal, and passing inwards is inserted into the aponeurosis between it and its fellow.

*Innervation.*—*R. hyoideo-mandibularis facialis.*

*Action.*—Both portions act as constrictors. The posterior portion will close the aperture of the gill cavity by shutting down upon it the branchiostegal membrane. The complete closure of the "gill-slit" is necessary in order that the hyoid apparatus and its muscles may properly perform their pumping action. The anterior portion approximates the hyoid arches, and thus aids the posterior portion, drawing the whole hyoid apparatus towards the side of the skull.

The *hyohyoideus* varies somewhat in different forms. In *Esox* it passes as a continuous sheet over the branchiostegal rays, not passing from one to the other as in *Amiurus* and the Cyprinoids. In *Perca* and *Esox* the muscle passes directly across to the hyoid arch of the opposite side, and in the latter there is a separation into two bundles of which the outermost passes forward and is inserted into the ceratohyal and hypohyal, and therefore corresponds to the anterior muscle of *Amiurus*. In *Perca* neither Stannius nor Cuvier nor Owen describes an anterior portion, but Owen states[1] that "In some fishes a transverse muscle, repeating the characters of 21, Fig. 135, (*i. e.*, the intermandibularis), passes from one ceratohyal to the other." Vetter terms that portion of the muscle which runs between the branchiostegal rays the '*hyohyoideus superior*,' grouping those portions coming from the most internal ray and from the ceratohyal together as the '*hyohyoideus inferior*,' an arrangement which in *Esox* is quite proper, but will not hold with *Amiurus*.

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[1] *Owen.—Loc. cit.*

3. Hyopectoralis, (No. 1 Cuv.; *Retractor hyoidei*, Ow.; *Sterno-hyoid*, Stan. et Vetter.)

This muscle is exposed by removing the anterior portion of the *hyohyoideus* and the inner part of its posterior portion. It arises from the upper (dorsal) surface of the clavicle and from the strong ridge separating this muscle from the erector of the pectoral fin. It passes forwards, lying anteriorly on the upper surface of the urohyal, and being separated from its fellow by the median crest on that bone. It is inserted into the anterior portion of the urohyal below its small upper plate. (Fig. 4, Hy. P.)

*Innervation.*—Branch from the united first and second spinal nerves.

*Action.*—By its contraction it draws the anterior extremities of the hyoid arches downwards, and so enlarges the cavity of the mouth. In respiration the branchiostegal membrane closing the gill-slit, the action of this muscle will cause the flow of water into the mouth. This being then closed by the powerful *add. mand.*, the *hyo-pectoralis* and *hyohyoideus* relaxes, and the *geniohyoid* then acting, draws the hyoid arches upwards and forces the water out by the gill-slit.

I have ventured to indicate this muscle by a new name. That used by Vetter is not appropriate owing to the absence of any structure which can be termed a sternum. Owen's name also is faulty, since the action is not so much to retract the hyoids as to depress their anterior extremities. The name applied above is analogous with those of the other muscles of the hyoid arch indicating its insertion and origin.

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## V.—MUSCLES OF THE BRANCHIAL ARCHES.

### A.—Ventral Muscles.

1. Musculus Hyobranchialis, (No. 35 Cuv.; *Pharyngo-hyoideus*, *Pharyngo-arcualis* and *Interac. obl. vent.* in part, Vetter).

After having exposed the hyopectoralis, it should be cut through and reflected, and the fascia covering the under surface of the branchial arches then removed. The *hyobranchialis* (Fig. 4, HBr.) will then be seen as a stout muscle lying to the side of the median line on either side on the under surface of the branchial arches. It arises from the posterior surface of the hypohyoid by a round tendon, which is continued some distance backwards on the dorsal surface of the muscle. Opposite the second branchial arch a slip (HBr[1]) separates from the main muscle and is inserted into the inner extremity of the anterior ridge of ceratobranchial iii. A second slip (HBr[2]) is inserted similarly into ceratobranchial iv., the main muscle passing straight backwards to be inserted into the anterior border of the pharyngeal inferior (ceratobranchial v.) In a specimen of *Amiurus nigricans* (Les) Gill, fibres were also seen passing from the main muscle to ceratobranchials i. and ii. Certain interarcual slips run parallel to the muscle proper, and, from their relation to the slips to the ceratobranchials, may be considered as secondary parts of it. One (HBr[3]) arises from the point of attachment of the slip to ceratobranchial iii., and passes back to the anterior ridge of ceratobranchial iv., its insertion being closely related with that of slip from main muscle to the same bone. A second bundle (HBr[4]) continues this first one backwards, and is inserted into the inferior pharyngeal (ceratobranchial) along with the main muscle.

*Action.*—The hyoid being fixed it will draw the branchial apparatus forward, the interarcual slips approximating the arches to which they are attached.

As indicated by the synonyms, the muscle under consideration is probably comparable to two or more distinct muscles in other *Teleostei.* The main muscle seems to have certain analogies with the muscle in *Perca,* termed by Vetter the *pharyngo-hyoideus,* and by Owen the *branchi-depressor,* which extends from the urohyal to the inferior pharyngeals on either side. The *pharyngo-arcualis,* which is present in *Esox* and the Cyprinoids (in which the *pharyngo-hyoideus* is absent), but absent in *Perca,* also presents resemblances. It arises from the anterior border of the inferior pharyngeal, and divides into two slips, the outer of which passes to ceratobranchial iv., and is, therefore, comparable to the interarcual slip extending between the same parts in *Amiurus.* The inner portion inserts into hypobranchial iii., uniting in *Esox* with the *obliqui ventrales* of ceratobranchial iv. and hypobranchial iii. The first of these latter muscles in *Esox* and the Cyprinoids sends a slip to the ceratohyal, and that of the fourth arch besides passing to its own ceratobranchial sends also a slip to the hypobranchial iii.

I am inclined to consider the hyobranchialis of *Amiurus* as equivalent to all these parts. If one imagines the *pharyngo-hyoideus* of *Perca,* and the *pharyngo-arcualis* of *Esox* and the Cyprinoids united, one will have a muscle passing from hyoid directly to the inferior pharyngeal, and, in addition, sending a slip from that bone to ceratobr. iv. ; and one can see in the slip of the obliquus ventralis of the fourth arch which passes forwards to the third, a homologue of the slip between ceratobrs. iii. & iv. in *Amiurus*. The hyoid and branchial arches being the hæmal arches of six of the vertebræ which enter into the skull, one may suppose that in ancestral forms there were sheets of muscle extending from one arch to the next, comparable to the myomeres of the trunk ; or rather, since these arches are so early concerned in the function of respiration, it may be imagined that each head cavity developed into muscle above and below, but aborted in its median portion. We would then have on the under surface of the branchial arches a series of muscles passing from the hyoid to first branchial arch, from that to the second, and so on. Next, the inner fibres of these myomeres united to form a muscular belly extending from the hyoid directly to the fifth arch. The outer fibres did not take part in this modification, or at least only to a partial extent, certain of them becoming detached from their anterior attachment and united to the large belly, the posterior attachment persisting. The fibres passing to ceratobrs. i. and ii. in *Amiurus nigricans*, are rudiments of these, and those to ceratobrs. iii. and iv. persisting examples. Those outer fibres which did not become modified form the interarcual slips between ceratobrs. iii. and iv., and iv. and v. In other fishes the process of specialization has gone on still farther, certain slips becoming aborted and others losing their original connections, so that the primary relations are lost.

2. Musculi Interarcuales Obliqui Ventrales, (No. 38, Cuv.)

On removing the preceding muscle, these (Fig. 1, Ob. $V^1$ and Ob. $V^2$) are exposed. They are three in number in *Amiurus*, and are small and triangular, extending from the hyobrs. i., ii. and iii., to the ceratobrs. of the same arches.

*Action.*—They draw the arches downwards towards the middle line and slightly forward.

These may be considered as modified representatives of the interarcual slips between the third and fourth, and fourth and fifth arches. The original course of the muscular fibres of the myomeres is represented by these latter, and since that of the fibres of the interarcuales obliqui is almost transverse, they must have been transferred from their original position. According to this view the fibres of the first muscle originally ran from the ceratohyal to ceratobr. i., as indeed slips do in *Esox* and the Cyprinoids; those of the second from ceratobr. i. to ceratobr. ii.; and those of the third from ceratobr. ii. to ceratobr. iii. This supposition is supported by the fact that in other Teleostei there is a fourth *obliquus ventralis* and no slip between ceratobrs. iii. and iv., as in *Amiurus*.

3. Musculi Transversi Ventrales, (No. 40, Cuv.; includes *Transv. pharyngei*, Vetter.)

These are two in number, exposed by the dissection required for the preceding muscles. The anterior one, (Fig. 4, $TV^1$), extends between the ceratobr. of either side of the fourth arch, across the lower surface of the branchial apparatus, the posterior ($TV^2$) holds a similar course between the inferior pharyngeals (ceratobr. v.)

*Action.*—They approximate the arches of opposite sides, the anterior one also drawing them slightly downwards.

The placing of the posterior muscle in a different category from the anterior, under the name of *pharyngeus transversus*, is quite unnecessary, the two being serially homologous. The origin of these muscles is indicated by the representative of the anterior one in the Cyprinoids, it being there small and merely part of one of the *obliqui ventrales*.

4. Pharyngo-Clavicularis Externus, (No. 36, Cuv.; *Branchiretractor*, Ow.) (Fig. 4, PhE.)

This muscle and the following one may be seen by the dissection required for the hyobranchialis, *et seq.*, or still better, by dividing a specimen longitudinally exactly in the middle line. The hyopectoralis will have to be removed from its attachment to the clavicle to expose the origin. The *pharyngo-clavicularis ext.* arises from the upper surface of the clavicle behind the insertion of the hyopectoralis, and passes upwards, forwards and inwards, to be inserted into the anterior extremity of the inferior pharyngeal (ceratobr. v.)

*Innervation.*—Branch from the first spinal nerve.

*Action.*—Draws the pharyngeal backwards, downwards and slightly outwards, opposing the *transversus* and *hyobranchialis*.

5. PHARYNGO-CLAVICULARIS INTERNUS, (No. 37, Cuv.; *Branchi-retractor*, Ow.) (Fig. 4, Ph. In.)

A thin band-like muscle, arising from the upper surface of the clavicle near the middle line, and is inserted slightly behind the preceding.

*Innervation.*—Same as preceding.

*Action.*—Same as *pharyngo-clav. ext.*

B.—DORSAL MUSCLES.

6. MUSCULI LEVATORES BRANCHIALES, (Nos. 30-33, Cuv.; *Branchi-levatores* and *Masto-branchialis*, Ow.; *Lev. branch. ext.* and *int.*, Vetter.)

These may be exposed from the inside by the dissection required for the *pharyngo-claviculares*, or from the outside by removing the opercular and hyomandibular apparatus and detaching the membrane extending from the upper moieties of the gill arches to the under surface of the skull. They are seven in number, three being attached to the superior pharyngeal.

(*a*) Arises from a concavity on the posterior part of the under surface of the pterotic. It is a round, stout muscle, which passes almost directly downwards, and is inserted into the posterior portion of the upper surface of the superior pharyngeal.

(*b*) Arises from the under surface of the pterotic in front of (*a*). It is broad and thin, and runs obliquely forwards to be inserted into the cartilages at the extremity of epibr. i.

(*c*) Arises from the pterotic in front of and slightly lower than (*b*). It passes down between epibrs. ii. and iii., and is inserted into the anterior portion of the upper surface of the superior pharyngeal.

(*d*) Arises from the sphenotic immediately below the articulation of the hyomandibular. It passes down between epibrs. ii. and iii., and is inserted just behind (*c*) (with whose fibres it intermingles somewhat below) into the antero-external portion of the upper surface of the superior pharyngeal.

(*e*) Is closely related to (*d*) lying on its outer surface. They arise together, and (*e*) passing downwards, is inserted into epibr. iii. at the base of its process.

(*f*) Arises in front of (*d*) and (*e*) from the sphenotic, and is inserted into the inner extremity of the anterior surface of epibr. ii.

(*g*) Arises immediately in front of the last, and is inserted into the upper surface of epibr. i, near its inner extremity.

*Innervation.*—(*a*) Is supplied by
(*b*) by a branch from *tr. branchialis i. vagi*; (*c*), (*d*) and (*e*) by branches from *tr. branchialis iii. vagi*; (*f*) by branch from coalesced *tr. branchialis* i. and ii., and (*g*) by a branch from the *glossopharyngeal.*

*Action.*—(*a*) By drawing the posterior part of the pharyngeal upwards, depresses its anterior portion; (*c*) and (*d*) act together, raising the anterior border and depressing the posterior, and at the same time the fibres of (*d*) will raise the outer border somewhat. These muscles impart a rocking motion to the superior pharyngeal, which must be very effective in grinding the food against the inferior pharyngeal; (*b*) draws the arches upwards and backwards, depressing the posterior ones; (*e*), (*f*) and (*g*) draw the arches directly upwards.

Vetter describes these muscles into two groups, '*internal*' and '*external.*' The latter in the Cyprinoids are five in number, in *Esox* three. They are inserted in the former into the pharyngo-brs. i., ii., iii. and iv., the three posterior sending a small slip to the epibr. i., ii. and iii., respectively. The fifth muscle is inserted into the posterior portion of the superior pharyngeal, and is therefore equivalent to (*a*). The external muscles are three, being inserted into the pharyngobrs. ii. and iii., and epibr. iv. It would be difficult to homologize the arrangement in *Amiurus* with that of the other described forms, but it is to be noticed that in the former the superior pharyngeal receives three muscles but only one in the latter.

### 7. Musculi Interarcuales Obliqui Dorsales.

These are exposed by the same dissection as the preceding, which must also be removed. They are three in number. The first arises from near the inner extremity of the posterior edge of epibr. i., and runs back above and slightly exterior to the second, to be inserted into the anterior edge of the upwardly directed process of epibr. iii. The second, large and stout, lies below the first. It arises from the posterior border of epibr. ii., near its inner extremity, and is inserted into the extremity and anterior edge of process of epibr. iii. The third arises from the inner extremity and anterior edge of the pharyngobrs., between the third and fourth arches, and, passing back, is inserted into the extremity and anterior edge of the process on epibr. iv.

*Innervation.*—The first is supplied by a branch from *Tr. branchialis iii. vagi*, and the second and third by a branch from *Tr. branchialis iv.* of the same nerve.

*Action.*—They will tend to approximate the arches, and also to tilt the posterior ones upwards.

In the *Cyprinoids* there are two sets of muscles, termed by Vetter, '*obliqui dorsales inferiores*,' and '*obl. dors. superiores.*' In *Amiurus* no such division can be made, nor is it possible to indicate homologies between the forms.

8. Musculi Transversi Dorsales, (Cuv. 34 and 39.)

Exposed by removal of the preceding muscles and by the detachment of the branchial arches from the skull. They are, like the corresponding ventral muscles, two in number. The *anterior* passes between the pharyngobrs. i., ii. and iii., of either side, the *posterior* between the ossa pharyngea superiora of opposite sides, the posterior fibres passing into the fascia forming the posterior boundary of the branchial cavity.

*Action.*—Approximate the arches of opposite sides.

These muscles probably correspond with the *transversi dorsales* of *Perca*, the anterior of which extends between epibr. ii., the posterior between pharyngobrs. iii. and iv. of opposite sides. In the *Cyprinoids* only a single muscle is present, which corresponds to the posterior muscle in *Amiurus*.

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## VI.—MUSCLES OF THE TRUNK.

These muscles, which are very numerous, one corresponding to each intervertebral region, have usually been described as forming one great muscle on each side, the great lateral muscle. This is convenient for description, the various muscles making up the great lateral mass, being serially homologous and almost identical in appearance. Each consists, in its typical form, of a muscular plate, (*myomere*), the fibres of which run parallel to the long axis of the body, and arise from and are inserted into a fibrous band (*myocomma*)[1] taking

[1] These terms are here employed in the same manner as by Wiedersheim in his lately published "Handbuch der Vergl. Anat. der Wirbelthiere." As originally used by Owen, myocomma signified the muscle, the derivation being given as κομμα—a segment. As here used its derivation will be from κομμα—a pause in a sentence.

origin from the centrum and processes of each vertebra. Each *myomere*, therefore, corresponds in its position to a primitive vertebra. For the purpose of description, the lateral muscle of each side may be divided into five longitudinal parts, not in all cases perfectly separable, but still sufficiently so for the purpose.

The *first*, or *most superior portion*, is not represented anteriorly, but commencing at the posterior ray of the dorsal fin, it runs backward to the rays of the caudal fin. It is the muscle termed by Owen the *supracarinalis*, and by Cuvier *le muscle grêle supèrieur*. It consists on either side of a thin band of muscular fibres, formed by the union of slips arising by tendons from the spinous processes as far forward as that of the second vertebra behind the last interspinal of the dorsal fin. From their tendinous origins the fibres of each slip run obliquely forwards, the upper fibres being horizontal and continued over to the next myomere. This muscle belongs, as far as its action is concerned, to the dorsal fin, since its function is to depress that structure, but from its origin it is plainly comparable to the series of myomeres of the lateral musculature.

The *second portion* is the largest, and is formed of that part of the lateral muscle above the lateral line. Separated from its fellow of the opposite side, posteriorly, by the *supracarinales*, it is in contact with it anteriorly, and shows no division into myomeres. Posteriorly, however, the segmentation is distinct, especially towards the lower edge, the distinctness vanishing anteriorly more rapidly above than below. The myocommata are bent abruptly so as to form an angle pointing backwards, and, accordingly, each myomere fits into the succeeding one, a transverse section of the body cutting through several. Anteriorly this portion is inserted into the supraoccipital bone and spine, the exoccipital, epiotic and pterotic. Fibres also pass to the upper surface of the plate formed by the transverse processes of the 3rd and 4th vertebrae, and some of the more superior ones are fastened to the under surface of the plate of the dorsal fin.

The *third portion* lies immediately below the lateral line; it is not perfectly separable from the second portion, and still less so from the fourth. Its fibres anteriorly run between the transverse processes and ribs, and the myocommata from these, and posteriorly between the myocommata from the hæmal arches. In consequence of this the plane of the myomere is curved anteriorly, being horizontal in its upper portion where it is attached to the transverse processes, and vertical below where it extends between the ribs. Toward the anterior region, where the ribs become shorter and finally vanish, this portion diminishes in breadth, the most anterior fibres being few in number and inserted into the under surface of the transverse processes of the 2nd and 3rd vertebræ.

The *fourth portion* is broad anteriorly, diminishing rapidly behind. Its fibres anteriorly extend between the lower extremities of the ribs and myocommata; posteriorly between the corresponding portions of the myocommata of the tail. The myomeres have a direction downwards and forwards, so that they are at an angle with those of the third portion. Anteriorly and below the portions of opposite sides are in contact, owing to the absence in that region of the fifth portion, and form a broad, stout muscle, which may be called the 'great ventral muscle.' The posterior fibres run directly forwards, those arising from the anterior shorter ribs downwards as well, so that there is formed between the anterior fibres of the third portion and those of the fourth a triangular space, the base of which is formed by the supraclavicle. Its floor is formed by a dense membrane, immediately below which is the swim-bladder. Anteriorly this portion is attached to the posterior border of the clavicle and to the posterior portion of the lower surface of the coracoid, so that, besides assisting portions two and three in bending the body laterally, it acts as a *retractor of the pectoral arch*. The median ventral portion is inserted by an aponeurosis into the posterior cartilaginous arch of the pelvis, forming Owen's *protractor ischii*, the more external fibres bending slightly outwards and inserting into the posterior angle of the pelvic bone.

The *fifth portion* corresponds to Owen's *infracarinalis*, and Cuvier's *muscle grêle inferieur du tronc*. It consists of two portions separated by the anal fin. The anterior moiety extends from the posterior cartilaginous arch of the pelvis to the base of the anterior ray of the anal fin. This Owen calls the *retractor ischii*, from its function of pulling the pelvis backwards after it has been drawn forwards by the fourth portion; in addition to this it has also the power, when the pelvis is fixed, of separating the rays of the anal fin. The posterior half extends between the posterior ray of the anal fin and the caudal fin, and draws the rays of the former backwards, aiding in their separation. These portions arise, similarly to the *supracarinalis*, from the extremities of the hæmal arches.

*Innervation.*—The fibres of each myomere are, of course, supplied by the spinal nerve corresponding to it segmentally. The *supra-carinales* are supplied by branches from the *ramus lateralis trigemini.* The muscular mass immediately in front of the dorsal fin is supplied by the dorsal branch of the fourth spinal, and the musculature anterior to that is supplied by branches from the *ram. lat. trig.*, with which the *rami dorsales ii.* and *iii.* completely unite. The *infra-carinales* are supplied by branches arising from a plexus formed by the union of the ventral branches of certain spinal nerves.

## VII.—MUSCLES OF THE PECTORAL ARCH AND FIN.

Certain muscles belonging partly to this arch, but acting principally on others, have already been described, as, for instance, the *hyopectoralis*, and the *pharyngo-hyoidei externus* and *internus.* The muscles here to be considered are those which act principally on the arch, and those which move the fin. Of the former, the '*great ventral muscle*,' which acts as a retractor, has already been described.

### 1. Trapezius.

This muscle arises from the posterior portion of the lower surface of the pterotic, a few fibres also coming from the supraclavicle. It passes downwards, expanding as it goes, and is inserted into the base of the ascending portion of the clavicle, the more anterior fibres passing into the dense fascia which forms the posterior wall of the branchial cavity.

*Innervation.*—Twigs from main branch of *first spinal nerve.*

*Action.*—It draws the pectoral arch upwards, and also makes tense the fascia into which the anterior fibres are inserted.

In the forms described by Vetter this muscle does not apparently occur, that named *trapezius* by him being merely the superficial anterior portion of the dorsal trunk musculature, which extends between the posterior surface of the skull and the post-temporal and supra-clavicular bones The *trapezius* as here defined corresponds rather with that of the *Elasmobranchs.* Stannius mentions its occurrence *in some Teleosts.*

Owing to the modification of the anterior fin ray, whereby it can be fixed, and only lowered after a certain amount of rotation, the muscles which move it are different to a certain extent from those of other fishes. Owen describes them in *Perca* as forming a pair, in two layers, on both the outer and inner sides of the antibrachio-carpal base: and the fibres of one layer run obliquely in a different direction from those of the other layer in both pairs of muscles. The outer pair abducts or protracts the fin, the inner pair adducts or retracts it, sweeping it back into contact with the flank: the first movement might be called 'extension,' the second, 'flexion.' The muscles in *Amiurus* can be reduced to a similar plan.

2. ABDUCTOR SUPERFICIALIS (No. 14, Cuv.; *Superficial abductor*, Ow.)

Consists of two portions, both lying in the groove on the under surface of the horizontal (inner) portion of the clavicle, and covered by the ventral musculature of the trunk. They pass over the bridge formed by the process of the coracoid, which articulates with the anterior ridge of the clavicle, and are inserted into the inferior[1] surfaces of the bases of the rays. The anterior portion (Fig. 5, $AbS^1$) is the smaller, and is partly concealed by the posterior. It arises from the outer portion of the anterior ridge of the clavicle, and is inserted into the inferior process of the base of the first ray. The posterior portion ($AbS^2$) arises from the posterior ridge and floor of the groove, and is inserted by as many tendons into the bases of the rays, except the first.

*Innervation.*—Supplied by a nerve arising from a branch which is composed of fibres from the external branch of *first spinal*, and from a branch from the united *second* and *third spinal.*

*Action.*—Abduct the fin. When the deep abductors are acting, they will also separate the rays.

3. ABDUCTOR PROFUNDUS (No. 15, Cuv.; *Deep abductor*, Ow.)

This is also divided into two portions, both of which, however, are inserted into the base of the first ray. The first (Figs. 5 and 6, $AbP^1$) lies below (*i.e.* dorsal to) the *abductor sup.*, and arises from the posterior surface of the anterior ridge of the clavicle and from the floor of the groove. It passes below the bridge formed by the coracoid, and is inserted with the second portion into the base of the semi-circular process of the first ray. The second portion (Figs. 5 and 6, $AbP^4$) arises from the upper (dorsal) surface of the coracoid

[1] The terms '*inferior*' and '*superior*,' etc., are applied to the parts as they are when the fin is abducted, *i. e.*, extended at right angles to the body.

plate, and from the under surface of the portion of the clavicle overlapping this. It passes below this overlapping portion of the clavicle, in the channel between it and the coracoid, and uniting with the first portion, is inserted with it.

*Innervation.*—The same as for the *abd. superf.*

*Action.*—This muscle abducts the first ray, and thus assists in abducting the entire fin, but at the same time it gives to the first ray the rotation which is necessary to complete its abduction and fixation. This rotation is brought about by the muscle being inserted into the upper surface of the ray.

The position of the second portion of this muscle appears somewhat anomalous, inasmuch as it is apparently in the upper surface of the arch, the *abd. superf.*, and even the other portion of the *abd. prof.*, lying in its lower surface. An examination of the structure of the arch explains the anomaly. The posterior portion of the arch which unites with its fellow by suture is not the posterior portion of the clavicle as it has been usually described, but is an enlargement of the coracoid. Now this latter lies really on the inferior surface of the arch, and therefore the upper surface of this enlargement is applied to the under surface of the clavicle, and accordingly a muscle lying upon its upper surface may yet lie on the under surface of the clavicle. Though the two portions of the deep abductor are widely separated at their origins, yet their union before insertion indicates that they originally constituted one muscle, homologous with the deep abductor of *Perca.*

4. ADDUCTOR SUPERFICIALIS.

Arises from the inner surface of the ascending portion of the clavicle and from the bridge-like spiculum of bone near its base; the deeper fibres arising from the radialia. It is inserted into the superior surfaces of the bases of all the rays, except the first, dividing into a separate tendon for each ray.

*Innervation.*—It is supplied by a branch from the combined *second* and *third spinal nerves.*

*Action.*—Adducts the fin. When the fin is abducted the rhythmical and successive action and relaxation of the superficial abductors and adductor will produce an undulatory movement of the fin.

5. Adductor Profundus, (No. 16, Cuv.)

This muscle (Fig. 5, AdP) lies below the ventral musculature. It arises from the posterior portion of the lower surface of the coracoid, extending inwards as far as the middle line. It passes below the thin bridge-like spiculum of bone on clavicle, and is inserted into the groove at the base of the semi-circular process at the base of the first ray.

*Innervation.*—Same nerve that supplied abductors.

*Action.*—It draws the ray, and with it the entire fin, towards the body. When the fin is abducted it acts obliquely on its point of insertion, and accordingly gives the rotation necessary to release the ray from its fixation.

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## VIII.—MUSCLES OF THE PELVIS AND PELVIC FIN.

The muscles which act on the pelvis have already been described in connection with the trunk musculature. The posterior fibres of the *great ventral muscle* and the portions of the *infracarinales* act as protractors and retractors of the pelvis.

The muscles which arise from the pelvis are those which move the fin. These are arranged in two layers on the ventral and dorsal surfaces of the pelvis, those of one side being separated from those of the other by a fibrous septum formed by a continuation backwards of the fascia which separates the two halves of the great ventral musculature. The ventral muscles act as abductors, the dorsal as adductors.

1. Abductor Superficialis Pelvis, (Fig. 7, AdS).

Arises from the thickened outer edge of the pelvis, and posteriorly from the aponeurosis formed by the median fibres of the ventral muscle (VA) and the septum between the muscles of opposite sides. The outer fibres run almost directly backwards, the inner almost directly outwards, the former being inserted into the base of the outer ray, and the latter into that of the inner one, while the intermediate fibres pass to the intermediate rays dividing imperfectly into separate tendons.

*Action.*—Abducts (*i.e.*, pulls downwards) the fin, and also separates the rays.

2. ADDUCTOR PROFUNDUS PELVIS.

This is seen on removing the preceding. It arises from the surface of the pelvis and from the septum, and is inserted below the preceding into the bases of the rays.

*Action.*—Assists the preceding in abduction but does not separate the rays.

3. ABDUCTOR SUPERFICIALIS PELVIS.

On cutting through the insertions of the ventral trunk muscles and bending back or removing the pelvis, the dorsal muscles are exposed. The superficial muscle does not cover the deep one as in the case of its ventral equivalent, but is of a triangular shape, expanding as it passes backwards and inwards to its insertion. It arises from the thickened outer edge of the pelvis; its outer fibres pass directly backwards, the inner ones backwards and inwards. It divides imperfectly into a number of tendons, one being inserted into the upper surface of the base of each ray.

*Action.*—Adducts the fin. The outer fibres also help to separate the rays.

4. ADDUCTOR PROFUNDUS PELVIS.

Lies to the inner side of the preceding. It arises from the dorsal surface of the pelvis and from the septum. Its outer fibres are stout and quickly become tendinous, passing under the superficial muscle, the inner ones being longer. It is inserted into the bases of the rays below the *add. superf.*

*Action.*—Aids the superficial muscle and also tends to approximate the rays.

*Innervation.*—The musculature of the pelvic fin is supplied by branches arising from a plexus formed by the union of the *rami vent. spinales*, x., xi., xii., xiii., and xiv. A plexus is first formed for the supply of the ventral portion of the musculature, but other branches are detached which form a similar plexus for the supply of the dorsal muscles.

The arrangement of this portion of the musculature of *Amiurus* corresponds very closely with that described by Cuvier, Stannius, &c., the only marked difference being the limitation in size of the *add. superf.*, which in *Perca* seems to cover more perfectly the *add.*

*prof.* Davidoff[1] in his valuable papers on the pelvis and pelvic musculature of fishes, treats the *Teleostei* very summarily, merely stating that the differences in musculature and innervation between the *Teleosts* and *Lepidosteus,* or, more especially *Amia,* are quite unimportant. In comparing *Amiurus* with his descriptions of either of the two forms mentioned, although the ground-plan is much the same yet the details are much simpler, it being impossible in *Amiurus* to distinguish, for instance, in the ventral musculature a *pars media,* or in the *abd. prof.* a *caput longum* from a *caput breve.* The names employed above for these muscles indicate their equivalency with those of the pectoral arch.

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## IX.—MUSCLES OF THE DORSAL FIN.

Owing to the modifications of the anterior rays of the dorsal fin in *Amiurus,* their muscles are also modified. Those of the *five posterior rays* have a typical arrangement. The *extrinsic* muscles are two in number, namely, the anterior superior fibres of the upper portion of the lateral musculature, which pass from the supraoccipital to the anterior portion of the plate which supports the defensive ray, and will have little or no action in moving the fin, and the *supracarinales* which will depress the rays.

Of the *intrinsic* muscles there are two to each ray, an *erector* and a *depressor.* The typical arrangement of these may be seen in the posterior five rays. In these each *erector* lies anterior to the depressor, and arises from the posterior border of the interspinal of the preceding ray. The *depressors* arise from the anterior border of the interspinal of the ray to which each belongs, and from the spinous process of the vertebra which supports that ray; each crosses its interspinal obliquely above so as to lie behind it. The erector is inserted into the anterior and the depressor into the posterior surface of the base of each ray.

Of the muscles of the *next anterior ray, i. e., the fourth*[2] the *depressor* is normal in its relations, arising from the anterior surface of the fourth interspinal and the extremity of the spinous process of the sixth vertebra, and, crossing over the interspinal, is inserted into the

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[1] *Davidoff*—Beitr. zur vergl. Anat. der hinteren Gliedmasse der Fische, ii. Th. Morph. Jahrb. vi, 1880.

[2] This will be the third apparent ray, the first having lost all its ray-like appearance. See paper on Osteology.

base of the posterior surface of the ray. The *erector* loses however its proper origin, arising instead from posterior edge of the horizontal plate on which the defensive (3rd) ray rests.

The *erector* of the *defensive* or *third ray* lies in the interval between the second and third interspinalia. It arises from the posterior edge of the first interspinal, the anterior edge of the second, and from the posterior portion of the expanded process of the fourth vertebra. It passes upwards and is inserted into the anterior surface of the base of the ray. The *depressor* has also its origin much increased. It arises from the sides of the third interspinal, from the anterior surface of the fourth, and from the spinous process of the fifth vertebra, and is inserted into the base of the anterior surface of the ray.

The *horse-shoe-shaped or second ray* has also an erector and depressor. The *erector* is small, and consists of a few fibres, which run obliquely backwards from their origin from the under surface of the anterior portion of the horizontal plate, and which, passing through the foramen in this plate in company with the depressor, are inserted into the anterior surface of the extremity of one of the limbs of the ray. The *depressor* is a much stouter muscle, arising from the base and posterior surface of the anteriorly directed osseous process of the fourth vertebra, which includes the spinous process of the third. It passes upwards and backwards through the foramen in the anterior portion of the horizontal plate behind the erector, and is inserted into the extremity of the limb of the ray.

*The muscles of the first ray are aborted.*

*Innervation.*—Supplied by branches from the *ramus lateralis trigemini* with which the *R. dors. spinal.* unite.

*Action.*—The action of the *muscles of the posterior rays* are sufficiently expressed by their names. With regard to those of the *second ray* there is something to be said, since it is by these that the fixation of the third ray is produced, and its depression permitted. The depressor draws the horse-shoe-shaped ray downwards, so that it slips over the smooth extremity of the interspinal, and its limbs come into apposition with the flanges on the sides of the fourth spinous process which encloses its interspinal. The *third or defensive ray* is attached to the extremity of the second by ligament, so that its depression will now be impossible. In other words, it is the fixation of the second ray which causes the fixation of the third.

Depression of the defensive ray is, of course, produced by its own depressor; but it is permitted by the action of the erector of the second, which draws its ray upwards, setting it astride of its spinal process, and releasing its limbs from their apposition with the fourth spinous process, and so allowing of its depression. It is to be noticed that the erection of the third and succeeding rays is accompanied or succeeded by the contraction of the depressor of the second and similarly their depression with the action of the second erector.

The abnormal relations of these muscles can be explained by the modifications of the parts. Those of the anterior ray, which is almost unrecognizable and firmly fixed, are aborted. The interspinal of the first ray having lost its original relations and become bent upwards from its attachment to the spinous process of the third vertebra until it lies longitudinally, its muscles have lost their attachment to it, and so the erector of the second which ought to arise from its posterior surface has transferred its attachment to the more solid horizontal plate. The second depressor ought to arise from the anterior surface of the second interspinal, but the membrane bone which develops round the fourth vertebra, growing in as it were between the muscle and the interspinal, separates them, and the muscle passes farther forwards on the plate until it reaches the base of the anterior ascending process, thereby acquiring greater obliquity of action. The erectors and depressors of the third ray have in part their normal relations, but owing to the weight and ossification of the ray they have to move, have become enlarged, and extended their origin beyond the typical limits. The erector of the fourth ray has been crowded out from its original insertion by the aggression of the third depressor, and has become inserted into the horizontal plate where its action is more forcible.

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## X.—MUSCLES OF THE ANAL FIN.

The *infracarinales* act to a certain extent upon the rays of the anal fin. The portion named by Owen the '*retractor ischii*,' is inserted posteriorly into the base of the anterior ray, the posterior portion is inserted into the base of the posterior ray. Thus, when these act simultaneously, or even when one acts and the other remains fixed, the rays will be divaricated.

Erectors and Depressors.

These are on the same plan as the muscles of the posterior rays of the dorsal fin. The *erectors* arise from the interspinals supporting the preceding ray and the hæmal process (or fascia connecting the hæmal arches) of the corresponding vertebra. The *depressors* arise from the interspinals supporting the rays to which they belong. These muscles are concealed by the lateral trunk muscles, which require to be pulled aside to expose them.

*Innervation.*—Supplied by branches from a longitudinal collecting stem which form a plexus into which the ventral branches of spinal nerves xix.–xxx. enter.

Lateral muscles.

These are not represented in the dorsal fin. They consist of a number of small muscles, one on each side for each ray, arising from the fascia covering the outer surface of the lateral musculature, and which, passing downwards and towards the median line, are inserted into the lateral surfaces of the bases of the rays ventral to the insertion of the erectors and depressors.

*Innervation.*—Supplied by a superficial plexus similar to that which innervates the preceding muscles, and coming from the same spinal nerves.

*Action.*—By the successive contractions of the muscles of one side from before backwards, a corresponding relaxation of the opposing muscle occurring at the same time, the sinuous motion characteristic of the anal fin is produced.

## XI.—MUSCLES OF THE CAUDAL FIN.

The muscles of the caudal fin are formed principally of the posterior portions of the lateral muscles of the trunk. From the intermuscular septa of the last few myomeres a fascia (Fig. 8, f) is given off, which is fastened posteriorly to the bases of the fin-rays. On contraction of the myomeres, this fascia acts on the rays and draws them either to one side or the other, as the case may be. The uppermost and lowermost portions of the myocomma forming the posterior boundary of the last myomere are prolonged into separate tendons (Fig. 8, $My^1$ and $My^2$) inserted into the abaxial[1] surface of the outer-

[1] The terms *abaxial* and *axial* refer to the surfaces of the rays looking respectively away from or towards the axis of the body.

most two or three rays above and below, and thus act as divaricators of the rays.

A deep layer of muscle may be seen on cutting through the attachment of the fascia and reflecting the superficial muscles. It consists of two portions separated by the vertebral column. Owing to the direction taken by the terminal filament of the notochord, the two portions are unsymmetrical, that below the column being greater than that above. The *dorsal portion* (Fig. 9, d) consists of a single muscle arising from the spinous processes of the last two or three vertebræ, and passes almost directly backwards. Three or four tendons begin near the origin of the muscle, and are inserted into the bases of the upper three or four rays.

The *ventral portion* is divisible into two parts. The upper (Fig. 9, $v^1$) is a triangular muscle, imperfectly separable into two parts lying dorsal to the middle line. It arises by an expanded origin from the broad surface of the fourth hæmal arch below the notochordal filament; passing upwards and backwards it crosses the dorsal portion before its insertion, and dividing into two long tendons is inserted into the axial surfaces of the two upper fin rays. It pulls them downwards towards the middle line as well as laterally, and thus acts as an opponent of the uppermost tendons of the superficial layer, and aids the intrinsic muscles. The lower part forms a broadly triangular muscular mass (Fig. 9, $v^2$), the base resting on the fin rays. It arises from the 'flossenträger' and the bodies and hæmal processes of the last two or three vertebræ, the very lowest portions arising from the extremities of the hæmal processes of the fourth and fifth vertebræ (counting from behind) not reaching up to the centra. Numerous tendons run along the muscle, as a rule one for each ray, into the bases of which they are inserted. The lowermost portions are inserted into the rays imbedded in the adipose tissue, which are not functionally parts of the fin. This part of the muscle aids the superficial musculature, the lower fibres serving to approximate the rays.

The *intrinsic muscles* (Fig. 8, It), lie immediately below the integument posteriorly to the attachment of the fascia. One muscle is supplied to each ray of the fin proper, none being inserted into the fins in the adipose tissue. Each arises from the abaxial surface of a ray, and is inserted into the axial surface of the next external (*i.e.*, dorsal or ventral, as the case may be,) to it. Certain of the fibres of each muscle do not arise from the succeeding axial ray but may be traced across it and several others to the fascia near the axial line, so that, viewed as a whole, their arrangement resembles that of a fan. The central muscles above and below lie entirely on the axial surface of the ray to which they are attached, and, since there is no median impaired ray, their fibres arise from the fascia between them and partly also from the fascia of the superficial muscle. These intrinsic muscles approximate the rays, being aided by the upper and lower portions of the deep musculature and opposing the upper and lower portions of the superficial muscles.

*Innervation.*—The intrinsic muscles are supplied from a plexus formed by ventral branches of spinal nerves xxxiii.–xli. The muscles above the spinal cord are supplied by branches from *R. lat. trigem.*, and from the small posterior *R. dorsales spinales.*

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On comparing the myological characters of the head of a *Teleost* with those of a *Selachian*, the first point that strikes one is the absence in the former of the well-marked constrictors found superficially in the latter ; in other words, the direction of the muscle fibres in the Teleosts appears to be more longitudinal than in the Selachians, and therefore the myomeres more similar to those of the trunk. It has been shown by Balfour and Gœtte that the musculature of the head develops in exactly the same manner as that of the trunk, *i.e.*, from the primitive vertebræ, and is, therefore, segmental in its origin, a myomere lying between the arches of each pair of vertebræ of which the head is composed. In *Amphioxus* there is no differentiation of the myomeres, the musculature from the tail to the head consisting of a series of similar myomeres separated by similar myocommata[1], and therefore represents more closely the original type than does the arrangement in either the Selachians or the Teleosts. Accordingly, the Teleosts would at first seem to present a more primitive type than do the Selachians, but a closer investigation shows this to be a mistake.

When one takes into consideration the presence of an osseous, and therefore more or less immovable, cranial skeleton in the Teleosts, the absence of the *constrictors* is easily understood. But even then one would suppose that in the more movable parts the constrictors

[1] The ventral musculature of *Amphioxus* would interfere with this generalization were it not that it must be considered as belonging to a different category from the trunk musculature.

would persist to a greater or less extent. And so indeed they have done. In the Teleosts there are as representatives of the *constrictors*, the *intermandibularis*, the *add.* and *lev. arc. pal.*, *lev.* and *add. operc.*, the *transversi dorsales* and *ventrales* of the branchial arches, the *interarcuales ventrales*, etc. In these muscles the course of the fibres is parallel to a plane at right angles to the axis of the body, and they act more or less as constrictors of the parts to which they are attached. The greater mass of the constrictors of the Selachians is in relation to the branchial cavity. Where the parts about the pharynx are comparatively elastic, constrictor muscles will be, of course, of great use in diminishing that cavity, and so forcing the water out through the gills; but when, on the other hand, the parts become less movable through ossification, other arrangements for the propulsion of the water appear. Membrane bones are developed to act as valves and protections to the gills, a portion of the constrictor musculature persisting, attached to them, and the lessening of the size of the pharyngeal cavity is produced by the elevation of certain parts in the floor of the mouth, and only slightly by the approximation of the walls by constrictors. These latter, therefore, become limited to certain parts, instead of forming a more or less unbroken sheet over the branchial region.

Bearing in mind the fact that in the head there were originally a number of myomeres, as represented by the head-cavities, which have been specialized into a number of distinct muscles; and that to a very large extent the muscle fibres have lost their original direction, it is possible by means of the innervation to refer to their respective myomeres the various muscles.

*The Cranial Muscles.*—Leaving out of consideration the muscles of the eyeball, which belong to a myomere or myomeres in front of the mouth, the first muscle segment to be considered will be that supplied by the fifth nerve. Belonging to this there is, in the first place, the *add. mand.*, the fibres of which have, to a large extent, a longitudinal direction, and which extends between the mandibular and hyoid arches. Reasoning from analogy one would have expected to find this muscle and those belonging to the same myomere extending between the first præoral and the mandibular arches, but we find them in reality lying superficially to certain muscles supplied by the facial nerve. The development of the first præoral (or palatine) arch being in comparison with the succeeding ones so limited, may explain the want of relation of the myomere to it, but still one would expect to find the muscles in relation to parts situated near it, *i.e.*, in front of the orbit. In the Selachians this is the case; the origin of the *add. mand.* is in these forms entirely in front of the eye, and its action is essentially that of a constrictor. It seems that there has been first of all a gradual passage backwards of the origin of the *add. mand.*, (and also of the other *trigeminal* muscles), until in the Teleosts it has come to lie entirely behind the orbit, and that secondarily, there has been a downward growth of the muscle, so that the fibres have extended on to the *hyomandibular*, &c., the lowermost assuming a horizontal direction. The relations of the origin of the *add. mand.* in the *Cyprinoids*, *Perca* and *Esox*, are in support of this supposition. Vetter has pointed out that the *add. mand.* of the *Cyprinoids* is very much specialized, that of *Perca* slightly less so, and that of *Esox*, to which *Amiurus* is most comparable in this matter, more primitive than either; and we find that in *Esox*, the most primitive form, the muscle arises in part from the cranial bones, (viz., the pterotic and sphenotic), whereas in the others the origin has passed lower down.

Why there should have been this passage backwards of the muscle to behind the orbit, it is rather difficult to say. Perhaps an explanation may be found in the fact that the muscle acts in the Teleosts more or less as a retractor of the mouth parts, justifying in this respect Owen's designation of it as the *retractor oris*. If an upward movement of the mandible were all that was required, the arrangement which obtains in the Elasmobranchs would certainly be most effective, whereas, if retraction were also required, such a backward progression would be necessary.

It may also be pointed out that since the muscle lies entirely behind the eyeball, the size of that structure will necessarily assist in determining the extent of the limitation of the origin to the hyoid arch. In *Amiurus* where the eye is so very small, the origin persists much further forward than in any of the other forms examined, in all of which the eyeball is comparatively large.

*The* adductor mandibulæ *of the Teleosts has been derived from a constrictor muscle; its relations to the hyoid arch have been produced by a necessity for its action as a* retractor oris; *and the extent of its departure from its original position is* partly *determined by the size of the eyeball.*

The nature of the *add. tentaculi* has already been considered, it being merely a separation of the deeper fibres of the *add. mand.* The *lev. arc. pal.* is plainly derived from a constrictor, but its function has been changed by the development of osseous structures, so that instead of assisting in the contraction of the pharyngeal cavity, it enlarges it by raising the hyomandibular apparatus, etc. The reason why a trigeminal muscle should act as the opponent of muscles supplied by the seventh nerve, is that the forward growth superficially of the hyoidean muscles was prevented by the presence in primitive forms of the spiracle. The *dil. operc.* is evidently a portion of the *lev. arc. pal.* adapted to the necessities of the opercular apparatus. The incongruity between its action and its innervation is even more apparent than in the *lev. arc. pal.*, but is explicable in the same way as Vetter has pointed out.

The *intermandibularis* is without doubt the representative of the most anterior ventral portions of the Selachian constrictor. It is supplied by both the fifth and the seventh nerve, and instead, therefore, of being assigned to the group of muscles supplied by the fifth nerve, as Vetter has done, it must be considered as representing the ventral portion of a constrictor layer lying between the palatine and mandibular and the mandibular and hyoidean arches. The anterior moiety of such a layer would be supplied by the fifth, and the posterior by the seventh nerve. In the Teleosts this layer has contracted in breadth very much, until it forms merely a narrow band between the extremities of the mandibular arch, but, with the gradual narrowing, there has been, so to speak, a corresponding lengthening out of the innervating branch from the *facialis* and a shortening of that from the *trigeminus*, so that even when limited to the mandibular arch it still possesses its hyoidean nerve.

Just as all the muscles of the mandibular arch (*i.e.*, those supplied by the fifth nerve), are derived from a constrictor, so are all those of the hyoid arch, (*i.e.*, those supplied by the seventh nerve.) The *add. arc. pal.* has apparently an abnormal position, extending between the skull and the palatine, metapterygoid and hyomandibular, thus coming into relation not only with the arches to which it belongs but also with the arch in front of it. The only explanation to be given for this is that the muscle has extended its insertion forwards as necessity required it. In *Amiurus*, owing to the necessity for motion of the palatine for the purpose of erecting (abducting) the tentacle supporting maxilla, the muscle has extended farther forwards than in any other Teleosts hitherto described. The muscles are very mobile structures, modification being in them more frequent and more complete than in the nerves, &c.

The *add. hyomand.*, *add. operc.* and *lev. operc.*, are all very closely related, not only in position but also in innervation. They belonged originally to the same constrictor layer from which the *add. arc. pal.* developed, constituting the posterior part of it. The *lev. operc.* is a specialization of the superficial fibres of the most posterior portion—that portion from which also the *add. operc.* originated. These three muscles and the *add. arc. pal.* are comparable to the dorsal portion of the constrictor of the Elasmobranchs; the *geniohyoideus*, *hyohyoideus* and portion of the *intermand.* being comparable to its ventral portion.

*The Branchial Muscles.*—The muscles supplied by the *glossopharyngeal* and *vagus* are small in bulk when compared with those already discussed. In the Teleosts the muscles chiefly concerned in the respiratory act are not those belonging strictly to the branchial but those of the mandibular and hyoid arches. It is by means of these that the cavity of the mouth is increased, and thus an inflow of water produced, and it is by them also that the water is forced out below the opercular apparatus, passing in its way over the branchial filaments. Accordingly, we find the branchial muscles somewhat retrograded in bulk from the condition seen in the Elasmobranchs, and this retrogression has been accompanied by a corresponding increase in size and strength of the hyoidean and mandibular muscles.

I regret exceedingly that I cannot give details in regard to the innervation of many of the muscles, but, nevertheless, there are certain points which may be indicated. Most of the muscles of the branchial arches may also be reduced to the constrictor type, however much they may be modified. In the first place the *lev. branch.* are evidently the superior portions of the constrictor musculature, as are also the *mm. trans. dors.* and *interarc. obl. dors.* The latter have been slightly diverted from their constrictor direction, but as their name implies are still somewhat oblique. The lateral portion of the original constrictor has entirely aborted in *Amiurus*, though in certain forms, as *Esox*, muscles are found at the angles of the arches, *i.e.*, where the upper limbs join the lower. No such muscles could, however, be detected in *Amiurus*.

The ventral muscles partly represent the ventral portions of the constrictors. Certain of them retain their original transverse direction as the *transv. vent.* and the *obliqui vent.* The *hyobranchiales*, however, I feel disposed to consider as comparable to the ventral musculature of the trunk, in which case they must be considered as retaining for the greater part their original direction, the lateral portions merging into the constrictor type. A reason for this supposition is the explanation it affords for the dissimilarities between these muscles in various forms, and for the very evident relation which exists between the *obliqui vent.* and the slips from the *hyobranch.* As these points have already been treated of in connection with the description of the latter muscles, it will not be necessary to repeat them here.

The absence of any similar longitudinal muscles in the preceding arches points to the opposite view, but owing to the great changes which these have undergone, they may have disappeared by a continuation of the process by which the *intermandib.* has become so much reduced. There is a possibility that the *geniohyoid* may represent this ventral musculature, but I am rather inclined to refer it to the constrictor series.

With regard to the musculature of the head it may be concluded that. in the theoretical ancestral type of the *Teleostei*, it *consisted of two portions, a dorsal greater one, constrictor in its nature, and a ventral smaller one, the fibres of which retained their original longitudinal direction.*

*The Trunk Muscles.*—The *hyopectoralis* by its innervation belongs to the first, or rather to the first and second spinal segments, and is referable to the longitudinal ventral portion of those segments. This being the case its attachment to the hyoid is rather peculiar. One would expect the musculature of the first spinal segment to be attached anteriorly to the posterior surface of the last arch or myocomma of the cranium. Between the hyoid and the first spinal segment there are five arches, to the most posterior of which one would expect to find the *hyopectoralis* attached, or if it were continued further forward one would expect to find its anterior portions supplied by branches from the *trunc. branch. vagi.* This does not seem to be the case here, nor does Vetter describe any such arrangement in the forms he investigated. Probably along with the increased development of the hyoid apparatus, and the greater or less retrogression of the branchial apparatus, there has been, *pari passu*, an extension forwards of the *hyopectoralis*. The hyoid apparatus virtually covers in the branchial arches, and the muscle losing its attachment to the fifth branchial arch has extended forwards and become attached to extremity of the hyoid, thus retaining, of course, its original innervation.

The *pharyngo-claviculares* give a certain support to this idea. The *phar.-clav. int.* appears to be composed of the most external fibres of the ventral musculature of the first or first and second spinal segments. The innervation in *Amiurus* would assign it to the first segment only, but Vetter has described its innervation as being from the first and second spinal nerves. In this case, then, we have a muscle whose fibres run in the same direction as those of the *hyopectoralis*, whose origin is the same, and whose innervation is the same, and which retains the insertion which one would assign to such a muscle on theoretical grounds, and therefore indicates that a change such as has been described above has taken place in the *hyopectoralis*.

The *pharyngo-clavicularis ext.* comes from fibres slightly external to the *internus*. Its innervation in *Amiurus* refers it to the first spinal segment. Vetter, however, states its innervation to be from the vagus. Theoretically one would certainly expect the innervation described for *Amiurus*, or even that described for the *phar.-clav. int.* by Vetter. I am inclined to believe that the innervation given by Vetter for the *externus* is a mistake, since in all its relations the muscle belongs to the spinal segments.

The musculature of the trunk is divisible into a dorsal portion, which is not however constrictor, and a ventral, of which the *hyopectoralis* is the anterior portion and the *hyobranchialis* the anterior con tinuation. The segmentation of the dorsal portion is very complete, and the innervation of the segments by their proper spinal nerves is throughout typical. The organs of locomotion have in certain places brought about certain departures from the general regularity. The fins, paired and unpaired, will be spoken of later. Just now attention is directed to the *supra-* and *infracarinales*. Concerning these the points to be noted are the almost complete absence of any signs of segmentation on the surface, while below it is very evident; and, secondly, the innervation. In both cases the innervation is practically a plexus. In the *infracarinales*, branches from the ventral stems of certain spinal nerves unite to form a plexus by which the muscle is supplied, and in the *supracarinales* the *R. lat. trigem.* acts as a collector for branches from the dorsal stems. The action of both muscles is on the fins, and the plexus is probably necessary to give the various parts of the muscle simultaneous contraction and so produce effective action on the dorsal, anal, or ventral fins.

*The Pectoral Fin Muscles.*—In the Teleosts the muscles of the pectoral fin have been described as consisting of two layers, an abductor and an adductor layer, each being again separated into a superficial and deep layer. At first sight the arrangement in *Amiurus* appears to depart somewhat widely from this type, but further investigation shows that the departure from it is merely apparent, the true relations of the muscles being obscured by the excessive development of the coracoid, whereby one portion of the *abductor profundus* appears to lie on a different surface of the arch from the other portion. The explanation of this has already been given in connection with the description of the muscle. With regard to the innervation of these muscles it is found that, as in higher animals, there is a well marked plexus, consisting of the first three spinal nerves. Following out the line of argument hitherto adopted, what conclusion is reached? · Simply that the pectoral fin, or at any rate its musculature, is derived from three myomeres. It does not appear that this conclusion can be escaped. Dohrn, on embryological grounds, comes to the same conclusion,[1] *i.e.*, that the pectoral is formed by the accrescence of several segments. This is, of course, in direct opposition to the Gegenbaurian theory, which seems now to have received its quietus, having been founded on the structure of the fin in an exceptionally modified form, and not representing in the least the original features.

Another fact may be here pointed out. The muscles of the fin all lie on the external, inferior or posterior surface of the pectoral arch. This would tend to indicate that the arch, or a part of it, is of the nature of a rib, or is formed by the union of several rib-like structures. The manner in which certain muscles are inserted into it, and others take their origin from it, supports this theory. Perhaps, with Gegenbaur, one can after all, though in a different sense, refer the pectoral girdle to the type of a branchial or similar arch, considering the arches of the other segments of which the fin is composed either to have united with this one or to have entirely aborted.

*The Pelvic Fin Muscles.*—Similar remarks apply to the pelvic fin.

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[1] *Dohrn.*—Mitth aus d. Zool. Station zu Neaple, Vol V., 1884.

A greater number of segments (5) appear, however, to enter into its composition. It may be pointed out that the direction of the fin is not exactly similar to that of the pectoral fin, which is more normal in this regard. One may suppose, however, that the absence of a true pelvic arch has something to do with this. If one imagines a partially aborted pectoral arch in the normal position, with the metapterygials, etc., directed somewhat backwards, one would have an intermediate stage between what obtains in the pectoral and pelvic fins of the Teleosts.

*The Dorsal Fin Muscles.*—The innervation of the *erectores* and *depressores* of the dorsal fin is similar to that for the *supracarinales, i.e.*, the *ram. lat. trigem.* acts as a collector for the dorsal branches of the spinal nerves, and gives off branches to the muscles. It would seem, from the relations of these muscles, and also from their innervation, that *they are serially homologous with the supracarinales.* Dohrn's views[1] on the subject of the impaired fins receives confirmation from the paired nature of the muscles, and still more from the fact that a blood-vessel passes horizontally along through the base of each ray, the ray splitting readily upwards from this channel, pointing to a coalescence of two parts, one on either side of the middle line, in the formation of the fin.

*The Anal Fin Muscles.*—With regard to the *erectores* and *depressores* of this fin, the remarks made on those of the fin just described apply equally well. They are really serially homologous with the *infracarinales.* The lateral muscles of the anal fin are, however, of an entirely different nature. Their innervation is from a superficial plexus similar to that supplying the *erectores* and *depressores.* The muscles lie completely outside the fascia covering the lateral muscles of the trunk, and the plexus which supplies them is peculiar in being in a similar manner superficial and formed from a plexus. The probability is that the muscles are dermal in their nature, and that the plexus is a secondary one, produced from the deeper plexus already present as the muscles gradually developed from the dermal tissue.

*The Caudal Fin Muscles.*—These are nearly all modified portions of the lateral musculature of the trunk. The intrinsic muscles are not, however, but must probably be referred to the class of dermal muscles. The innervation of the dorsal portions of the fin and of the anterior continuation of that dorsal portion is interesting in showing the relations of these parts to the dorsal and adipose fins.

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[1] *Dohrn.—Loc. cit.*

The various systems of muscles have now been considered, and it merely remains to give tables indicating the general relations of the various systems to each other and referring the various muscles to their proper segments. The muscles or their representatives belonging to pre-mandibular arches, I will not include in the table, as they have not been considered in the preceding pages. The first table indicates the relations of the cranial muscles, the second those of the muscles of the trunk, including under that term all the body posterior to the head.

MUSCLES OF THE HEAD.

| Nerves. | Dorsal Constrictor Muscles. | Ventral Longitudinal Muscles. |
|---|---|---|
| V. | Adductor mandibulæ, Add. tentaculi, Levator arcus palatini, Dilatator operculi. | Wanting. |
| V. & VII. | Intermandibularis. | |
| VII. | Adductor arcûs palatini, Add. hyomandib., Add. operculi, Levator operculi, Geniohyoideus, Hyohyoideus, | Wanting. |
| IX. & X. | Levatores branchiales, Musculi transversi dorsales, Interarcuales obliqui dorsales, Transversi ventrales, Obliqui ventrales. | Hyobranchialis. |

MUSCLES OF THE TRUNK.

| Nerves. | Dorsal Portion. | Lateral Portion, (Upper & Lower Division). | Ventral Portion |
|---|---|---|---|
| 1–3 | Wanting. | Trapezius (?) Muscles of the pectoral fin. Lateral musculature, (anterior part). | Hyopectoralis. Pharyngo-claviculares. Ventral musculature, (anterior part). |
| 3–30 | Muscles of the dorsal fin. Supracarinales, (anterior portion). | Muscles of Pelvic fin. Lateral musculature, (median part). | Ventral musculature, (posterior part). Infracarinales, (anterior part). Muscles of Anal fin (except the lateral muscles. |
| 30–End | Supracarinales, (posterior portion). Dorsal muscles of Caudal fin. | Lateral musculature, (posterior portion). Greater portion of muscles of Caudal fin. | Infracarinales, (posterior portion). Lower muscles of Caudal fin. |

Dermal Muscles.

Lateral muscles of Anal fin, and the intrinsic muscles of Caudal.

As regards the *trapezius*, I cannot state positively whether it should come in the first or second column of the table, and with regard to how far the muscles on the dorsal region immediately behind the skull correspond to the *supracarinales* and muscles of the dorsal fin, I am equally uncertain. It is probable that the muscles corresponding to these portions have, in the anterior spinal region, completely disappeared, in consequence of the specialization of the anterior vertebræ. The fact that the erector of the second spine of the dorsal fin is attached to the base of the fourth spinous process, and this on its part is united with the posterior wall of the skull closing in above the other vertebræ, seems to favour this view.

GUELPH, June 3rd, 1884.

## ON THE

# NERVOUS SYSTEM AND SENSE ORGANS OF *AMIURUS.*

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[*Read before the Canadian Institute, January the 12th, 1884.*]

In the course of the investigations, the results of which are detailed in the following pages, some features in connection with the nervous system and sense organs of *Amiurus* appeared to me of special interest. These have been elaborated at the expense of other points which would prove no doubt equally worthy of closer examination, but which did not at first sight appear so promising as fields of enquiry. The treatment is consequently not monographical, although for the sake of completeness a short account has been inserted of some structures which have not been subjected to special study.

Of the sense organs, the olfactory does not appear to be either more or less developed than is usual in Teleosts. The eyes on the other hand are extremely small, a condition which is compensated for by the exquisite development of tactile sensibility on the head and especially on the barblets. The latter serve to increase the range of the tactile sense ; especially is this the case with those which are carried on the ends of the modified superior maxillary bones, for their muscular connections enable them to be swept freely at the sides of the head. Also, the auditory organ and the sense organs lodged in the canals of the lateral line and head are well developed, and the former is connected with the air-bladder in such a manner as to indicate functional relationships of the highest importance.

The importance of these sense-organs is sufficiently indicated by the large size of the nerves distributed to them, and the central connections of the latter naturally determine many peculiarities in the architecture of the central nervous system. Considerable space is therefore devoted to the origin and distribution of the trigeminus group and to the auditory apparatus. The following order is observed in the description of the various parts :—

I. Central nervous system.
II. Peripheral nervous system.
III. Sense organs.

## I. CENTRAL NERVOUS SYSTEM.

### *A.*—THE BRAIN.

As in most other Teleosts the cranial cavity of *Amiurus* is by no means filled up by the brain, which is surrounded by a large quantity of areolar connective tissue rich in vessels and fat. This tissue is continued backwards into the neural canal and into the cavities in which the semicircular canals are lodged, to which, and indeed to the whole auditory labyrinth, the tissue acts as 'perilymph.'

The recent observations of Mayser[1] and Rabl-Rückhard[2] have confirmed Stieda's interpretation of the various parts of the Teleost brain, and are thus entirely opposed to the views expressed by Fritsch in his "Untersuchungen über den feineren Bau des Fischgehirns." As was to be expected from the affinity of the Siluroids to the Cyprinoids, I have found Mayser's researches, which are chiefly based on the latter group, of the greatest service in studying the brain of *Amiurus*. The points in which that genus differs from *Cyprinus* I shall call attention to in the course of my description My observations have, however, not been extended to the study of the finer structure of the brain, and the sections figured are rather intended to complete the topographical description than to furnish an exhaustive account of the nerve-fibre tracts.

Owing to the abundant perilymphatic tissue it is easy to remove the roof of the brain case without injuring the brain. The appearance of the organ when so exposed is represented in Fig. 13, Pl. I. In front we have the so-called *cerebral hemispheres* (*CH*) which after the brain has been hardened appear to be two solid masses separated by a longitudinal medial groove, but which in the recent condition are seen to be two oval thickenings in the floor of a sac whose roof and walls are extremely thin and transparent, and whose cavity is the *ventriculus communis* of the secondary forebrain, *prosencephalon*. In comparison with many other Teleostean forms the cerebral hemispheres of *Amiurus* are of large size. From the ventral surface of

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[1] Zeit. wiss. Zool. XXXVI. [2] Arch. Anat. Phys. 1882-3.

each, in front of the hilus where the vessels for the fore-brain enter, arises the long slender olfactory tract (Fig. 14). With its neighbour it runs along the floor of the brain case near the middle line till it reaches the olfactory lobe which lies directly against the nasal sac, so that the numerous olfactory nerves are extremely short. It is only recently that Rabl-Rückhard has pointed out that each olfactory tract and lobe is a hollow outgrowth of the secondary fore-brain, carrying with it a process of the *ventriculus communis*. Each tract instead of being a solid cord is in fact a tube, the roof and sides of which are extremely thin, while the floor is so thickened as nearly to fill the cavity of the tube. In young specimens where the olfactory tract is extremely short and the olfactory lobe still lies close to the cerebral hemispheres it is easy enough to demonstrate this, but it becomes more difficult to do so in the adult, when the tracts have become much elongated.

From the dorsal aspect it is impossible to see anything of the primary forebrain or *thalamencephalon*, for both it and the medial portion of the roof of the midbrain are covered by the great impair *cerebellum* (*CB*), which, in fact, partly overlaps the cerebral hemispheres. At each side of the cerebellum, however, are to be seen the lateral parts of the midbrain, the optic lobes (*LO*), which in accordance with the small size of the eyes are themselves very small. Behind these the cerebellum is continuous by its postero-lateral angles with the *tubercula acustica*, which are themselves joined behind the cerebellum by a bridge of gray matter which roofs over the fourth ventricle in front of the trigeminal lobes. The great size of the cerebellum, its direction forwards so as to overlap the forebrain, and the great size of the *tubercula acustica* are prominent peculiarities of the brain of *Amiurus*. In accordance with the great size of the fifth and vagus nerves, the lobes of the medulla oblongata in which these take origin are proportionately large. They project from the floor of the fourth ventricle, so as to leave merely an irregular sagittal slit in place of the usual rhomboidal groove. Of the two pairs of lobes, the anterior or trigeminal (*LT*) are the larger, and one of them not uncommonly projects beyond the middle line so as to encroach on that of the other side. No fusion ever takes place, as is the case with the Cyprinoids, so that there is always the slit-like fourth ventricle between the trigeminal lobes of *Amiurus*, whereas in the Cyprinoids they are coalesced into one *lobus impar*. The vagus lobes are never so large as the trigeminal; the slit between them is always wider, and no encroachment beyond the middle line is observable. The slit becomes shallower posteriorly and does not in the posterior planes of the origin of the second root of the vagus, extend down to the central canal of the cord. This region is that of the *commissura cerebri infima* of Haller, where the posterior columns of the medulla are divaricated from each other so as to leave a wide V-shaped slit on section, which, however, does not extend to the central canal. The posterior boundary of this slit may be regarded as the point of passage of the medulla oblongata into the spinal cord, a point which is indicated by no marked constriction, for immediately behind the vagus lobes the brain tapers off quite gradually into the cord.

From the ventral aspect various other parts of the brain may be seen. (Fig. 14.) The ventral surface of the cerebral hemispheres is marked by the formation of a lateral lobe which gives on transverse section the outline represented in Fig. 18, Pl. V. Immediately behind the cerebral hemispheres is the crossing of the optic nerves, which can be followed in the form of the optic tracts towards the optic lobes. Behind the optic chiasma is the *commissura transversa* of Haller; the latter structure lies on the anterior part of the floor of the primary forebrain or *thalamencephalon.* We shall see afterwards that the roof of this part of the brain is extremely short from before backwards; its floor on the other hand is extraordinarily developed, for not only is there the large *tuber cinereum* with the hypophysis connected with it, but also the large *lobi inferiores* (*LI*), and the *saccus vasculosus* enclosed between the posterior tips of these, all of which structures contain prolongations from the third ventricle.

Owing to the small size of the optic lobes these are barely visible from the ventral aspect, and the floor of the midbrain being chiefly developed into the swellings, *tori semicirculares,* which nearly fill up the optic lobes, is practically excluded from the basal aspect of the brain. The *ganglion interpedunculare* (Fig. 7, Pl. V.) represents the boundary between the midbrain and oblongata.

The points of origin of most of the cranial nerves can be studied from the ventral aspect. Those of the olfactory and optic tracts have already been referred to above. The third nerve (*oculomotorius*) leaves the base of the midbrain just in front of the posterior tip of the lobus inferior which must be raised to see its point of emergence. Further up on the lateral aspect of the brain, immediately behind the optic lobe, emerges the fourth nerve (*trochlearis*). and the posterior tip of the optic lobe must be pushed forwards to see its precise point of emergence.

The sixth nerve (*abducens*) leaves the medulla oblongata by two slender strands on each side which take their origin near the ventral longitudinal fissure. All of these nerves after leaving the brain associate themselves with the trigeminus group in a way which necessitates the description of their further course with that nerve.

The *trigeminus group* not only includes the fifth nerve, but also the seventh. The motor root of the latter is quite distinct from the trigeminal roots, emerging as it does in front of the auditory nerve, and immediately directing itself forward to join the trigeminal complex. (Fig. 15, Pl. I.) Formerly this motor root was considered to be the only representative of the facial, but first Balfour detected in embryo Selachians a dorsal root taking its course through the orbit, and more recently van Wijhe discovered the part which the *R. dorsalis VII.* plays in the formation of the *ramus ophthalmicus superficialis.* In the adult *Amiurus* it is impossible to isolate any *R. dorsalis VII.* from the neighbouring roots of the trigeminus, and I shall consequently only describe the motor root as *N. VII.*, referring to the others as acustic roots of the trigeminal complex as they take origin from the *tuberculum acusticum.*

Curiously Friant has committed the mistake[1] of according solely to these branches (*R. buccalis* and *ophthalmicus superficialis*) the name of seventh nerve, and of supposing that their destination is "animer tous les muscles sous-cutanés ou peauciers de la face ainsi que ceux qui entourent l'orifice nasal"! He describes the proper motor facial as *R. hyoideo-mandibularis* of the trigeminus.

In studying the roots of the trigeminal complex after the ganglion has been detached from the brain, Fig. 16, Pl. I., the two principal roots are readily seen separated by a white band which stretches forwards from the root of the auditory nerve. The upper and more posterior of these, the dorsal geniculated root of the trigeminus (*N. V., gen. dors.*), can be followed at once into the trigeminal lobe, the lower, which is somewhat anterior in position and considerably

[1] Recherches anatomiques sur les nerfs Trijumeau et Facial des poissons osseux. Nancy 1879. p. 84.

more slender, extends transversely inwards into the medulla oblongata, and also backwards into the spinal cord. It includes the transverse and ascending roots of the trigeminus (*N. V., asc. et trans.*). In addition to these three other more superficial roots enter the ganglionic complex, and their points of origin can be seen without dissection. Fig. 15, Pl. I. One of these has been already referred to as the motor root of the seventh (*N. VII.*), the others, which take origin high up from beneath the crest of the *tuberculum acusticum*, are what I have referred to as acustic roots of the trigeminus.

It is desirable at this stage to examine the branches which leave the trigeminal complex, and then to study the mode in which the various roots contribute to the formation of these.

Examining the ganglionic complex *in situ* from the medial aspect (Fig. 17, Pl. I.), the strong *Ramus lateralis V.* is seen ascending obliquely backwards to the foramen through which it escapes in the occipital region. From the dorsal edge, various other dorsal branches arise, some extremely slender ($\delta$), which may only reach the membranes, or penetrate into the skull, others, the *Ramus oticus* (*R. ot.*), and *Ramus ophthalmicus superficialis* (*R. o. s.*), are of greater importance. The course of the former[1] is outwards and upwards to its foramen in the sphenotic, or the latter forwards to its foramen above that, through which the larger *Ramus ophthalmicus profundus* escapes. The latter nerve carries with it on its medial aspect the trochlearis, but entirely within its sheath, so that it (*N. IV.*) can only be recognized in sections of the complex by its broad fibres contrasting with the narrow fibres of the ophthalmicus, Cutting across the *R. ophthalmicus profundus* the slender ciliary nerve, *R. ciliaris*, is seen to issue behind and outside it by a distinct foramen. The rest of the trigeminal group emerges by three distinct apertures, which are frequently not entirely surrounded by bone, but merely separated by bony spicules. They are for the infero-medial strand, the supero-lateral strand and the facialis. The two latter frequently issue together, but there may be a separating spicule of bone. I have selected the expressions infero-medial and supero-lateral strands for the bulk of the trigeminus group, because it is only after emergence through the skull, that the rearrangement into *R. maxillaris, mandibularis*, &c., takes place.

[1] For the selection of this name for the dorsal branch in question, v. *Van Wijhe*:—"Over het Visceraalskelet en de Zenuven van den Kop der Ganoiden." Leiden, 1880, p. 25.

With the infero-medial strand (*IM.*) issue the third and sixth nerves, the former being merely loosely attached to its medial aspect, the latter within its sheath along the ventral edge. With the supero-lateral strand issues the *ramus buccalis,* but in a separate sheath.

Of the branches mentioned, the *R. buccalis, oticus,* and *ophthalmicus superficialis*, can be traced directly to the roots from the tuberculum acusticum ; their fibres are for the most part extremely broad, similar to those which form the auditory nerve, but some fine fibres are received from the dorsal geniculated root. To the latter are traceable for the most part the *R. lateralis* and *ophthalmicus*, as well as the infero-medial strand, while the supero-lateral strand is formed in great part by the broad motor fibres of the ascending and transverse root. (*N. V., asc. et trans.*). The two principal roots thus assume a different relative position in the complex to what they have on emergence, immediately after which, indeed, they cross. It is to be understood that neither the infero-medial nor supero-lateral strands are exclusively formed of fibres coming from one of the principal roots, but only chiefly so. The facialis, again, as it emerges from its foramen, although it contains all the broad fibres (13 $\mu$) which emerge as the motor root of the seventh, has also acquired fibres from the *tuberculum acusticum* (10 $\mu$) and others of narrower diameter from the ganglionic complex, so that, although chiefly supplying the muscles of the palatine arches, the operculum and the hyoidean apparatus, it serves also as a path for fibres of different destiny.

The *auditory nerve* (*N. VIII.*, Figs. 14, 15 and 16, Pl. I.) leaves the *tuberculum acusticum* on a level with the motor root of the facial, and just behind that. Above it those fibres from the tuberculum acusticum which are destined for the vagus group, form a white band coursing backwards immediately under the crest of the *tuberculum.* (Fig. 3, Pl. V.). Almost immediately after its origin the auditory nerve divides into the shell-like ramus anterior, and the more cord-like ramus posterior, and indeed the cords of the latter, and the division between the anterior and posterior branches, may be carried very nearly up to the point of emergence from the brain. The fibres of the ramus posterior would seem to emerge somewhat higher than those of the ramus anterior. (Fig. 15, Pl. I.)

*The Vagus Group.*—This group of nerves escapes from the brain in two parts (Fig. 15, Pl. I.), anterior and posterior, vagus I. and II. The former is chiefly derived from the anterior planes of the vagus lobes, the latter from the posterior. With the former are associated the broad nerve fibres from the *tuberculum acusticum* referred to as the acustic root of the vagus group. (*R. ac. vag.* I.) Certain very slender motor roots, with a pronounced inclination backwards, join the two parts of the vagus group from the lower surface of the oblongata. One of these alone is connected with the glossopharyngeus after its separation from the anterior part, while two or three join the posterior part.

From the anterior part is detached the comparatively slender *glossopharyngeus* nerve, which escapes from the skull by a separate small aperture in front of the foramen for the vagus proper, and immediately expands into a large *ganglion trunci* (*G. IX.*) The rest of the vagus group, formed of the whole of the posterior part (*Vag. II.*) as well as of the greater portion of the anterior part (*Vag. I.*) escapes through an independent foramen, and then forms the large ganglionic complex (*G. X.*) from which the various branches of the vagus group are derived.

As springing from the oblongata within the cranial cavity may be mentioned the 1st spinal nerve, which does so by two distinct roots escaping through the occipital region in the same horizontal plane as the osseous roof of the *cavum sinus imparis.*

Reserving for separate description the course of the cranial nerves outside the brain case, I proceed to consider certain points as to the structure of the brain, which the diagrams on Plate V. will serve to elucidate.

The section represented in Fig. 1 is through the vagus lobes of the oblongata near their posterior border, and in fact through the *commissura cerebri infima* of Haller. It may be compared with Fig. 22, Taf. XVI. of Mayser's paper, but it will be observed that the vagus lobes are not so widely divaricated from each other in *Amiurus* as in *Cyprinus.* The sensory root of vagus II. has a direction somewhat dorsal as it escapes, so that in horizontal sections of young fish transverse sections of this part of the root are met with above the level of its emergence from the oblongata (Fig. 11, Pl. IV.) In other respects the architecture is wonderfully alike. The ventral bundles of longitudinal fibres are subdivided on each side into two compartments by the *commissura accessoria* of Mauthner, and the extremely broad 'fibres of Mauthner' are found in the upper compartments. At either side of the central canal is the nucleus of one of the motor roots of the second part of the vagus, and on either side of the ventral longitudinal fibres the nucleus of the first spinal nerve.

Fig. 2 represents a section passing through the anterior part of the vagus lobes, and through the origin of the first part of the vagus. Those fibres which join the nerve from the *tuberculum acusticum* are cut transversely, and are seen above the eighth nerve in the next figure. The sensory vagus fibres arise chiefly from the periphery of the lobe, while fibres which originate near the wall of the fourth ventricle collect themselves into a strong bundle, reinforced by similarly originating fibres from the trigeminal lobe (Fig. 3) and are thence to be traced forwards into the cerebellum as the secondary vago-trigeminal tract of Mayser. (*Sec. V. T.*) This strong fasciculus lies immediately below the ascending roots of the fifth nerve. The fourth ventricle is slit-like in section, except where it becomes somewhat wider above where its roof is formed only by ependyma and pia. The slit-like section is retained except where encroached on by the trigeminal lobes, until it becomes opened out immediately in front of these (Fig. 4) to be closed again by the commissure of grey matter which joins the *tubercula acustica* (Fig. 5). These ganglia are further connected by fibres which decussate below the floor of the fourth ventricle. (Figs. 3 and 4).

From the various parts of the *tuberculum* fibres converge to form the auditory nerve (*N. VIII.*), but it also receives a contingent from a nucleus lying below the secondary vago-trigeminal fasciculus.

The whole of the trigeminal lobe serves to give origin to the sensory fibres of the fifth nerve which form the powerful 'dorsal geniculated root,' trending outwards in Fig. 4. In the same plane the motor fibres of the *facialis* (*N. VII.*) escape, partly derived from a nucleus represented in the figure, but largely composed of a strand which stretches outwards, forwards and downwards from the floor of the fourth ventricle. It may be recognized in transverse section in Fig. 3, before it has begun to assume the course above named.

Fig. 5 illustrates a section passing through the trigeminal roots. The fibres derived from the *tuberculum acusticum* are most superficial, the ascending and transverse fibres most anterior and ventral; the change of position which the latter undergo with regard to the dorsal geniculated root is represented in Fig. 6. In Figs. 4 and 5 the patches of ganglion-cells lateral to the ventral columns are the nuclei for the anterior and posterior roots of the sixth nerve.

From the floor of the fourth ventricle vessels ($v$) are distributed up the sides of the vagus and trigeminal lobes as well as up the posterior face of the laminated bridge of grey matter joining the *tubercula acustica* (*com. tub. ac.*)

This appears to give place gradually to the cortex of the cerebellum without again exposing the fourth ventricle, the roof of which is thus formed in the posterior part of this region by the cerebellar cortex, (Fig. 6), which is, however, gradually encroached on by the molecular layer until it is confined to the periphery. (Fig. 7).

Two great transverse ventral commissural systems are readily seen in sagittal sections of the brain, one behind, the other in front of the *ganglion interpedunculare ;* the former of these which appears to be equivalent to the fibres marked *pons varoli* (?) by Mayser, is represented in Fig. 6. It appears to be much more developed than the similar system in *Cyprinus*. The latter is the *commissura ansulata* ; its posterior bundles are those which stretch towards the *ganglion interpedunculare*, (Fig. 7), its anterior form the base of the brain immediately behind its junction with the *lobus inferior* (Fig. 8). Between the planes represented in Figs. 6 and 7, the fourth ventricle gradually becomes slit-like in section, its wall being formed of vertical fibres which connect the outer part of the 'Uebergangsganglion' of Mayser, ('transitionary,' because, according to Mayser's conception, it is situated partly in the hind and partly in the midbrain) with the molecular layer of the cerebellum. The slit-like section of the ventricle is soon altered by the decussations of fibres in this region, by which a dorsal part is separated off belonging to the cerebellum (Figs. 7 and 8). Most posteriorly is the decussation of the secondary vago-trigeminal fasciculi, some fibres of which are represented approaching the middle line in Fig. 7.

Fig. 7 is from a plane immediately behind the optic lobes, the tip of one of which is just caught in the section figured, with the fourth nerve emerging below and behind it. The nucleus of that nerve is in a more anterior plane (Fig. 8), as well as its decussation between the *valvula cerebelli* and the ventricle. From the plane represented in Fig. 8, as far as that in Fig. 11, the *valvula cerebelli* is to be met with, cortical substance at first predominating, but afterwards giving place to molecular substance especially near the ventricle, (Figs. 9 and 10). It is much simpler in its form than the *valvula* of the Cyprinoids, as may be judged from the sections: its anterior tip lying between the *tori longitudinales* is formed solely of cortex.

One of the most characteristic features of the brain of *Amiurus* is the forward growth of the cerebellum itself. Becoming independent of the valvula in a plane between those represented on Figs. 8 and 9, it projects forwards as far as the plane of the *commissura anterior* (Fig. 19). In its free part which thus overlies the roof of the mid-brain as well as the thin roofs of the intermediate and fore-brain, the molecular substance is always completely invested by cortex.

The great development of the hind-brain of *Amiurus* is associated with a comparatively small mid-brain, which only reaches the free surface in the form of the optic lobes. It is easy enough to determine the boundary between mid-brain and *thalamencephalon*; it is formed by the fusion of the *tori longitudinales* with the *commissura posterior*. Mayser selects, with other authors, the decussation of the fourth nerves as the boundary between mid- and hind-brain. The boundary between the parts formed from the second and third cerebral vesicles is more difficult to determine in the adult, owing to the manner in which the *valvula cerebelli* is projected forwards into the *mesocoele* (ventricle of the mid-brain), but it is to be understood that the lateral cornua of the mesocoele (ventricles of the optic lobes), [*VLO*], and consequently their walls, which form the lateral parts of the mid-brain, are to be found both in front of (Fig. 14) and behind (Fig. 8), the *aquæductus Sylvii* and its walls, which constitute the central part of the mid-brain. The lateral walls and roofs of the ventricles of the optic lobes are everywhere formed by the *tecta optica*, while the medial walls and floors are formed by the *tori semicirculares*. Penetrating the ventricles and thus effecting a union between the *tori semicirculares* and *tecta optica* are the radiating 'Stabkranz' fibres. (Radiatio thalami of Fritsch.) A comparison of Figs. 8 to 14 will show the course of the *tori longitudinales*. At first hardly projecting into the internal and upper angles of the ventricles of the optic lobes, they gradually become more prominent. In the more posterior planes separated widely by the *valvula cerebelli*, they converge till, at the plane of the *commissura posterior*, (Fig. 13), they are almost in contact. Immediately behind that the central part of the roof of the mid-brain is formed simply of transverse fibres traceable chiefly into the outer layers of the *tecta optica*. The mode in which the fusion of the *tori*, both with each other and the *commissura posterior*, is effected at the anterior boundary of the *aquæductus Sylvii*, is represented in Fig. 14, where their fibres are seen to descend with those of the posterior commissure into the optic thalami.

At this point the ventricles of the optic lobes die out, and the third ventricle is alone present in frontal sections. In the plane represented in Fig. 15, its cavity is prolonged upwards into a diverticulum, the origin of the *epiphysis*, which makes its way outwards through the roof (Fig. 16) to terminate in the adipose tissue above the roof of the *ventriculus communis* in the plane of the *commissura anterior*. No prolongation into the cranium such as has been described especially by Cattie[1], occurs here, and the wall is quite similar, histologically, to the roof of the *ventriculus communis*. Immediately in front of the diverticulum of the *epiphysis* the molecules of the *ganglia habenulæ* make their appearance (Figs. 16 and 17); the fibres which collect themselves into the bundles of Meynert soon group themselves into a cylindrical form, and are to be seen on either side close to the walls of the third ventricle at successively lower points (*M.B.*, Figs. 14, 13, 12), till they eventually distribute themselves, breaking through the strands of the *commissura ansulata*, to the *ganglion interpedunculare*.

Owing to the fact that the plane which represents the boundary of the primary fore-brain and mid-brain is an extremely oblique one, extending from the *ganglia habenulæ* above, downwards and backwards to the *ganglion interpedunculare*, the third ventricle and the ventricle of the mid-brain (mesocoele) are to be met with in communication with each other in the same frontal planes (Fig. 11.) In this region the infundibulum communicates below with the hypophysis, and from the ventricle two prolongations (*VLI*) are sent into the lobi inferiores, a shorter inferior cornu, and a longer superior and anterior one, which meet each other at one point, thus partly cutting off from the rest of the lobus inferior a somewhat cylindrical lobule. Backwards, the cavity of the infundibulum becomes folded, and is continuous with that of the *saccus vasculosus*, where all the nervous matter has disappeared with the exception of two cornua somewhat crescentic in section (Fig. 8), round which densely staining molecules are grouped.

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[1] Archives de Biologie. Tome II

The most powerful of the ventral commissural systems is, no doubt, that of the *commissura transversa Halleri*, which is situated for the most part in front of the *ganglia habenulæ*, although part of it is represented, receiving contingents from the inferior lobes and optic thalami, in Fig. 17. In Fig. 15, other commissural fibres are seen higher up on a level with the peduncular strands, these appear to belong to the *commissura horizontalis* of Fritsch.

Figs. 18, 19, 20, represent sections through different planes of the fore-brain, and confirm the views of Stieda and Rabl-Rückhard, that the secondary fore-brain is not formed of two solid masses as generally described, but that these—the lobi anteriores or cerebral hemispheres—are nothing but raised ganglia developed in the floor of a great impair ventricle, the *ventriculus communis*, the anterior outgrowth of the third ventricle. Each lobus anterior may be described as formed of a medial and lateral part. The latter becomes especially distinct behind (Fig. 18), and indeed its tip (*CHL*), Fig. 17, projects further back than the boundary between the secondary and primary fore-brain. Within the medial part of the lobus anterior, near its junction with the lateral, are situated the peduncular strands. In front of the *commissura transversa* the fissure of the *ventriculus communis* separating the anterior lobes extends so deep as to leave in parts very little to connect them, but ependyma and pia. The optic tracts, however, soon replace the commissura transversa, and bind the ventral surfaces of the anterior lobes together. (Fig. 18.) In front of this where the optic chiasma merely rests on the ventral surface of the brain, the lobes are joined by the *commissura anterior*. In its posterior planes this is formed of fibres ot two different characters, which give place in front to the ordinary grey matter of the anterior lobes. Still further forwards where the olfactory tracts are given off (Fig. 20), the lobes are widely separated, and lie free within the cavity of the *ventriculus communis*, except for a small place on the ventral surface of the olfactory tracts. This attachment persists in front, where the *ventriculus communis* has been subdivided into the ventricles of the olfactory tracts as described above.

### *B.*—THE SPINAL CORD.

I have not devoted any special study to the spinal cord. Sections in the anterior region resemble in the arrangement of grey and white matter the condition in *Silurus* as figured by Stieda.[1] A gradual

[1] Zeit. wiss. Zool. XVIII., Pl. I., Fig. 4.

tapering may be observed till the upturned portion of the notochord is reached where the cord suddenly loses its cylindrical form and dilates into a pyramidal swelling. This is, no doubt, owing to the greater size of the ventral as compared with the dorsal columns in this region where two pairs of powerful ventral roots are given off behind the last dorsal roots.

## II. PERIPHERAL NERVOUS SYSTEM.

The intracranial course of the cranial nerves has been described at page 355. It remains to follow them to their terminations outside the skull. Nothing further need be said with regard to the *olfactorius* and *opticus*.

Owing to the small size of the eyes, the dissection of the motor nerves of the eyeball is a matter of some difficulty, which may account for the fact that I have not been able to find any trace of an oculomotor or ciliary ganglion, although I have examined the whole of the third and ciliary nerves within the orbit for that purpose.

In the course of passing through the skull the third nerve leaves the infero-medial strand of the trigeminus, to enter a special canal in its course to the orbit which it reaches between the *R. ophthalmicus profundus* and the *R. ciliaris*. It divides immediately into the superior and inferior divisions, the former of which runs at once to the *rectus superior* while the latter crosses obliquely over the *rectus inferior* and *medius*, supplying them, to end by the long branch in the *obliquus inferior*.

In dissecting from the floor of the mouth, (Figs. 1, 2, 3, Pl. IV.) the *rectus externus* has to be reflected to expose the inferior division of the third taking this course.

The *trochlearis* accompanies the *R. ophthalmicus profundus* into the orbit and leaves it there about the middle of its course to pass obliquely forwards and outwards to end in the *obliquus superior*. In its course there, certain fibres from the *ophthalmicus* may be associated with it (Figs. 4, Pl. IV.) which end in the fat near the superior oblique muscle.

The *abducens* also leaves the ventral edge of the infero-medial strand, and crosses to accompany the third into the orbit; this it does apparently in the same sheath, although it may be readily separated from it, and is always lateral to it in position. It immediately enters the *rectus externus* on the posterior margin of that muscle.

### BRANCHES OF THE TRIGEMINUS GROUP.

The *ramus lateralis trigemini* leaves the skull by the foramen in the supraoccipital, and courses backwards near the middle line between the lateral musculature, and that of the interspinous bones. It is reinforced immediately after leaving the skull by the important dorsal branches of the first, second and third spinal nerves, and acts as a collector for slenderer branches from all the other *rami dorsales.* (Figs. 6, 14, 15, Pl. IV.)

The *ramus oticus* emerges from its foramen in the sphenotic and supplies the mucous canal running backwards and forwards from this point. Two short cutaneous branches penetrate vertically the *adductor mandibulæ* near its dorsal line of origin for the skin overlying that, and a larger posterior branch runs through the fibres of the *adductor mandibulæ* to become superficial over the *levator operculi.* The mucous canal in the preoperculum is supplied in its upper part by a descending branch, which runs underneath the *adductor mandibulæ*, and on the surface of the *dilatator operculi* to become superficial at the posterior edge of the former muscle. The *ramus oticus* thus contains ordinary sensory fibres in addition to those destined for the mucous canals.

The *ramus ophthalmicus superficialis* emerges from the skull through a canal which is considerably larger than, and lies dorsally from that through which the *R. opht. profundus* emerges. It gains the orbit immediately under the osseous roof of which it lies, and escapes from it on to the upper surface of the skull through a foramen above that through which the *profundus* passes. In its course to the mucous canals in the neighbourhood of the nasal sacs it crosses superficially to the outside of the *profundus*, but does not communicate with it. In the orbit it is separated from the *profundus* by the origin of the *dilatator operculi.*

The *ramus ophthalmicus profundus* follows the course implied above through the orbit, gives off a slender branch to join the *ramus ciliaris,* another to the skin and fat in front of the eye and along the outer border of the nasal sac. Immediately after reaching the upper surface of the skull a strong branch enters the nasal barblet, and the rest passes toward the middle line, a branch being given off along the medial border of the nasal sac as far as the extremity of the snout. (Fig. 4, Pl. IV.)

The *ramus ciliaris* takes origin from the *ophthalmicus* after that nerve has separated from the trigeminal complex, but within the cranial cavity, and partly also from the supero-lateral strand. It escapes into the orbit by a foramen lateral to that for the *R. ophthalmicus profundus.* Its branches there are partly represented in Fig. 3, Pl. IV.

The *ramus buccalis* emerges through the same foramen as the supero-lateral strand, but in a separate sheath. At its origin from the trigeminal complex it is very closely connected with the *ramus ophthalmicus superficialis,* although it contains fibres other than those derived from the *tuberculum acusticum.* In dissecting the *ramus maxillo-mandibularis* from the upper surface after reflection of the eye, the *ramus buccalis* is found on the surface of that nerve. As it courses forwards it divides into two branches, of which the deeper and more medial accompanies the *ramus maxillaris* to the subcutaneous tissue below and outside the nasal sac, and the lateral and more superficial is destined for the infraorbital mucous canal. A cutaneous branch becomes superficial at the posterior inferior angle of the orbit (Fig. 3, Pl. IV.), and afterwards communicates with a cutaneous branch of the facial below the edge of the *adductor mandibulæ.*

The remaining branches of the fifth proper are formed from the supero-lateral and infero-medial strands after they have emerged from the skull. The mode in which this is effected may be seen from Fig. 1, Pl. IV., which represents a dissection from the roof of the mouth.

*Ramus cutaneus palatinus.*—This small branch is derived from the infero-medial strand just after its escape. It ramifies in the mucous membrane of the roof of the mouth over the *M. adductor arcus palatini,* but also sends a branch backwards to the mucous membrane lining the gill-cover, and covering the *adductores hyomandibularis* and *operculi.*

*Ramus palatinus.*—This is a large branch of the infero-medial strand which runs forwards between the *adductor arcus palatini* and the skull, being flattened between the ligamentous attachment of this muscle to the parasphenoid and that bone. Here it detaches a superficial branch for the mucous membrane over the entopterygoid, and then penetrates the fleshy anterior part of the *adductor arcus palatini* where it forms two branches. The more medial of these is stronger and more superficial in the substance of the muscle, but both end in the premaxillary teeth and the mucous membrane of the lips and anterior part of the roof of the mouth.

*Ramus ad. m. adductorem mandibulæ.*—This strong branch is derived from the supero-lateral strand immediately on its emergence from the skull, soon gains the dorsal aspect of the retractor muscle of the maxillary barblet which it supplies, and then distributes itself in the fleshy mass of the *adductor mandibulæ* after giving off a superficial branch. This (Fig. 3, Pl. IV.) contains fibres for the *levator arcus palatini* and *dilatator operculi*, and also furnishes a cutaneous branch which communicates with a similar branch of the facial crossing the surface of the *adductor mandibulæ.*

The mode in which the *Rr. maxillaris* and *mandibularis* are formed by the redistribution of the fibres of the supero-lateral and infero-medial strands is shown in Fig. 1, Pl. IV. Each nerve contains elements from both strands.

*Ramus maxillaris.*—This branch is considerably smaller than the *R. mandibularis,* owing, no doubt, in part to the reduction and conversion of the superior maxillary bones. It is accompanied by the *ramus buccalis* as far as the hinder end of the palate bone where it divides into medial and lateral branches. The former turns over the dorsal surface of the palate bone, and ends in the lateral premaxillary teeth and the neighbouring skin, while the latter, after detaching some cutaneous branches, passes between the split tendon of the retractor muscle of the maxillary barblet and divides into two branches for the anterior and posterior aspects of the barblet.

*Ramus mandibularis.*—The two constituent strands may remain separate while the nerve gains the dorsal aspect of the retractor muscle of the maxillary barblet. Here it gives off a branch which accompanies the tendon of that muscle to the posterior aspect of the barblet, and then divides into the external and internal branches. The former, *R. externus* is given off at the anterior border of the insertion of the *adductor mandibulæ,* and passes along the external edge of the lower lip communicating with a fine cutaneous branch of the facial which accompanies it at a somewhat lower level. The *ramus internus* gains the inner aspect of the jaw where the *R. externus* is given off, and after passing under a cartilaginous loop ends in the mandibular barblets, teeth and mucous membrane, as well as in the intermandibular muscle which it helps to supply along with a motor filament from the facial.

*Facialis.*—The mucous membrane lining the gill-cover has to be removed to expose the facial in its passage from its foramen of exit from the skull to its point of entry into the hyomandibular canal. In the exposed part it gives off (1) a *ramus opercularis* which runs backwards to the *adductores hyomandibularis* and *operculi*, and (2) a *ramus ad M. adduct. arc. palatini* which curves forwards round the posterior edge of that muscle, passes through the muscular substance supplying it, and then enters the anterior part of the muscle where it is situated more superficially, and is joined by a branch of the *ramus palatinus V.* While in the hyomandibular canal a few branches escape to the muscles of the branchiostegal rays, and to the mucous membrane there. On escaping from the hyomandibular canal a stout *ramus externus* is given off which courses along the lower edge of the *adductor mandibulæ* to communicate with the *r. ext. mandibularis* as described above. In its course several small cutaneous filaments are detached, two of which effect communication with branches of the fifth emerging under the edge of the *levator arcus palatini.*

The remainder of the seventh passes along the posterior border of the ceratohyal, and then into the fibres of the geniohyoid and intermandibular muscles.

*Glossopharyngeus.*—I have already described this nerve as far as the formation of its ganglion. From this the nerve runs forward in contact with the skull and medial to all the *levatores branchiarum*, the most anterior of which it supplies. Before being distributed to the first branchial arch it gives a filament to the wedge of fat and connective tissue between the pharyngobranchials and the *adductor arcus palatini.*

*Vagus.*—From the large ganglionic plexus in which lobes can be distinguished belonging to the different trunks (Fig. 13, Pl. IV.) the *trunci branchiales vagi* are given off. The first and second trunks come off together, and are somewhat slenderer than the third and fourth. With the fifth come off the branches to the contractile palate and behind it a *truncus intestinalis.* Between *tr. branch. III.* and *IV.*

an independent branch arises for the oblique dorsal musculature of the gill arches, which is, however, in part supplied by a branch of *tr. branch. IV.*

Directly behind the most posterior of the *levatores branchiarum*, and separated by it from the nerves in front, the *ramus lateralis vagi* originates from its subdivision of the ganglionic complex. It is at first parallel in its direction to the transverse portion of the supraclavicle, but afterwards crosses it (Fig. 14, Pl. IV.) and becomes superficial over the air-bladder and behind the ascending process of the supraclavicle. Here it gives off its branch in the course of the accessory lateral line which can be traced along the line of junction of the ventral and lateral musculature as far as the line of attachment of the superficial muscles of the anal fin (Fig. 6, Pl. I.), while the stem is continued backwards in the line between the dorsal and ventral parts of the lateral musculature. Whether as Mayser asserts for *Cyprinus* the fibres of the *ramus lateralis* are those which I have named *radix acusticus vagi I.*, I have been unable to demonstrate in *Amiurus*, but the fact that the mucous canals of the head are supplied by fibres from the *tuberculum acusticum* would lead one to conclude that the same is true of those of the trunk.

## SPINAL NERVES.

Of these there are forty-one pairs, of which the first emerge through the exoccipitals, the more anterior of those which follow by separate apertures for the dorsal and ventral roots through the arches of the corresponding vertebræ (*e. g.*, the 7th pair through the arch of the 6th vertebra) and the more posterior through notches on the posterior borders of the arches, which are closed into foramina by articulating processes from the succeeding vertebræ.

The second and third spinal nerves have no foramina, for owing to the modification of the anterior vertebræ in connection with the auditory organ, the wall of the neural canal is membranous in that region. The dorsal and ventral root of the second are further apart from each other than those of the third, but they emerge very close to these, much closer than their points of origin from the spinal cord would indicate. (Fig. 8, Pl. IV., and Figs. 2 and 3, Pl. VI.) This backward position of the points of emergence of the roots of the second nerve is to be explained by the formation of that diverticulum of the dura mater known as the *atrium sinus imparis* and the alteration of the arch of the first vertebra in contact with it. The fourth nerve is, however, quite normal in its emergence, escaping through the arch of the third vertebra towards its union with the arch of the fourth. Further particulars as to the neural canal in this region are to be found under the description of the auditory organ. There also the nature of the *saccus paravertebralis* is described in which the ganglia of the first four spinal nerves lie.

The ventral branches of the first four nerves go to form the brachial plexus, according to the diagram, Fig. 5, Pl. IV. The dorsal branches, especially of the second and third, are of large size, and join the *ramus lateralis V.*, as already described. As the ventral branches of the second and third pass outwards towards the plexus, they are extremely close together and may lie in the same sheath in a groove between the ventral edges of the strong anterior part of the fourth tranverse process (Fig. 13, Pl. IV.) and the transverse process of the supraclavicle. The ventral branch of the fourth is much slenderer, and after escaping from the neural canal gains the posterior aspect of the part of the fourth transverse process referred to.

After the ventral branch of the first nerve leaves the *saccus paravertebralis*, it rests on the trapezius muscle which it supplies, and then divides into medial and lateral branches. The former (1 Fig. 5), is intended for the pharyngo-clavicular muscles, the latter reinforced by a branch from the second nerve is destined for the supply of the abductor muscles and the deep adductor. (2 and 3, Fig. 5).

The remainder of the second nerve joins the third; the superficial adductor is supplied from this junction, a slender cutaneous filament courses to the skin in front of the fin, and a large nerve enters the defensive spine of the fin. The fourth nerve assists in the supply of the superficial adductor, it sends a delicate filament to the skin below the fin, and is distributed also to the upper part of the ventral musculature there. Fig. 5 also represents the method in which the following myotomes are supplied by the fifth, sixth and seventh nerves, and the nature of the communications between these. The ventral branch of the fifth runs down the intermuscular septum between the third and fourth myotomes of the ventral musculature and the following nerves conduct themselves similarly, supplying chiefly the myotomes in front of them.

Five nerves (the tenth, eleventh, twelfth, thirteenth and fourteenth) enter into the supply of the musculature of the ventral fin, branches for the superficial muscles forming an independent plexus from that into which the branches for the deep muscle enter.

A general scheme for the more posterior nerves is represented in Fig. 6, Pl. IV., in which the *rami dorsales* are seen to furnish branches for the *R. lateralis V.* as well as branches for the interspinous muscles. Each *R. ventralis*, as described by Stannius, crosses over an intermuscular septum into the following myotome, where the branches (*Rmv*) for the ventral parts of the lateral musculature are given off, and then all are connected by two longitudinal cords (like *nervi collectores*) from the nodal points of which the branches for the deep (*Rmp*) and for the superficial musculature (*Rms*) of the anal and caudal fins are derived. The infracarinal muscles are supplied by nerves which are apparently homodynamous with those going to the superficial musculature of the fins.

The nineteenth to the thirty-third *rami ventrales* take part in the innervation of the anal fin, while the caudal fin receives the succeeding nerves, of which the two last pairs consist only of very strong ventral branches corresponding to the terminal swelling of the upturned tip of the spinal cord.

### SYMPATHETIC NERVOUS SYSTEM.

I have not devoted any attention to the sympathetic system; a thorough study of it, especially in its relations to the somewhat puzzling suprarenal capsules of the Teleosts, would no doubt yield facts of much interest.

The most readily-detected ganglia are to be found on the sides of the body of the first vertebra, giving off there branches with the branches of the aorta, as well as the ganglionated cord backwards along each of those vessels. Two branches of large size pass forwards and downwards under the branchial veins and are joined by a transverse commissure under the basioccipital. Thence the anterior communicating branches to the ganglia of the vagus and trigeminus groups pass forwards.

## III. ORGANS OF SPECIAL SENSE.

Although my detailed observations have been confined to what is unquestionably the point of highest interest in connection with the sense organs—the relationship of the air-bladder to the auditory labyrinth—I prefix, for the sake of completeness, a few particulars as to the olfactory organ and eye.

With respect to the former, *Amiurus* differ very slightly from *Silurus glanis*. Like most Teleosts the nasal sacs communicate with the outside by two apertures, which are separated by the whole of the length of the roof of the sac, as much as 12 mm. in specimens of moderate size. The anterior aperture is somewhat oblique and prolonged into a short tube of 2 mm. in diameter, while the posterior, twice as wide, is overhung by the nasal barblet which originates immediately in front of it. In connection with the roof of the sac are both the nasal and adnasal or antorbital bones. The apertures are situated in the same sagittal plane, but after the removal of the roof, it is evident that the sacs themselves converge backwards. (Fig. 12 Pl. I.) A high epithelium clothes the roof and the posterior part of the floor of the sac. The rest of the floor is elevated into the Schneiderian folds which are disposed on either side of a median raphe. On each side of the raphe there are fifteen to sixteen of these arranged in a somewhat fan-like fashion. Immediately behind and underneath the folds is the olfactory bulb from which the short nerve fibres distribute themselves to the neuro-epithelium.

The small size of the eye in *Amiurus* renders it a somewhat unfavorable subject for investigation. As far as concerns the disposition of the muscles of the eye, the retrobulbar tissue and the coats of the optic nerve, I have not observed anything departing from the normal condition of affairs. The sclerotic coat is destitute of bone, is entirely fibrous in the neighbourhood of the entrance of the optic nerve, but becomes cartilaginous forwards until it passes into the *substantia propria corneæ*. A comparatively thick layer of subconjunctival tissue separates this from the external epithelium.

I have not satisfied myself of the presence of any rudiment of the chorioideal gland ; but the existence of a rudimentary pseudobranchia renders worthy of more careful investigation the distribution in the eye of the *arteria ophthalmica magna*. The *argentea* is well developed, especially in the iris, but there is no *tapetum*. Like *Anguilla*, which *Amiurus* further resembles in the small size of the eye, the pigmentary epithelium of the retina is extremely thick, as much so as the rest of the retina, but unlike *Anguilla* there are no retinal vessels. So far as I have observed the lens, its capsule, *campanula Halleri* and *processus falciformis* offer no exceptional features.

## AUDITORY ORGAN.

In many respects the labyrinth of *Amiurus* resembles that of the Cyprinoids. The *pars superior* and *inferior* are equally widely separated, and while the connecting narrow but thick-walled *ductus sacculo-utricularis* is very distinct, the *pars inferior* lies largely behind the *pars superior*. The latter is especially distinguished by the large size of the *recessus utriculi*, and of the contained macula and otolith (*lapillus*), Fig. 9, Pl. I. Unlike the *pars inferior* it lies comparatively free in the cranial cavity, except for certain parts of the semi-circular canals. The wall of the skull opposite the *fovea rec. utr.* is extremely thin, but over against the thin-walled *utriculus* is much thicker. Where the *ductus sacculo-utricularis* opens into the *pars inferior*, the latter also looks freely into the cranial cavity. At this point the *foveæ sacculi*, which are hollowed out on the upper surface of the basi-occipital bone, are separated from each other by a median crest, somewhat wider anteriorly, where the anterior tips of the sacculi (processes of Comparetti)[1] diverge forwards into small recesses of the prootics. To this crest the wall of the labyrinth is attached, as represented in Figs. 8 and 9, Pl. VI.; the relationship to it of the posterior branches of the auditory nerve is seen from the same figures. Further back the *foveæ* are separated by the median *cavum sinus imparis;* whose floor is hollowed out in the basi-occipital, but whose walls and roof are furnished by the ex-occipitals. The relationship of these cavities may be gathered from Fig. 15, Pl. IV., which represents a frontal section through the head of a young fish of 3–4 ctm., and from the figures on Plate VI. It will be seen that the ex-occipitals also form the lateral wall and roof of each *fovea sacculi*, and that especially the *lagenæ cochleæ* are lodged in these bones.

Figs. 9 and 10, Pl. 1, represent the medial and lateral aspects of the labyrinth. The relative position of the *lagena cochleæ*, and *sacculus*, and of the contained *maculæ acusticæ*, may be better seen from Fig. 15, Pl. IV. The otoliths which rest on the *maculæ acusticæ* of the *recessus utriculi*, *lagena cochleæ*, and *sacculus* respectively, and which

[1] *Hasse*:—Anatomische Studien I., 592.

are designated *lapillus, asteriscus* and *sagitta*, are represented × six diameters in Figs. 18, 17, 16, Pl. IV.

As will be seen from Fig. 11, Pl. I., the inferior parts of the labyrinth of both sides are nearest to each other where the *ductus sacculo-utriculares* open into them. In front and behind that plane they diverge from each other, but where they are nearest are connected by a short, thin-walled, transverse *ductus endolymphaticus*, which sends back a pyriform thin-walled *saccus endolymphaticus* (*sinus impar*) into the *cavum sinus imparis*, but by no means filling up the *cavum*. (Figs. 7 and 8, Pl. VI.) The horizontal section, Fig. 13, Pl. IV., passes through the ductus. I find no *macula acustica* in either *ductus* or *sinus endolymphaticus*, such as described by Nusbaum[1] and figured by him[2] for *Cyprinus*. The horizontal series from which Fig. 13 is taken is quite perfect, and although the small *maculæ acusticæ neglectæ* are easily enough detected, no trace of any thickened neuro-epithelium exists in the parts referred to, nor does any branch of the cochlear nerve reach them.

The mode of branching of the auditory nerve is indicated in Fig. 10, Pl. I. It presents no difference from the scheme propounded by Retzius.[3] As already mentioned, the anterior division which, immediately after its origin, spreads itself out in a shell-like fashion, arises somewhat lower from the *tuberculum acusticum* than the posterior. It furnishes branches to the *macula acustica recessus utriculi*, *crista acustica ampullæ sagittalis*, and *crista acustica ampullæ horizontalis*. The cords of the posterior division may be separated nearly up to their origin ; of these the most anterior in origin and ventral in position is destined for the *macula acustica sacculi*, the next is for the *papilla acustica lagenæ cochleæ*, and the highest and most posterior in origin, as well as the most dorsal in its backward course, is for the *crista acustica ampullæ frontalis*. The latter slender cord, which furnishes a twig to the *maculæ acusticæ neglectæ*, may be coalesced with the foregoing for some distance after leaving the brain. I have not noticed the maculæ neglectæ in the fresh adult labyrinth, but they are very plain although of small size on opposite sides of the basal part of the utriculus in the horizontal series

[1] Zool. Anzeiger IV., 552.

[2] Relations of the Auditory organ and Air-bladder in the Cyprinoids (Polish) Lemberg, 1883. T. IV., Fig. 19.

[3] Arch. Anat. Phys. 1880, p. 240.

referred to above, and in the preparations from which the figures on Pl. VI. are taken. Fig. 8, Pl. I., represents the medial macula neglecta from one of the horizontal sections.

## ON THE RELATIONSHIP BETWEEN THE AIR-BLADDER AND THE AUDITORY LABYRINTH.

E. H. Weber, in his treatise '*De aure animalium aquatilium*' first made known the fact that the Cyprinoids and Siluroids are characterized by a remarkable communication between the auditory labyrinth and the air-bladder, which is effected by a chain of bones named by him *stapes*, *incus* and *malleus* after analogy with the auditory ossicles in the mammalia. It was soon ascertained that this chain of bones represents certain altered constituents of the anterior vertebræ, but the precise morphology of the parts involved was first ascertained by Baudelot,[1] and afterwards by Nusbaum (*l. c.*) for the Cyprinoids. Weber's interpretation of the number of vertebræ concerned in *Silurus* is even further from the truth than his account of the parts in *Cyprinus*, owing to the more intimate coalescence of certain of the altered vertebræ.[2]

These it will be convenient to describe in the first place. The sixth vertebra resembles in all respects those which immediately follow it. It is the first rib-bearing vertebra, the ribs being articulated to the extremities of the costiferous pedicles or 'Basal-Stümpfe.' The vertebræ in front have only structures homodynamous with the basal pedicles; they are generally spoken of as transverse processes. In front of the sixth all the vertebræ are coalesced in the adult. Of these the fifth is the most independent, especially as regards its neural arch, and spinous and transverse processes, but its body, which resembles those in front of it and differs from that of the sixth in having a deep ventral furrow for the aorta (aortic canal), is completely fused with that of the fourth. The suture may still be evident on the outside (Fig. 7, Pl. IV.), although generally concealed by membrane bone deposited in connection with the air-bladder here, but can always be seen on vertical section (Fig. 8, Pl. IV.) The second, third and fourth vertebral centra are completely fused in the adult. The neural canal over them is a continuous tube of membrane bone, the ossification of which originates near the rudimentary cartilaginous

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[1] Comptes Rendus, 1868, p. 330.

[2] See my preliminary note on this subject. Zool. Anz. VII., 248.

neural arches of the third and fourth vertebra in the young. (See the horizontal section, Fig. 12, Pl. IV.) The tube is perforated near its posterior margin by the roots of the fifth nerve, not far from its anterior margin by the roots of the fourth, and its anterior margin has two notches which correspond to the roots of the third nerve. That part of the tube which intervenes between the third and fourth nerves represents, therefore, the third neural arch; that between the fourth and fifth nerves the fourth neural arch. The second neural arch, apart from its cartilaginous rudiment, is entirely membranous in the adult. Immediately behind the point of emergence of the fourth nerve the tube expands into the fourth transverse process, which forms a broad, flat plate (Fig. 7, Pl. IV.), extending back as far as the fifth transverse process, and forwards to articulate by its thick anterior margin with the transverse process of the supraclavicle. Immediately in front of and below the same point the modified third transverse process, or '*malleus*,' is articulated moveably to the line of junction of the neural canal and the vertebral centra. The form of the *malleus* may be gathered from Fig. 7; its posterior sickle-shaped end, which rests partly on the ventral surface of the fourth transverse process and on the side of the body of the fourth vertebra, is really developed in the *tunica externa* of the air-bladder, and its junction with the anterior part is only secondary. Fig. 12, Pl. IV. Its anterior part passes forwards and outwards, lying in a horizontal plane, and its tip projects slightly beyond the anterior surface of the body of the first vertebra.

The neural tube is continued above into two neural spines. (Fig. 8, Pl. IV.) One of these, which projects upwards and backwards from over the fourth vertebra, is the fourth neural spine. The other projects forwards from over the third vertebra, and is continued as a perichondrial ossification of the cartilaginous roof of the most anterior part of the neural canal and articulates in front with the supra- and exoccipitals above the foramen magnum. As the osseous neural canal is deficient over the second vertebra, so its transverse process is obsolete. The cartilaginous neural arch in the young is, however, quite as distinct as in the other vertebræ. (See Figs. 12 and 13, Pl. IV.) We shall meet with a further rudiment of the second neural arch shortly.

Like the more posterior vertebrae the fifth is amphicœlous; the posterior cone of the fourth is of large size, (Figs 8 and 13, Pl. IV.) while the anterior cone is very small and the intervertebral growth of the notochord does not take place between the fourth and third vertebræ. Nor does it do so between the second and third, because there is only one notochordal plug between the comparatively flat posterior face of the first vertebra and the deep conical hollow of the anterior face of the conjoined second and third vertebræ.

Dorsally the first vertebral centrum is quite free from that which follows, but ventrally they are suturally united by delicate plates which dovetail into each other on either side of the aortic canal. Also the anterior face of the first centrum is comparatively flat, much more so than the posterior face of the basioccipital bone against which it abuts. The dorsal surface—that which looks into the neural canal—has two sockets, separated by a narrow median partition, (Fig. 3, Pl. VI.) In these, rotate freely, the permanently cartilaginous balls which represent the proximal parts of the first neural arches, and which, in fact, are the articular processes of the '*stapedes.*' It will be observed from Fig. 12, Pl. IV., that more cartilage is present in the first vertebra than in any of those which succeed it. Fig. 8*a* represents the form of the complete *stapes.* Besides the 'articular' it possesses two other processes, which are merely ossified in membrane; these are the slender, 'ascending' process which lies in the neural canal immediately in front of the point of emergence of the second spinal nerve-roots, and the spoon-shaped 'anterior' process which does not form part of the wall of the neural canal, being separated from the spinal cord by a diverticulum of dura mater, the *atrium sinus imparis*, (Figs. 12 and 13, Pl. IV., and 4, Pl. VI.), to the lateral wall of which the spoon-shaped process fits closely.

It is obvious that the anterior process of the *stapes* passes beyond the anterior face of the vertebra to which it belongs. It rests upon the exoccipital at the side of the posterior aperture of the *cavum sinus imparis*, immediately below the *foramen magnum* (Fig. 5, Pl. VI.) and its rounded anterior border fits into a notch on the posterior margin of that bone, which is very distinct in a profile view of this part of the skull.

Returning to the *malleus* it will be remembered that its tip also projects in front of the body of the first vertebra. The internal edge of the tip will be found to be connected by a stout ligament whose fibres have a tendinous lustre with the roughened lateral surface of the spoon-shaped process of the *stapes.* In the ligament is a small bone—the *incus*—irregularly oblong in the adult, but style-shaped in the young, which may be connected by a few fibres with that cartilaginous patch which represents the proximal part of the second neural arch (Fig. 12, Pl. IV.)

From the study of *Amiurus* alone it would be impossible to say that the *incus* bears the same relation to the cartilaginous neural arch of the second vertebra as the anterior process of the stapes does to that of the first, but in *Catostomus* the proximal end of the style-like incus contains cartilage and projects from the second vertebra, and in *Cyprinus* the *incus* has not only articular and anterior, but also an ascending process like the *stapes* of *Amiurus*.

A fourth ossicle—the '*claustrum*'—assists in forming the wall of the neural canal between the ascending process of the *stapes* and the exoccipital. It is somewhat triangular in form, and its apex projecting downwards and backwards fits into the angle between the ascending and anterior processes of the stapes. (Fig. 8*a*, Pl. IV.) It is developed in cartilage, and represents the first pair of intercalary neural arches which were first pointed out by Gœtte in the pike, but which are present to a greater or less extent in the anterior region of the vertebral column in most Physostomous forms. Over the second vertebra in the roof of the neural canal, a considerable amount of cartilage persists even in the adult. This does not exhibit any segmentation, or very little trace of such, (Fig. 10, Pl. IV.), but probably belongs, in part, at least, to the system of intercalary neural pieces. For the relation of the dorsal ends of the claustra in the young, *vide* Figs. 9 and 10, Pl. IV. According to Baudelot they meet in the middle line of the roof of the neural canal in *Silurus glanis*, but this is never the case in *Amiurus*. (Fig. 4, Pl. VI.) Unlike the third and fourth vertebræ both the first and second are destitute of transverse processes, at least they are almost obsolete in the first and quite so in the second.

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The *cavum sinus imparis* has been referred to above as hollowed out in the basi-occipital bone, which also furnishes part of its lateral walls. The ex-occipitals furnish the remainder of the lateral walls and the osseous roof of the *cavum*. (Fig. 6, Pl. VI.) This roof is inclined downwards anteriorly, (Fig. 8, Pl. IV. and Fig. 8, Pl. VI.) in such a manner as to narrow the aperture of communication between the *cavum* and the cranial cavity. The aperture suffices, however, to admit the *sinus endolymphaticus* from the transverse *ductus* which crosses immediately in front of and below the aperture. (Fig. 8, Pl. VI.) Neither the *cavum* nor its osseous roof continue backwards as far as the posterior face of the basi-occipital, but the roof becomes membranous and is continuous with a thickened patch of *dura mater* which forms the posterior wall of the cavum, and is attached to the centre of the exposed upper surface of the basi-occipital and to the crest separating the sockets on the upper surface of the body of the first vertebra. (Figs. 3, 4, 5, Pl. VI.) On either side of this patch the *cavum* is continuous by its posterior aperture with a diverticulum, the *atrium sinus imparis,* resting on the upper surface of the exoccipital, bounded medially by the thickened dura mater and laterally by the spoon-shaped process of the *stapes.* The latter rests moveably on a thickened cushion of dura mater, which is attached in front to the notch of the exoccipital referred to above, and is perforated by the ligament connecting the *stapes* with the tip of the *malleus.* Were it not for the *stapes* and its ligament the *atrium sinus imparis* would be in free communication with the *saccus paravertebralis* by the so-called *apertura externa atrii.* As it is the *saccus* has no other aperture of communication with the cranial cavity such as exists in *Cyprinus*,[1] and the contained semi-fluid tissue which fills the *saccus* and permits the movements of the *malleus* is therefore not part of the perilymphatic tissue surrounding the brain, nor is it similar to the entirely fluid contents of the *cavum* and *atria sinus imparis.*

One or two further points may be noted with regard to the neural canal before investigating further the nature of the movements of the ossicles.

The white thickened patch of *dura mater* which bounds the *cavum sinus imparis* posteriorly is continued back somewhat further than the body of the first vertebra, and has important relations to the walls of the neural canal. From it an oblique stripe ascends in the wall, parallel to and behind the ascending process of the *stapes* and reaches the roof of the neural canal. (Figs. 8 and 8*a*, Pl. IV.) Behind it lie the roots of the third nerve; the ventral root of the second escapes in front of it and in the angle behind the ascending and articular processes of the *stapes*, while the dorsal root perforates the stripe above the tip of the ascending process. That part of the patch which forms the medial wall of the *atrium* is further connected in front of the

[1] *Hasse—loc cit,* p. 589.

ascending process with the *claustrum*, but the *claustrum* can hardly be said to have any relation to the *atrium*. It lies dorsally to it, but its thin edge bears no such relation to the roof of the *atrium* as the *claustrum* does in *Cyprinus*[1], nor can it have any influence on the shape of the atrial cavity. The patch is further connected with the thickened cushion of dura mater which partly closes the *apertura externa atrii*. The cushion is somewhat horseshoe-shaped, the convexity fitting into the notch of the exoccipital before referred to, while the ligament of the *stapes* fills up the concavity. Of the two arms the lower is connected with the patch of dura mater, the upper behind the *claustrum* with the oblique stripe referred to above, which possibly represents the ascending process of the *incus*.

## THE AIR-BLADDER OF *AMIURUS*,

When exposed in situ is found to be covered by peritoneum which is reflected on to the œsophagus by the air-duct. Outwardly it appears to be oval in form and undivided. It is formed of a thick *tunica externa* and a delicate *tunica interna* which contains very few vessels. If the external tunic be cut into, the internal tunic may be removed readily without its collapsing. It differs at first sight from the outer in form, for its anterior third is impair, while its posterior end is formed of two separate sacs opening into the anterior one. A nearer examination of the external tunic shows that it is also divided posteriorly by a median vertical partition forming two chambers in which the sacs of the internal tunic are received. Immediately in front of the ventral end of the partition is the orifice of the air-duct which thus opens into the anterior chamber. The partition does not terminate by a sharp edge, but splits as it were into two flattened bands which are attached dorsally to the vertebral column, and slant downwards and forwards as they grow wider to become continuous with the ventral surface of the air-bladder. They narrow the apertures of communication between the posterior and anterior parts of the air-bladder, and simultaneously form two small ventral *culs-de-sac* from the posterior chamber on either side of the median partition. Except for these bands the posterior part of the bladder is entirely free from the vertebral column; it is only in the anterior division that we have to look for certain connections with the osseous

[1] *Hasse—loc cit*, 591.

structures lying above it. The lines of attachment may be understood from Fig. 7.

It is necessary to look more closely at the connections of the malleus. As observed above it articulates in an oblique groove on the side of the third vertebra. Outside this point its upper surface is connected by ligament with the ventral face of the fourth transverse process, and its postero-external angle here passes into the crescentic ossification (*co*), which may be described as the posterior sickle-shaped part of the *malleus*, although it is not developed as a part of the third transverse process. It is in fact an ossification in the tunica externa of the air-bladder, and only secondarily becomes connected with the third transverse process. A sharp ridge separates these anterior and posterior parts of the *malleus*. The dorsal and lateral limb of the crescent rests on the ventral face of the fourth transverse process, while its ventral and medial limb rests on a groove on the sides of the body of the fourth vertebra.

In the concavity of the crescent, and connected with it in the recent state by fibres of tendinous lustre, is the thickened knob-like end of an oblique ossification (*o.o*) which is free from the body of the vertebra, but becomes coalesced as it runs backwards and outwards with the posterior part of the ventral face of the fourth transverse process. Between the body of the vertebra and this oblique ossification is a triangular space in which lies the *vena cava inferior*. The course of this vessel is ventral to the origin of the third and fourth transverse processes, but dorsal to both the oblique and crescentic ossifications, the intervening space being larger on the right than on the left side to accommodate the larger vessel.

Across the posterior part of the triangular space described the upper end of the flat band is attached. All the dorsal median wall of the anterior chamber is likewise firmly bound down to the sides of the bodies of the fourth and fifth vertebrae, and especially to the sharp ridges bounding the aortic canal. Further forwar s also, the dorsal wall is attached to the sharp ridge separating the third and fourth vertebræ by strong fibres to the knob of the oblique ossification, and to the ventral edge of the thickened anterior part of the fourth transverse process.

The fibres of the unattached parts of the anterior chamber chiefly converge (1) from the anterior wall to the crest separating the anterior and posterior parts of the malleus, and (2) from the rest of the chamber to the convex margin of the posterior part, leaving, however, the medial end free. These are the points with which fibres are left in connection if the air-bladder be removed forcibly from the vertebral column.

It is easy to demonstrate that if the fibres of the air-bladder attached to the sickle-shaped part of the *malleus* be put on the stretch, it (the posterior part of the *malleus*) is pulled outwards and downwards from the vertebral column, the ligament between it and the knob serving as a hinge. Simultaneously, however, owing to the form of the articulation with the third vertebra, the anterior end, and consequently the spoon-shaped process of the *stapes* move inwards, the cavity of the *atrium sinus imparis* is diminished, and the contained fluid urged onwards. As the result of more fluid being forced into the *cavum sinus imparis*, the *saccus endolymphaticus* which floats freely in it must be compressed, and a current of endolymph urged forwards which must impinge very directly on the *macula acustica sacculi* of each side. (Fig. 8, Pl. VI.) The position of these *maculæ* with relation to the *saccus* and *ductus endolymphaticus* would appear to render unnecessary the special maculæ described by Nusbaum in *Cyprinus*. In any case altered tension in the anterior part of the air-bladder will be brought within range of perception by the auditory nerve.

Hasse has suggested (*loc. cit.* p. 596) that in *Cyprinus* such altered tensions will directly affect the spinal cord, the semi-fluid tissue surrounding it undergoing compression through the medial wall of the *atrium* and the *claustrum*. A glance at Fig. 4 will show that this is hardly likely to be the case in *Amiurus*, for the medial wall of the *atrium* is formed of somewhat dense tissue, and the *claustrum* can be affected very little by the movements of the *stapes*. It is certain, however, in *Amiurus* that when the fluid in the *cavum sinus imparis* is urged forwards, that in the spinal canal is propelled in the same direction. The reason for this is to be sought for in another diverticulum of the *cavum* which lies above the spinal cord, and communicates with the *atria* at their points of entrance into the *cavum*. (Fig. 5, Pl. VI.) From this point the sac is continued some little distance forwards through the foramen magnum into the adipose tissue above the medulla oblongata. It terminates there in two lobes, the division into which is indicated in Fig. 6, and is filled with the same fluid contents as the *cavum* and *atria*.

Whether the sac, *receptaculum dorsale (rsi)*, acts as a reservoir for this fluid or serves to receive any excess driven out of the *atria*, I am unable to say, but its distension is not likely to produce any immediate effect on the spinal cord, separated as it is from it by the thick cushion of loose adipose tissue which would entirely redistribute any pressure. That the forward movement of the fluid in the *cavum sinus imparis* should have any direct effect on the base of brain, as suggested also by Hasse, is, I conceive, improbable, owing to the thick cushion of adipose tissue which separates the brain from the floor of the skull. (Fig. 9. Pl. VI.) I am inclined to believe, then, that it is solely through the auditory nerve, and specially through its saccular branches, that the central nervous system is informed of the movements of *malleus* and *stapes*, and consequently of the state of distension of the air-bladder.

It is probable that the currents in the endolymph produced in this way are different in character from those brought about by ordinary sound waves, but on the other hand the difference is not likely to be of such moment as to remove the phenomena in question entirely from the domain of sound.

Whether the air-bladder and apparatus in connection with it are also sensitive to the alternations of pressure incident to sound waves, and whether this be not one of the principal channels through which the endolymph of the *partes inferiores* of the labyrinth is set in motion, must be a matter for further investigation. No very free interchange of endolymph can take place between the superior and inferior parts of the labyrinth, for the *ductus sacculo-utricularis* is thick walled and its narrow lumen is blocked up by a valve projecting obliquely across it. Although the endolymph, then, in the superior part may be very readily set in motion by the vibrations transmitted through the thin wall of the skull opposite the recessus utriculi, yet the inferior part must be in a great measure protected from such by its concealed position.

Hasse (*l. c.* 599) while not entirely excluding the possibility of alterations in volume of the air-bladder exerting an influence on the production of auditory sensation, adduces several arguments for believing that such must be of very subordinate nature in the *Cyprinidæ*. The first of these is that the direction of the stroke of the *stapes* not being coincident with the plane of the *apertura posterior* of the *cavum*, the fluid contents of the *atrium* will not be urged into the *cavum* with full force. Secondly, the fluid is imbedded in reticular tissue; and thirdly, any impulse communicated to the transverse *ductus* will be deadened by the close apposition of the saccular nerves. But in *Amiurus* the fluid in the *atria* and *cavum* is not imbedded in the meshes of the reticular tissue, the wall of the *saccus endolymphaticus* is so thin that any motion in the surrounding fluid must disturb its contents, and the currents so produced must certainly affect the neuroepithelium as much if not far more than the currents produced by ordinary sound waves. I should be inclined to look upon the dorsal reservoir which I have described above rather as a safety-valve to prevent too great a disturbance of the neuroepithelium by the violence of currents produced by sudden expansions of the air-bladder.

It is interesting to consider, in the light of Moreau's researches[1], what advantage it is to the fish to be provided with an apparatus which records the varying states of distension of the air-bladder dependent on the greater or less weight of the superincumbent column of water. The chief function of the air-bladder, according to Moreau, is to enable its possessor to alter its specific gravity so as to be in equilibrium in one particular plane where it may remain with little or no muscular effort, but from which it can only displace itself vertically upwards or downwards by muscular effort.

In Physoclystous fishes (those with no air-duct), this complete accommodation to a new level takes place slowly, for the volume of air in the air-bladder is not altered by muscular contraction but is reduced in amount through absorption and increased in amount through excretion by the walls of the bladder, the retia mirabilia there being probably the organs engaged in this physiological process. In Physostomous fishes, on the other hand, accommodation to a new higher level is more quickly effected by the ejection of bubbles of air through the air duct, while the additional amount of air necessary to produce equilibrium under increased pressure is slowly formed by the walls of the air-bladder. The *Physostomi* are therefore possessed of greater freedom of movement than the *Physoclysti* under artificially diminished pressure or at a higher level than that in which they were

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[1] Recherches experimentales sur les fonctions de la vessie natatoire. Ann. des Sci. Nat. T. 4, 1876.

It would be extremely interesting to examine the morphological nature of the 'safety-valve' described by Moreau in *Caranc trachurus.*

in equilibrium, and the recording apparatus connecting the air-bladder with the auditory organ, when present, probably enables them to measure the precise amount of air, which must be disengaged in order to restore equilibrium at a new higher level. The mode in which air is discharged in *Amiurus* is not known to me, but the duct, tortuous where it opens into the oesophagus, must be much straighter when the ventral wall of the anterior part of the air-bladder is distended than when such is not the case. Further investigation must show whether the duct participates actively in disengaging the air-bubbles, and if so, under control of what nerve it does so.

The whole physiology of audition in the Teleosts is so obscure that it is worth while reopening the question of the possible role of the air-bladder and its accessory ossicles in connection therewith. *Amiurus* would be admirably adapted for physiological experiment, for it is very readily kept in captivity, and has extraordinary vitality. If the above descriptions serve as an accurate morphological basis for such experiments part of my object will be fulfilled.

In my note on this subject in the *Zoologischer Anzeiger* cited above, I have remarked that the parts concerned in *Amiurus* indicate a much further specialization of the condition in the Cyprinoids. I propose, in a future paper, to investigate the alterations which the anterior vertebræ have undergone in other sub-families of Siluroids, for the researches of Reissner (Müller's Archiv, 1868). and those of Müller himself, (same journal, 1842) indicate that these must depart very widely from the condition found in *Amiurus*.

It is among the Cyprinoids, nevertheless, that a less altered and more primitive condition of affairs must be sought, and it is possible that an extension of research, anatomical and developmental, may explain the steps by which parts of the anterior vertebræ became modified in connection with the air-bladder.

# ALIMENTARY CANAL, LIVER, PANCREAS,

## AND AIR-BLADDER OF *AMIURUS CATUS.*

BY A. B. MACALLUM, B.A.

[*Read before the Canadian Institute, April the 5th, 1884.*]

## THE ALIMENTARY CANAL.

### COARSE ANATOMY.

The cavity of the mouth is very capacious. Its entrance is guarded by plates of teeth situated on the maxillaries above and on the mandibles below. These are the only regions of the mouth where teeth are found. In front of them above and below along the margin of the mouth portions of skin, frequently pale or discolored, are transitional between the outer skin and the membrane of the mouth, and function as lips.

Behind the pads of teeth and running concentrically with them are folds, one above and one below, arising from a relaxation of the lining membrane; that behind the maxillæ is largest, but both may be absent. In one specimen of *Amiurus nigricans*, the fold reached downward and backward into the cavity of the mouth fully one-half inch.

The lining membrane of the mouth is generally colorless. That of the sunken palate may have a dark color. When hardened the membrane shows minute blotches on a white ground, caused by beaker organs (taste-buds?) and the vascular papillæ of the subjacent tissue.

The 'tongue' is most distinctly observable when the hyoid bone is pushed up by the finger from below, and is then an oblong flattened elevation. A ridge or rather a row of papillæ runs medially over its surface backward into the pharynx. This is the seat of numerous beaker organs, especially in the young cat-fish.

The palate is sunk from the maxillæ and is divided into two shallow depressions by the parasphenoid.

The surface of the pharyngeal floor anteriorly inclines on each side somewhat toward the base of the gill arches.

In the immediate neighbourhood of the epipharyngeal bones, the membrane becomes much thickened and thrown into folds, for the most part longitudinal. The thickness of the membrane here is due to the accumulation of striated muscular fibres, which at the commencement of the œsophagus forms a species of sphincter muscle.

The passage of the pharynx into the œsophagus is of a funnel form, its base being some distance posterior to the epipharyngeal teeth-pads. The folds give an appearance of ribbing to the funnel. this being seen most distinctly when the jaws are widely separated,

The superior teeth-pads, one on each side of the middle line, are of round or oval shape, and situated on the epipharyngeal bones. The membrane surrounding and covering the pads is thin, sensitive, and contractile.

The hypopharyngeal pads are rhomboidal on surface view and are placed opposite the epipharyngeals, with their long axis directed outward and backward.

Both sets of structures are extremely sensitive. When the epipharyngeal pads are touched, the membrane shrinks, the pads are thrust down, and at the same time those of the floor are elevated in opposition. This is for the purpose of comminuting the food as it passes into the œsophagus, mere contact of food or other matter serving to bring the pads into action.

The lining membrane of the straight œsophagus is longitudinally folded, and is perfectly colorless in the fresh condition. Its muscular walls are thick. Near its posterior end the œsophagus receives the opening of the duct of the air-bladder.

The folds which anteriorly are longitudinal, become arranged in the stomach in every direction and disappear when it has been distended by, and hardened in, chromic acid and alcohol. The openings of its glands are scarcely observable with the naked eye.

The stomach of *Amiurus* belongs to the *cœcal* type, the cœcum, however, not being distinctly marked off as such. It possesses with the cardia the same axis longitudinally placed, and is short blunt-cone like. Its *rugæ* are like those of the cardia, and both portions are tinged chocolate-red when the stomach is in the digesting state.

The *pylorus*, which is of smaller diameter, starts from the left side of the junction of the cardia and cœcum and extends forward beside the former to near its anterior termination, where a circular constriction visible on the outer surface of the pylorus denotes its termination and the commencement of the midgut. This constriction gives rise on its inner surface to a low pyloric valve.

The lining membrane of the pylorus is pale in contrast to the color of the cardia and cœcum. Its folds are at first low and broad, but approaching the valve they become higher and thinner, and are arranged longitudinally.

The midgut passes forward beside the œsophagus until it reaches above the posterior lobes of the liver, at which point it takes a sharp turn to the right under the œsophagus. In this transverse portion it receives the pancreatic and bile ducts, after which it turns backward to run on the right of, and on a level with, the stomach. Behind, it is thrown into loops of greater or less magnitude, which rarely touch one another, and may number from eight to twelve. The part of the midgut in the neighbourhood of the stomach is provided with slightly thicker muscular walls than the posterior half.

The outer serous coating is unpigmented. The longitudinal folds on the inner surface are thick and high, but their continuity is not distinctly marked, owing to slight transverse furrows, which give to a fold the appearance of a series of low villi.

The lumen of the midgut is separated from that of the endgut or rectum by a circular valve which is of little height in the relaxed specimen, but when distended by chromic acid and alcohol, and thus hardened, it is broad, thin and semi-membranous, leaving a lumen of small diameter in the centre. The folds of the midgut in the neighbourhood are distinctly longitudinal and pass over into those of the midgut. Its course is quite straight but for the slight downward curve to terminate in the vent.

The body cavity and the pericardial chamber are separated by a partition formed of the partially apposited pericardial and peritoneal membranes which contain between them a quantity of aponeurotic fibres. This *aponeurotic* wall, as it is called, is perforated by the œsophagus and the hepatic veins, and over these latter the peritoneal membrane is continued to join that covering the liver forming a support for that organ. From the aponeurotic wall the mesentery spreads out on each side, above and backward, enclosing the duct of the air-bladder between its folds. Below the œsophagus the membrane runs out over the liver to form its serous coat. This fold also passes down over the stomach on the commencement of the midgut when it embraces the gall-bladder, the bile and pancreatic ducts.

From the cœcum a fold of the left portion of the mesentery passes to the larger loops of the midgut.

The air-bladder is covered by a peritoneal plate arising from the lateral walls of the body cavity and meeting in the middle line. To the walls of the air-bladder it is less closely applied than elsewhere.

Large pellets of fat are distributed in the mesentery, most frequently in the fold connecting the cœcum and midgut.

The mesentery is not always continuous, there frequently appearing in it large, clear spaces, the positions of which are, however, irregular.

The following table of measurements of the intestinal tract, includes those of one specimen of *A. catus* and two of *A. nigricans*. The length of the body, as here given, is from the termination of the snout to the base of the caudal fin. It will be seen from examination that the lengths of the same parts in the three are not relatively proportional. For instance, in *A. catus* the length of the midgut is 1·25 times that of the body, while in the smaller specimen of *A. nigricans* it is 1·14, and in the larger 1·8. In the numerous measurements that I have made of the intestinal tract of cat-fishes of various sizes, it was observed that with the increase in body length there is more than a corresponding increase in the various parts, and especially so in the midgut. The whole intestine also from the commencement of the œsophagus to the vent varies from 1·5 to 2·3 times the length of the body.

| | Length of body. | Œsophagus. | Stomach (Cardia and Cœcum). | Pylorus. | Midgut. | Endgut. | Body cavity. | Air-bladder. |
|---|---|---|---|---|---|---|---|---|
| | c. | c. | | | | | | |
| *A. catus* .......... | 31 | 3·5 | 3 | 2 | 40 | 5 | 10 | 5·5 |
| *A. nigricans* (1).... | 38 | 2·2 | 2 | 1·5 | 32 | 4·8 | 7·5 | 3·8 |
| *A. nigricans* (2).... | 60 | 5 | 6 | 3 | 110 | 9 | — | — |

## FINE ANATOMY.

### MOUTH AND PHARYNX.

The *mucous membranes* of the mouth and pharynx are exceedingly similar in structure, so that the following description applies justly to any portion of both cavities, not excepting the inner surfaces of the gill arches.

It falls very distinctly into two coats, of which the outer is the epithelial and the deeper corresponds in position to the dermis. The latter is formed of connective tissue fibres, elastic fibres, and nerve strands, the latter apparently very numerous; imbedded in this coat are a large number of capillaries. Pigment cells are found at the boundary of the two coats. The lower is at no point marked off from the subjacent stratum which is formed largely of areolar connective tissue; above it gives off both vascular and sensory papillae, which rise into pockets of the epithelial coat. The vascular papillae are rare, the great majority of the papillae form the base on which the beaker organs are situated. These have been already described in the paper treating of the skin. The vascular papillae are provided with several finely branching capillaries which ascend to their summit.

Below the base of the beaker organs there is a rich deposit of nerve cells easy to be observed, through the deep staining of their nuclei with Bismarck brown. The nerve fibrils are at this point also observable and can be followed into the epithelial coat. Forked pigment cells abound in the summit of the papillae and elsewhere along the boundary may form a one-celled layer.

Most frequently one beaker organ only is to be found on the summit of each papilla, but three to five may occur. The epithelial coat is clearly marked off from the deeper by columnar cells at its base. In itself there is a marked division into regions corresponding in position but not in consistency to those of the skin of higher vertebrates, denominated horny and mucous layers. Here they pass imperceptibly into one another.

The superficial layer is formed of cells, generally triangular, each provided with a nucleus and a thickened peripheral wall. (Fig. 1). They are succeeded below by somewhat horizontally flattened cells whose nuclei also bear the appearance of being slightly flattened, and are surrounded by but little protoplasm. There are several layers of this description. They pass gradually below into cells which are at first cubical, thin columnar, their long axis directed perpendicular to the surface. While the flattened cells show but little protoplasm, these have much and it is finely granular. The columnar shape is not a perfect one, being variously angled until the base of the superficial stratum is reached, where they are much more elongated than elsewhere, and here they evidence the possession of a cell membrane.

At the lower half of the layers formed of columnar cells, are structures which when viewed carelessly appear as nuclei of the cells. Yet they are everywhere quite distinct from these in that they are smaller and they take on a deeper staining in Bismarck brown. Profuse in the lower columnar layers, they are sparsely distributed towards the layers formed of cubical or flattened cells. They are about the size of the nucleoli of the surrounding cells. Each, however, contains a nucleolar body and is provided with a short, delicate process directed towards the deeper stratum. As they stain more deeply than the nuclei and nucleoli of the surrounding cells, I must regard them as separate structures. They are most favorably seen in the lips. They may be regarded as the terminal free nerve endings to the fibrils which come from the deeper coat below.

Besides the structures described, there are in the epithelial layer two others which merit special description. The first of these is the 'slime cell.' It is present in all portions of the epithelial stratum, and in accordance with this distribution it presents various shapes. On the surface it is of flask shape, the long neck of which is thrust out between the cuticular cells. (Fig. 1). The body of the flask is rounded and rests on the layers of flattened cells. The contents of the flask project beyond the superficial border in the form of a plug. No separation can be seen in ordinary preparations between its mucigenous and its protoplasmic portions. Such can only be observed in osmic acid specimens. The rounded body is not continued downwards into fine processes, as is usual in beaker cells. The nucleus is seen with the aid of osmic acid, and is usually surrounded by a clearly defined protoplasmic stroma or reticulation, which stains vividly in Bismarck brown or hematoxylon. The reticulation is observable even in the neck of the cell.

Three, most frequently four, cuticular cells separate two neighbouring slime cells.

They take an intense brown color in Bismarck brown and a deep purple color in Kleinenberg's hematoxylon, even when the surrounding cells are little acted on. They are of oval shape in the deeper epithelial layers and their long axis is generally perpendicular to the surface. They are placed sometimes horizontally in the layers formed of flattened epithelium. Their reticulation is wider meshed, and permits a view of the large oval nucleus placed in the centre of the cell. In the lower columnar layers they are of smaller size becoming more so towards the base, where one can easily observe their differentiation from the surrounding cells. The reticulation is at first fine and delicate, but becomes coarser and more marked as the cell increases in size and thrust upward.

These cells have been described in other fishes under the name of beaker cells. I have prefered to use the term 'slime cells,' sometimes employed in referring to them. They do not conduct themselves towards reagents or staining fluids in the same manner as beaker cells, from which they differ in shape. In no portion of the alimentary tract does the beaker cell show a reticulation in its mucigenous portion, nor does it stain generally with Bismarck brown or hematoxylon any more deeply than do the surrounding cells. The beaker cell again, it is quite probable, is simply a degradation of the ordinary surface cylinder cell, while the slime cells show a gradual growth and differentiation from those of the deeper epithelial layers. The beaker cells and the slime cells must be regarded as two distinct kinds of cells producing secretions, which probably are chemically different.

The other kind of cells referred to as present in the epithelial layers of the membrane is known under the names of slime cells, club or clavate cells. They are found in the outer skin also more highly developed, and of a slightly larger size than in the membrane of the mouth.

These clavate cells are confined to the deeper epithelial layers touching with their rounded heads the layers of flattened epithelium. They are shaped exactly like a club, the larger ends rather blunt, while the neck or handle tapers away into a fine thread-like continuation, which I have traced to the base of the epithelial stratum. (Fig. 1). The structure is provided with a distinct wall, and contains in it two materially different fluid substances. That filling the greater part of the head is strongly light refracting and contains, situated toward the base of the cell, one or more rounded or oval bodies provided with radiating strands which have been termed the nuclei. They may sometimes be found in the fluid which fills the neck of the cells, and are provided with nucleoli. These nuclear bodies stain slightly in Bismarck brown, much more so than the substance of the neck which lines the walls of the head for some distance, thus serving as a cap for the clear glassy portion. This substance takes a dirty brown stain in hematoxylon. So much is to be learned from specimens hardened in alcohol alone.

When these cells are obtained by maceration in Müller's fluid, or in a solution of potassic bichromate preferably, they show some interesting points, in addition to what has been given. The light refracting substance is less in quantity, the strands come out more clearly, and the substance filling the neck and serving as a cap to the clear glassy substance is very finely granular. This latter was observed in some cases to enclose the nuclear bodies and the clear glassy substance in the form of a capsule. The nuclear bodies may be one for each clavate cell, but varies, there being often three or four, and I have observed in one case six. Two in each cell is a common occurrence, and then they are placed to one another in such a manner as to lead casually to the belief that they were just previously formed from a single one by division. The cell wall often appears shrunken, probably owing to the action of the reagent employed.

A great deal of attention has been given to these cells. Kölliker[1] first described them in the Lamprey under the name of slime cells. Max Schultze[2] observed a transverse striation on the neck of the cell, which conducted itself as far as regards polarization the same as striated muscular fibre. He also observed longitudinal striæ which united at the blunt end in concentric lines. According to his view, they are probably end organs of a neuro-muscular nature. F. E. Schulze[3] also describes the striation of these forms in the eel, and found globules, apparently composed of fat, in the centres of several cells. No cell membrane was observed by him, and in many cases he found an opening at the head of the cells. His view is that they are comparable to the cells of the sebaceous glands of higher vertebrates.

My own observations are not confirmatory of the striation described by Max Schultze and F. E. Schulze. There are to be found neither openings in the cellular walls nor fat globules. In one or two cases I have observed a portion of the clear glassy material situated on the outside of the cap, and separated from the surrounding fluid on the field of the microscope by a clear line which was continu-

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[1] Verhandl. der Physik. Medic. Gesellschaft in Würzburg, Bd. VII. and VIII.

[2] Arch. für Anat. und Physiol. 1861, pp. 228 and 281.

[3] Arch. für Mikr. Anat. Bd. III., 1867.

ous with that bounding the remainder of the cell ; this was clear enough evidence of the possession of a cell-membrane. Again, several other forms or variations of structure were observed in a few cases, and these I am in doubt whether to classify as normal or pathological. They were obtained by maceration in Müller's fluid, and in them the finely granular material of the neck and cap of the cell was aggregated into clumps, with clear spaces between them ; in the centre of each of these clumps a round body, much smaller than the nuclear body proper, was observed. The nuclear bodies themselves retained their usual appearance. Sometimes an optical section of the cell instead of showing clumps yet revealed their round central bodies as regularly disposed as those of the clumps.

Whether these structures are secretory or nervous in function it is impossible to say. From the constant presence of the clear glassy fluid, and its disposition at the head of the cell, one would be inclined to the former view.

As already mentioned, the description of the mucous membrane of the mouth applies equally to that of the pharynx. The slime cells, however, increase in number, and just behind the teeth-pads they become aggregated together into patches, one above and one below. At the commencement of the œsophagus they dwindle away, and before the posterior moiety of the œsophagus is reached have completely vanished.

The clavate cells are distributed equally throughout mouth and pharynx.

A tranverse set of striated muscle fibres connect the two hypopharyngeal bones. Behind them it gradually surrounds the pharynx, and immediately before the œsophagus is reached it forms a thick muscular layer. At this point is the origin of the muscle fibres forming the inner longitudinal layer of the œsophagus.

## ŒSOPHAGUS.

The low epithelium of the pharynx passes into that of the œsophagus, with a gradual increase in the height of the constituent cells.

The *muscularis mucosœ* is represented by but a few fibres, while the *submucosa* is thin and shows no distinction from the tissue sheathing the longitudinal muscle bundles. These latter are widely separated and coarsely grouped, and, although first appearing anteriorly at the commencement of the foregut, yet they may take origin anywhere at the base of the submucosa.

The outer circular layer is also composed of striated fibres, very coarsely arranged, more so towards the serous coating. The connective tissue sheathing, which separates the longitudinal muscle bundles from each other also widely separates them from the outer circular muscle coat.

When the inner surface of the œsophagus is folded a small quantity of the submucosa enters into the summits of the folds whose central cavities are filled by the fibres of the muscularis mucosæ and by the blood capillaries which pierce the muscularis and delicately branch just under the epithelium.

The epithelium of the œsophagus is several layered, that is, between the base of the superficial cells are one or two series of cells destined to replace the cast-off superficial ones. The cells constituting the epithelium are long, slender and cylindrical, interspersed among which are a number of beaker cells. The protoplasm of the cylinder cells is granular in the upper half of the cell, to which there is a distinct peripheral wall. The tapering continuations of these can be traced between the younger cylinder cells into the fibrous tissue resting on the muscularis mucosæ. Their nuclei are oval and are situated near the basal process of the cell.

The beaker cells show a size attained nowhere else in the intestinal tract. The theca of the cell is much inflated and filled with a mucigenous fluid, in which are scattered faintly refracting bodies. The protoplasm of the cell is found in the basal process surrounding the oval nucleus, which possesses a reticulation, frequently strongly marked. The protoplasm also passes up the sides of the theca for a short distance, in the form of a cap for the mucigenous portion, both portions being quite distinct after maceration. The opening may be as wide as the diameter of the theca, or it may be as narrow as a transverse measurement of the cylinder cell.

Studied in fresh condition cylinder cells show every stage of degradation into beaker cells. The first stage is evinced by the loss of the peripheral wall, followed by a swelling up and transformation of the contents near that end of the cylinder.

### STOMACH.

At the junction of the œsophagus and stomach the mucous membrane becomes more broadly plicated, the folds being irregularly directed over the cardia and cœcum. The opening of the glands on the surface of the membrane can scarcely be detected with the naked eye.

The inner longitudinal layer of muscle fibres of the œsophagus vanishes, its place being taken by the more abundant submucosa. The outer œsophageal layer of circular fibres becomes the inner circular layer of the stomach, in the anterior portion of which is still found a certain amount of striated fibres. At the same point an outer longitudinal layer of smooth muscle takes its origin.

Oblique muscular layers are almost totally absent, such as are present being modifications of the two other layers.

The *muscularis mucosæ* acquires quite a thickness. In it smooth fibres alone are present, and a more abundant mucous tissue separates it from the epithelium.

Two portions may be distinguished in the stomach, the pepsin-secreting region (including the *cardia* and *coecum*) and the *pylorus*. The two portions can be observed as distinct by the naked eye, the former being always more or less flushed while the latter is uniformly pale or discolored.

The superficial epithelium of the anterior section does not differ from that of the posterior or pylorus. In both it consists of delicate cylinders, not quite as long on the average as those of the œsophagus, difficult to isolate to their fullest extent, as their basal processes run into and are interwoven with the fibrous tissue of the mucosa. In the first state their contents are similar throughout and finely granuled. The nucleus is large, oval and situated near the inner third of the cell. The contents of each cell project beyond the general surface with a faintly arched refracting border, which, at first view, may be taken for a membrane for that portion of the cell ; it is destroyed by the action of water after some minutes or by the immediate action of Müller's fluid.

F. E. Schulze[1] who first described fully and carefully the superficial epithelium of the stomach, denied the presence of a peripheral wall for these cells, and stated their function to be that of secreting mucous to cover the surface, which should thus be protected from injury by the digesting fluid. Haidenhain[2] describes these cells as perfectly closed on their peripheral border, and states that the apparent opening

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1 Archiv für Mikr. Anat., Bd. III.
2 Archiv für Mikr. Anat. Bd. VI., page 372.

of the cell on its free surface is due to the reagents employed. Ebstein[1] found both closed and open cells, the latter form arising from the first through the transformation of their contents into mucous. Biedermann[2] found the cells always open and the mouth of each containing a plug which is chemically and morphologically different from the remainder of the cell. The stopper shows a longitudinal striation. Regéczy[3] regarded these cells as ciliated, having found cilia on them in the frog and in some fishes, frequently on a portion of the peripheral membrane. In some cases the cilia were cemented in one mass at the end of the cell, and in others, again, he observed the absence of these cilia apparently through their withdrawal into the cell. They are very easily destroyed by chemical reagents, which cause also a swelling up of the contents of the cell.

The many different views of the structure of these cells are no doubt due to observing epithelium prepared in a manner which changes more or less its normal appearance. Alcohol, Muller's fluid, solutions of potassic bichromate, and ammonia bichromate, cause a swelling up and an emptying of the contents of the cell in its outer third. When examined in the fresh state all cells have the arched, glancing border, apparently due to the meeting of two fluids of different consistency. The contents are similar throughout the cell, and finely granuled. Owing to the action of the reagents mentioned the outer two-thirds of the cell becomes clear and glassy, and the arched border is absent. When a specimen is hardened in osmic acid, on the other hand, the arched border is preserved, the outer third of the cell contents is somewhat more coarsely granuled, and more darkly stained than the remainder, the latter effect not by any means due to the greater ease with which the acid attains to that portion of the cell. Rarely did the use of this reagent betray the absence of the arched border or the apparent presence of a peripheral cell-wall. At the same time the division of its contents into mucigen and protoplasm not coinciding with that shown by other reagents was a constant one throughout. A structure closing the mouth of the cell and answering to Biedermann's 'plug,' has never been observed by me in the stomachs of the many fishes which I have studied.

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1 Archiv für Mikr. Anat. Bd. VI., page 519.

2 Wiener Akad. Sitzungberichte LXX., Bd. III., s. 377.

3 Archiv für Mikr. Anat. Bd. XVIII., page 408.

The cell is long and slender, passing down into a smooth, delicate process, imbedded in the tissue of the mucosa. In transverse section, it is irregularly six-sided, the membrane of which, if there is one, is approximated to those of the neighbouring cells in such a manner as to surrender its appearance of being a structure independent of the substance cementing the cells together, which cementing substance Edinger[1] indeed believes it to be. Maceration by various methods, however, produces isolated cells provided with a distinct membrane at every point, except at the peripheral end.

In the crypts into which the peptic glands open, these cells are slightly shorter and broader, the mucigenous portion being more distinctly marked in osmic acid specimens. In these crypts, and especially towards the pyloris, there is another variety of cells, few in number it is true, but quite distinct from the previously described cell. They are slightly swollen in their outer halves, their basal processes are short, and the whole cell is not acted on by osmic acid, but remains clear and distinct while the surrounding cells are very much darkened. These cells are grouped in twos and threes, here and there.

*Peptic glands* are absent only in the pylorus. From four to ten, or more, may open in one crypt of the membrane lined by cylinder cells. Several glands may open by one common neck into the crypt, but branching never occurs below the neck in the body or base of the gland. Each consists of three portions, a neck, by which it is attached to the surface crypt, a body, and a base. In all three parts the cells differ considerably in shape and structure, but pass into one another generally. Those of the neck form the 'Schaltstücken' of Rollet, and are transitional between those of the crypt and those of the body of the gland. They are subcubical in shape, and finely granular in contents, like cylinder cells or those of the crypt. Although the transverse diameter of the gland is narrowest at this point, yet the lumen is quite distinct. The cells of the body of the gland are cubical or rhomboidal in longitudinal section of the gland, and are provided at their inner lower edges with a process which overlaps tile-fashion the cell next below. The nucleus is large, oval, and situated in the inner half of each cell, while large coarse granules abound in all parts, but principally in the outer half. These granules

[1] Archiv für Mikr. Anat. Bd. XIV.

take a brownish-black tinge in osmic acid, by which also the nucleus is rendered indistinct.

The cells in the base of the gland are nearly oval, not provided with a process, coarsely granuled, and the large nucleus situated in the centre of the cell. The granules are to be found equally in all parts of the cell, which, on the whole, takes a slightly darker stain than those of the body of the gland, which are never found to bulge outside the general limit. The former when not in a resting state give an irregular appearance to the base. This was best seen in young specimens of cat-fish which are always feeding. Macerating the mucous membrane of such specimens in Ranvier's alcohol, Müller's fluid or in a mixture of the latter and serum, appearances, such as Fig. 5 gives, were obtained. There the cells of the body of the gland are rhomboidal in outline and form a pretty regular inner border. Those at the base, however, cause a bulging out of the membrane, some being situated in wedge-shaped niches between the other cells. During activity they preserve this form, shrinking to a certain extent when resting.

Between the cells of the body of the gland and those of the base, staining reagents show not the slightest difference, carmine, hematoxylon, aniline blue, stain all alike in intensity. The slight difference obtainable in osmic acid hardly merits mention. The granules in all are equally coarse, and four or five hours after the introduction of food into the stomach are arranged about the lumen, which in these glands is more or less indistinct. The cells are unprovided with a membrane, and in serum are all spherical, the processes being retracted. They, however, preserve their original forms in Müller's fluid and Ranvier's alcohol.

F. E. Schulze[1] describes in *Silurus glanis* large spherical cells lying in niche-like swellings of the basement membrane, and he evidently intended a comparison of these with similarly situated cells in higher vertebrates. As *Amiurus* and *Silurus* belong to the same family, it is quite probable that these structures are alike in both and that they have no more morphological value than what I have attributed to them.

Edinger[2] discovered in *Perca fluviatilis* differences in these cells which, however, he does not describe. Still he believes that a dis-

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[1] *Loc. cit.* [2] *Loc. cit.*

tinction of these into parietal and chief cells, such as obtains in higher vertebrates, is totally absent in fishes. Nussbaum[1] describes two varieties of peptic cells in the pike; one consisting of large coarsely granuled cells situated anteriorly and followed by a zone of second variety behind, which includes small finely granuled cells. Such a distinction in these cells, both as regards structure, relative position and size, it may be remembered also exists in the frog. Langley and Sewall[2] find but one kind of cells in the stomach of *Gasteropodus trispinatus*.

Cajetan[3] corroborates Nussbaum's description of the cells in the pike, and also finds a similar distinction in the cells of *Cobitis barbatula*.

In spite of these discoveries of Nussbaum and Cajetan, which are of but doubtful value as regards a functional difference, Edinger's statement, that chief and parietal cells, as such separately, are absent in fishes, is still to a great extent true, and it may be regarded as established that whatever may be the functions of these cells in higher vertebrates, such functions are performed by one kind of cells in fishes. In those fishes of which I have studied the stomach glands for the sake of comparison with those of *Amiurus*, all, with the exception of the sturgeon, showed not the slightest difference from the description already given above. I can only compare these glands to those of the œsophagus of the frog, as described by Langley[4].

The pyloric mucous surface is like that of the cardia and cœcum in the forms of its constituent cells. True glands are absent, what is usually called such in fishes, being simply indippings or crypts of the membrane, and clothed with long cylinder cells which are not different from those of the general surface. They are found up to the pyloric valve, where they pass gradually into the crypts of the midgut. It may be mentioned that as the pylorus is approached, the crypts into which the peptic glands open elongate, the glands diminish in length, and finally vanish, leaving in their place a much elongated crypt.

The *membrana propria* of the peptic glands consists of fibres of the mucosa closely applied in the form of a sheath, in which are

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[1] Archiv für Mikr. Anat. Bd. XXI. [2] Journal of Physiol. Vol. II.

[3] Zur Lehre von der Anat. und Physiol. des Tract. Intest. der Fische., Bonn, 1883.

[4] The Histology and Physiology of the pepsin-forming glands. Phil. Trans. Vol. 172, Pt. III.

scattered connective tissue corpuscles. It never separates with the gland from the mucosa.

The relation of the capillaries to the various portions of the fish's stomach has been pretty accurately described by Melnikow for *Lota vulgaris*. These vessels in *Amiurus* present no difference from the given description, except in their connection with the glands. The following description must, therefore, follow Melnikow's[1] to a great extent.

The arteries of the mesenteric coat become divided into two or more branches, which pass between the longitudinal muscle bundles, the proper vessels of which are accompanied by venous capillaries. The greater branches run into the circular layer between whose bundles they pass to the submucosa. The outline of the vessels formed around these bundles is generally quadrate. In the submucosa the arterial branches take an upward and a backward course toward the muscularis mucosae. Those distributed to the base of a crypt or sulcus immediately pierce the muscularis, within which they run parallel to the surface and then in between the base of the glands. Arteries of large diameter in the submucosa run parallel to the surfaces of the folds, and give off branches which ascend into the extreme summit, each of which again in the immediate neighbourhood of the mucularis muscosae divides into two or three smaller branches. These latter pierce the muscularis mucosae and then break up into a number of very fine twigs, which ascend between the glands and parallel to them. Each of these give off to the others near it a transverse twig, and in this manner arise a polygonal often an hexagonal field when the glands are viewed in transverse section As many as ten or twelve transverse bands may surround a gland. When they reach the base of the epithelial layer and the base of the crypts they run very close to these and pass over into venous capillaries which collect gradually into ones of still greater size till they reach the submucosa.

## MIDGUT.

The folds of the mucous membrane are highest in the neighbourhood of the pyloric valve and appear most distinctly in villi-like prominences. Such a view is not always obtainable, only so in the

[1] Ueber die Verbreitungweise der Gefässe in den Häuten des Darmkanals der *Lota vulgaris*. Archiv für Anat. und Physiol. 1866.

relaxed intestine. A partial distension of the midgut with chromic acid and alcohol easily demonstrates the connected character or continuity of these prominences as longitudinal folds.

The musculature consists of an outer longitudinal layer with an inner one of smooth fibres. The latter is the thickest, and in the pyloric valve increases so as to form the constricting muscle.

The *muscularis mucosae* is but a thin layer compared to that of the stomach, and is formed of smooth fibres. The submucosa is very much supplied with fissure-like cavities which are part of the larger lymph vessels. Frequently these and the mucosa to the height of the fold are closely beset with lymph corpuscles, so much so as to obscure the fibrillar character of the tissues. They frequently are more numerous, approximating to patches, but with no definite limit at certain points, at the base of the cylinder cells in the height of a villus. They are probably the analogues of Peyer's glands which appear to be absent in fishes, although the sturgeon has in the mucosa of its spiral valve a number of closed spherical cavities surrounded by a sheath of dense adenoid tissue and filled by a great quantity of corpuscles. These, I would say, are the nearest, probably the only, approach to a likeness of Peyer's glands in fishes.

The surface of the membrane is increased by deep crypts which are lined with an epithelium like that of the general surface. These crypts are never branched, being simply straight tubules. They represent in fishes the Lieberkühnian glands of higher vertebrates, although the epithelium constituting them is not differentiated.

The epithelium consists of long cylinder cells, among which are found modifications of them in the form of beaker cells. The cylinder cell is of equal diameter in its upper two-thirds, and has a fine basal process running into the tissue of the mucosa. I have never succeeded in isolating it to its fullest extent. As far as it has been separated it was observed to be varicose in its course and frequently branched. The situation of the large oval nucleus is various, and when a section is viewed several layers or stratifications of nuclei are observed. Nucleolar bodies may be present in the nuclei. In the protoplasm of the upper half of the cell are a quantity of granules, fine and coarse, the latter abounding, and after food has been in the midgut for some time, fat globules. These diminish in quantity towards the nucleus. In transverse section these cells appear hexagonal in outline. The peripheral wall is quite thick, and is provided with the usual pore canals. Outside of the cell walls, and of a diameter equal to that of the cell, are sometimes in hardened sections small masses which show a striation parallel to the pore canals. These are probably in all cases due to a destruction of the excessively fine cilia which has been described by Thanhoffer[1] in the frog, and by Edinger[2] in the eel, pike, carp, &c., and observed by myself in scrapings from the intestine of the living fish. I have never succeeded in observing their movement. Edinger suggests that they are in constant action during digestion. It is impossible to verify this with certainty, as removal of the cell apparently causes instantaneous death. In this respect, as in their extraordinary delicacy, they are comparable to the cilia of the cylinder cells mingled with the olfactory cells of the nasal cavity of higher vertebrates.

The beaker cells are quite different from those of the œsophagus, and this difference corresponds to that between the ordinary cylinder cells of the midgut and the œsophagus. In both cases the beaker cells are not original structures, but are metamorphosed products of cylinder cells. I might mention here that I observed in fresh ciliated epithelium from the spiral valve of the sturgeon, several cases of beaker cells still possessing a fringe of cilia. On the other hand the effects of the drug pilocarpin teaches quite clearly the origin of the beaker cells. After the peristaltic contractions caused by this drug have passed away, beaker cells are found to be totally absent from the surface of the intestine and Lieberkühnian crypts, their place being occupied by cylinder cells. A fresh supply is obtained in the resting intestine, and these can only come from the cylinder cells.

The theca of the beaker cell presents various shapes and sizes graded from the cylinder cell. Sometimes a short portion of the wall is swollen to form the theca ; the peripheral wall is lost and the contents become very coarsely granular, the remainder of the contents of the cell being unchanged. Further progress shows the advance of the transformation nearer the nucleus, which, however, it does not embrace ; at the same time the theca loses its swollen character and becomes elongated. The opening may be as wide or wider than the original cell, and through it frequently projects a rounded mass of the swollen contents.

The crypts of mucous surface are simply those of the pylorus in

[1] Plüger's Archiv, Bd. VIII., p. 391. [2] *Loc. cit.*

which the gastric epithelium is replaced at the pyloric valve by epithelium proper to the midgut.

Edinger found in the carp these crypts surrounded by lymph vessels imbedded in the fibrillæ of the submucosa. Such has been my observations with these structures in the cat-fish. Soluble Prussian blue injected by means of a hypodermic syringe into the wall of the intestine, generally filled vessels of irregular size surrounding the crypts.

The arteries of the intestine pass through the muscular layers at right angles and reaching the submucosa, the large branches run for a short distance parallel to the surface, and give off divisions which ascend into the mucosa and between the crypts. Their twigs then form meshes embracing the crypts. The capillaries run immediately under the superficial epithelium. Fine venous capillaries are continued from these and unite as they progress towards the submucosa into larger branches. The arterial branches in the summit of a fold also form a connected mesh of fine capillaries.

## ENDGUT.

The muscular walls of the endgut or rectum assume a thickness greater than in the midgut. The outer longitudinal fibres become arranged in separate bundles posteriorly which go to insert themselves in the walls of the vent. The circular layer has a thickness relative to the longitudinal one proportionally greater than in the midgut. Large bundles from it grow inward carrying the submucosa with them between the two surfaces of the valve separating the midgut and endgut. This acts as a sphincter muscle in making the valve tense. The folds of the mucous surface of the endgut are less conspicuous than they are in the midgut. They are fewer in number, narrow and longitudinally arranged. No transverse furrows on these give the appearance of villi. The crypts are about as numerous as in the midgut, but narrower and longer. Crypts are present on both surfaces of the valve, and like its epithelium present transitional forms between those of the midgut and those of the endgut.

The epithelium is constituted of cylinder cells not differing in shape from those of the midgut. They are, however, not so long, that is, the portion outside the nucleus is shorter, the peripheral wall is thinner, and appears to pass without clear distinction into the protoplasmic contents below, which are of the same character as those of the superficial cells of the midgut. The peripheral wall rarely shows pore canals; when these are present they are few to the cell. The beaker cells are like those of the midgut in every respect, excepting that their theca are rounder and shorter. The crypts are clothed with an epithelium like that of the ordinary surface. As the vent is approached the height of the epithelial cells grows less and less, until finally at the vent it is columnar or even flattened. In the latter half of the endgut clavate cells have been sometimes observed differing not from the description given of these above.

The arteries and capillaries are arranged in the endgut just as in the midgut. The course of the arteries in the submucosa is parallel to the course of the folds, to every one of which there is apparently a large submucous branch.

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## THE LIVER.

The liver of the cat-fish is situated at the anterior termination of the belly cavity, and is closely applied both to the aponeurotic wall and to the œsophagus. The peritoneal covering of the aponeurotic wall is reflected over the hepatic veins to the liver, while a fold of the mesenteric membrane, embracing the œsophagus expands to cover the liver, and, passing behind it, is closely attached to the surface of the gall-bladder to the pancreatic- and bile-ducts.

The liver is in weight about from one-thirtieth to one-twentieth that of the body as a whole. Its color is reddish-brown,—pathological conditions, which also increase or diminish its weight, vary its color, especially during the summer months. I have in several cases observed an extremely yellow color, due, probably, to the resorption of the bile. There is no pigment in any part of the liver beyond the proper pigment of the bile and such blotchings as sometimes were present were due to no discoverable reason.

The liver is easily lacerable, and is of a jelly-like consistency. This latter property is due to oily fluids which show their presence in pieces hardened in alcohol by the strong 'fishy' smell.

The lobated formation of the liver is not distinctly marked. The lateral halves are quite similar, although that of the left may have quite a number of lappits distributed on its posterior surface which are absent from the right. The bridge connecting the two portions is not as thick as the remainder of the mass of the liver. A sulcus on the postero-inferior surface forms a line of division over which sometimes a lappet from the left stretches on the right half for a little distance.

The lobes distinguishable on both halves, in the majority of cases observed, are as follows :—

An antero-lateral lobe, not constant, stretching upward and backward ; it is generally long and slender.

A postero-lateral, somewhat smaller than the preceding, and directed horizontally outwards.

A postero-median, large, directed backward, that of the right side almost covering the gall-bladder.

These lobes may or may not be the same in size for both halves, as a considerable amount of variation is always present.

The lobulation on the surface of the liver in the cat-fish does not appear prominently or clearly. This is owing to the smallness of the lobules and to their passing almost without interruption into one another. In the gorged condition of the liver they can be easily seen as polygonal spaces, and measure about 0·5 mm. on the average.

The *gall-bladder* is of elongated oval shape, with its long axis directed straight backwards. Anteriorly it passes into an arch-like cystic duct toward the middle line which receives 8-10 hepatocystic ducts in its course and becomes the ductus choledochus, at first large but decreasing in diameter backwards. It enters into the intestine in intimate connection with the pancreatic duct which lies above it. Both open separately, each on papillæ on the inner surface of the transversely ducted portion of the mid-gut, about two centimetres from the pyloric constriction.

There are two coats to the liver. The outermost, the *serosa*, easily separable, is simply the peritoneal fold, and having all the characters of the mesenteric tissue. The other, more closely applied and inside the former, is apparently of flat epitheloid structures, hardly isolable from the close arrangement of the hepatic capillaries on which they lie. They may be analogous to the cortical cells described by Eberth[1] in the amphibian liver.

The liver of the cat-fish is very poor in interlobular tissue. A fair amount enters the portal canal, but following the finer ramifications of the portal vein, the pancreas increases in volume, its acini twining

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[1] Archiv für Mikr. Anat.—Bd. III., page 430.

around the walls of the vein leaving but little room for other structures than the gall-ducts and hepatic arteries. In the finer interlobular septa picrocarmine reveals very little connective tissue.

The arrangement of the blood vessels in the liver is, on the whole, the same as in the higher vertebrates. There are, however, minor differences. The interlobular veinlets, before they pass into the radial capillaries, are closely gathered together to form as it were a wall to separate two neighbouring lobules which are thereby sharply defined. The course of the radial capillaries from the central vein outwards is very irregular. The spaces enclosed by two adjacent radials and their transverse branches, instead of being uniformly quadrilateral as in higher vertebrates, are more or less rounded.

The different gall-ducts are lined with an outer fibrous and an inner epithelial coat. The fibrous layer is formed of connective tissue fibrils and plain muscle fibres, the latter situated inside the former, which passes into the differently arranged scanty connective tissue surrounding the duct. Staining with picrocarmine easily reveals this arrangement. The inner or lining coat of epithelium consists of a single layer of short cylinder cells. They are slightly granular, and their nuclei are placed near the bases of the respective cells. A peripheral wall is present. As the ducts become more finely branched these cells become columnar, then oval; at the same time the fibrous layer loses its connective fibrils, those of the muscular coat becoming much decreased in quantity and finally vanishing. When the connective tissue is absent but the muscular fibrils still present, the epithelium becomes scale-like, forming, when the muscle fibres vanish, a thin wall for the lumen of the gall capillary. I have not succeeded in following them to their terminations in the hepatic cylinders, but believe that they terminate, as Hering and others describe, by their epithelium becoming exchanged for liver-cells, which here, however, do not possess a thickened border disposed toward the lumen of the gall capillary.

As already stated, very little if any connective tissue enters between the lobules, and thence the sole supporting stroma is formed by the blood capillaries. There is a complete absence of those cells, other than hepatic, which sometimes characterize the livers of higher vertebrates. Kupffer's stellate cells, which are rendered remarkably distinct in other livers by methylene blue, cannot be detected here.

The hepatic cells are of small diameter, speaking comparatively, measuring on the overage 12 $\mu$, the smallest observed being 9·5 $\mu$, and the largest twice that size. Their characteristics are most easily observed in the fresh state, when they are obtained by drawing the edge of a knife over the cut surface of the liver. Examined in salt solution, at the ordinary temperature of the room, the single cells exhibit curious movements and forms. This fact has been fully described for the hepatic cells of mammalian livers. The movement is usually designated as an amœboid one, but is sensibly different from it, as no protrusion of processes occurs. In the majority of cases a circular constriction appears at one pole of the cell, and slowly travels toward the opposite pole ; when at the equator of the cell it gives the appearance of a dumb-bell. Before this constriction has disappeared a second one may arise, and even a third, at the same pole. The locomotion arising from this may be little or nothing. An increase of temperature has no effect on the rapidity of the contraction or constriction. A flow of the contents of the cell from one part to the other during contraction occurs, while that portion of the cell which forms a thin sheath for it apparently brings about the contractions or constrictions. The sheath is quite free from granules, and formed of a clear substance not marked off definitely from the granular central mass other than by the absence of granules.

When in the resting state the cell is perfectly spherical, although such is not the case in the fresh liver. Young cat-fishes of about one to two inches in length, offer livers which when carefully removed give good opportunities on account of the thinness of the lobes for observing therefrom any movement of the cell.

The liver cell contains beside large nuclei of 3 $\mu$ and 4 $\mu$ in diameter, oil globules, and a few pigment granules. In the nucleus may be one or more nucleolar bodies. In the cell itself, in fresh condition, there can be observed five processes radiating from the nucleus. Hardened in Müller's fluid or in a solution of potassic bichromate, the fine intracellular reticulation can be observed to be unequally distributed throughout the cell. It seems to be aggregated around the nucleus, and from there radiates to the side of the cell which borders on the gall capillary, *i.e.*, away from the blood capillary. The reticulation encloses nearly all the pigmented granules, the remainder of the cell being pretty free from them.

Kupffer has described delicate offshoots of the gall capillary penetrating the cell and terminating in swollen cavities occupied by oil globules. I have tried to verify such a description as far as the liver of the cat-fish is concerned, and although I have employed artificial injections of Berlin blue and natural injections of sodium sulphindigodate, yet I have found nothing answering to Kupffer's view. In the artificial injection which Kupffer employed it is quite possible that lateral canals penetrating the hepatic cells with bulbous terminations may have been due to mechanical causes.

The hepatic cells are arranged in a definite way, and this arrangement appears different according as the lobule is cut longitudinally or transversely. When cut longitudinally the capillaries, when they run parallel, are separated by cylinders usually of two rows of cells, this cylinder being interrupted at every fifth or sixth cell by a branch between the two capillaries. Between the two rows of cells will always be found a gall capillary. In this case the resemblance to the tubular gland is very striking. It is also to be noted that nuclei of the hepatic cells are situated nearest the blood capillary.

When the lobule is cut transversely, towards its centre there are a number of capillaries also cut across and placed in the field of the microscope at pretty definite positions. Around these capillaries the hepatic cells are circularly arranged in such a way that the circles are contiguous and that invariably two cells separate two neighbouring capillaries. Here, again, the gall capillary is to be found between the two cells. When the section contains a number of capillaries cut regularly across, and at a position where they are joined by cross branches, such a view as that given in Fig. 10, is obtained. In this figure the resemblance to a gland tubule is complete.

If the fresh isolated cell be carefully observed no trace of thickening or marking on the cell surface can be found; when the gall capillary was situated where the blood capillary cannot now be distinguished. This has special importance regarding the question of the absence or of the independent existence of the gall capillary.

Hering[1] maintained that the liver cells were a direct continuation of the epithelium clothing the coarser gall ducts and that the liver cells enclose between them the gall capillaries as intercellular passages.

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[1] Sitzungberichte der Wiener Akad., Ad. LIV., and Arch. für Mikr. Anat., Bd. III.

Eberth[1] also describes them as ending in the same manner, but also finds that they are lined by a doubly contoured membrane very delicate and browning in silver nitrate injections. This membrane is no where isolable or independent of the cells in contact with it, and is absent altogether in fishes. Haidenhain and Peszke,[2] by filling the gall capillaries with sodium sulphindigodate and macerating the liver tissue in a solution of potassic bichromate and sodium chloride obtained the capillaries filled with the blue compound completely isolated as minute pieces of tubules, formed of a doubly contoured membrane otherwise apparently structureless.

My observations agree in the main with those of Hering and Eberth: in the case of the latter author as far as the structure of the capillaries in fishes is concerned.

In uninjected livers it is almost impossible to find the gall capillary. On the other hand, when injected artificially or by the natural method, it is of considerable breadth. Injection of silver nitrate will but fix and harden the adjacent portions of the liver cells, and thus is formed, apparently only, a capillary membrane. Peszke's method will not show the presence of an independent capillary in fishes. From these facts I would conclude that the capillary is an intercellular passage, which in hardened sections is absent, but which during life exists by reason of the power of the cells to select and deposit in that particular position the necessary products of its secretion. If the cell is in active secretion the passage has a greater diameter. If secreted products be absent, or if they be dissolved out, as is the case in hardening reagents, the passage disappears. The presence or absence of it therefore is much like the presence or absence of a lumen in the gastric glands in some vertebrates.

The gall-bladder is not folded to any extent on its inner surface when in the fresh condition. In hardened portions when the muscular coat has shrunken, the mucous coat is thrown into minute folds. These two coats are not sharply distinguishable. The outer bundles of muscular tissue are longitudinally arranged, but in quantity are very few. They frequently take an oblique direction, especially about the mouth of the bladder and in the cystic duct. The inner circularly arranged coat of muscular fibres is by far the thickest. Into it the fibrous tissue of the mucous coat enters and frequently

[1] Virchow's Archiv, Bd. 39, and Arch. für Mikr. Anat., Bd. III.

[2] Hermann's Handbuch der Physiologie, Bd. V.

separates the fibres into bundles. Both muscular coats may at positions quite change their directions, so as to leave it doubtful if there is more than one coat. Fibrous connective tissue enveloped these on the outside, and on this again is superposed the mesentery. The mucous coat contains coarse connective tissue fibres and has imbedded in it numerous arterial branches which divide and rise under the epithelium layer. Very few lymph corpuscles were observed. Beneath the epithelium the fibres become arranged more densely and give the appearance of a muscularis mucosae. They form a basement on which the epithelium sits. This stratum of densely arranged fibres runs up into minute ridges in which small arterial capillaries and venous capillaries anastomose.

The epithelium consists in the main portion of the bladder of long cylinder cells, slender, but of larger transverse diameter in its mouth and in the cystic duct. The protoplasm is very finely granular and surrounds a large oval nucleus. The outer peripheral border, easily lost in reagents, does not possess the striation that Virchow[1] describes for other vertebrates. The basal processes are very slender, often divide into two or more branches, and interlace with the fibres of the mucosa.

In the main portion of the gall-bladder there are but few glandular follicles or crypts. In the arched portion of the duct of the bladder they are much more numerous, and a few may be of such length that a portion of it is bent so as to be parallel with the mucous layer. The cells lining them are cylindrical or rather columnar, which in sections never exhibit a peripheral border, at least it is not manifest in fresh. A cross section of the tubules very often reveals slimy masses in the lumen. The cells do not differ otherwise from those of the general surface, and may have each a peripheral border like them.

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## THE PANCREAS.

For nearly half a century before 1873 the presence or absence of a pancreas in the Teleost fishes had been one of the disputed questions among anatomists. It may be convenient to go briefly into the history of this dispute, as it led to the discovery ultimately of a true pancreas.

[1] Virchow's Archiv, Bd. XI., page 574.

As early as 1827, Weber[1] described the presence of a duct in *Cyprinus carpio* running parallel to the ductus choledochus and originating in the central lobe of the liver ; as he found no distinct pancreas, he regarded the portion of liver mentioned as performing its function, since it differed from the rest of the liver in color, form, attachment to the intestine, and division into lobules.

A little later Brandt and Ratzeburg described a glandular body in *Silurus glanis,* much like the liver and extended behind it envelop-ing the ductus choledochus. This organ, they believe, to be the pancreas.

Cuvier[2] maintained that the pyloric coeca were glandular organs performing the functions of a pancreas.

Alessandrini[3] discovered a pancreas in the pike and the sturgeon, the latter having also a complicated pyloric appendage.

Johannes Müller[4] and Steller separately showed that in some fishes both pancreas and pyloric coeca may coexist, while in others the former, as a well developed organ, may occur in the absence of the latter. The genus *Lota* was mentioned as an example of the first-named condition and *Silurus* and *Muræna* of the latter condition.

The organ described as the pancreas in the pike by Weber, Cuvier believed to be part of the liver proper, and added that he had seen an excretory duct in a very large *Silurus*, opening into the midgut and terminating in the right lobe of the liver. This duct he re-garded as an hepato-intestinal duct.

The view that the organ generally regarded as the liver in fishes is divided into a bile-secreting portion and a trypsin-secreting portion was held by Stannius.

Bernard[5] in 1856 described a pancreas present in the intestines of an unknown specimen of fish and also in the turbot. In those fishes in which a pancreas was not observed, Bernard supposed that its functions were performed by the mucous coats of the midgut.

Nothing important was added to these observations until 1873, when Legouis[6] determined the presence of a pancreas in all fishes studied by him. His work has been the most important yet as lay-

[1] Meckel's Archiv, 1827.

[2] Cuvier et Valenciennes. Histoire Naturelle des Poissons, Paris, 1828.

[3] Novi Commen. Acad. Scien. Institut, Bonon, 1836, Tome II.

[4] Müller's Archiv, 1840, page 132.

[5] Leçons de Physiologie experimentale. Tome II., page 478.

[6] Annales des Sciences Naturelles, 1873.

ing at rest a question of long standing, although his statements were contradicted by Krukenberg[1] and confirmed by Nussbaum[2]. Cajetan[3], a pupil of the latter, studied and described the pancreas in *Anguilla vulgaris*, *Esox lucius*, *Trutta fario*, *Perca fluviatilis* and *Cobitis barbatula*, and tests his results by digestive experiments in several cases.

There are no pyloric appendages in the cat-fish. In searching the intestines microscropically a pancreas also is not to be found. I could find no organ in *Amiurus* as that described by Brandt and Ratzeburg as occurring in *Silurus*. On the other hand, in endeavoring to find the duct described in the last named fish by Cuvier, I discovered one which but little answered to it, but which as I found afterwards is the duct of the true pancreas.

This pancreatic duct runs almost parallel to the ductus choledochus and above it. The pancreatic duct is always the paler of the two, as the other takes more or less the color of bile. Half way between the intestine and the liver it divides into two or three branches, which run above the arched portion of the ductus choledochus into the liver substance along with the cystic ducts on both the right and left side of the middle line.

In the larger channel cat-fishes the duct is large enough to admit the insertion of a canula for the purposes of injection, and by this means the branching of the duct can be easily perceived. The finer tubules, *i. e.*, those of the gland proper, cannot be injected.

If the interlobular branches of the portal vein be injected with some material which will fill them to the exclusion of the finer branches, and if a section of liver thus injected be made, in such a section we can at once see the distribution of the gland tubules of the pancreas.

They are found to be arranged some circularly, some obliquely and some longitudinally about the interlobular vein, the arrangement being so distinct as at once to mark them off from the surrounding hepatic tissue. The cellular elements of these acini are light colored when compared to the hepatic cells, and take a lighter or a darker stain than those, according to the staining fluid used.

Fig. 11 gives a view of such a section. It is there observed, as is usual in other sections, that the gall ducts are to be found outside of the pancreatic tubules, some of which are cut across.

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[1] Kukne's Physiol. Untersuch. Bd. II. p. 385. [2] *Loc. cit.* [3] *Loc. cit.*

A glycerine extract of the liver digests fibrin in a 0·5 % solution of sodium bicarbonate, requiring but a few hours for a piece of moderate size.

In young cat-fishes, of from one to two inches in length, and from which I made a series of sections in the neighbourhood of the liver and midgut, I was unable to find a trace of pancreas. This is possibly to be explained, as Bernard suggested, by the supposition that digestion by the stomach is quite sufficient for the food of young fishes. It is also to be observed that hepatic tissue does not penetrate between all the capillary vessels of the liver. It is quite safe to say that the pancreas is of later development, and is connected with the portal vein in some such way as to be dragged by it into the liver when the latter increases in size.

The fact discovered by Krukenberg that the extracts of the livers of different fishes accomplished a tryptic digestion may be explained by the possible distribution of the pancreas in the liver in the way that is described above. Among those fishes studied by this physiologist, were *Perca fluviatilis*, *Labrax lupus*, *Belone rostrata*, *Crenilabrus pavo*, *Dentex vulgaris*, *Trigla hirundo*, *Sargus Rondeletii*, *Gobius niger*, *&c.* In *Perca fluviatilis*, according to Cajetan, the pancreatic ducts entwine about the portal branches till they sink into the liver. It may be added that it is possible in this fish, as well as in those given above, that the pancreas follows the portal vein as it does in the cat-fish. The organs so affected are, however, by no means to be denominated a hepato-pancreas, as that name is understood in invertebrate anatomy.

A more careful study of the pancreatic tubules in the cat-fish shows that it undergoes the ordinary changes effected during digestion. In a fasting condition the cells are filled with granules, the round nucleus situated near the outer part of the cell, and the whole stains feebly in carmine. When the liver is cut out four or five hours after the fish has been feeding, the granules are gathered into a region adjacent to the lumen of the gland, and this portion stains feebly, the rest of the cell strongly, in carmine. Fig. 11 gives a representation of this stage.

I could observe a membrana propria for these gland tubules as little as in those of the gastric glands. The fibres of the connective tissue surrounding them are arranged in a dense sheath which serves all the purposes of membrane.

## THE AIR-BLADDER.

The air-bladder of the cat-fish takes up in length about one half that of the belly cavity, and measures across at its broadest end from one-half to two-thirds its length. It narrows posteriorly and has a rounded termination, while the anterior face is broad and is covered by the head portion of the renal organs. It is covered up on its lower surface by the peritoneal folds.

The dorsal surface has a groove into which the vertebral column fits, elsewhere the surface is even. The duct arises from it at the commencement of the middle third, and passes forward and downward to the œsophagus.

There are three cavities in the air-bladder, two of which each communicate with a third, the anterior one. The long axis of the last named is directed transversely and occupies the broadest portion of the bladder. The long axis of the two others are parallel and are directed backward. The connection of each of these with the anterior one is by an aperture narrower than its own transverse diameter. It is with the anterior chamber that the duct communicates, opening at its posterior lower edge.

There are two coats in the wall of the air-bladder. The outer white, and of some thickness, exists as such at all points, except a part of the dorsal surface. On the sickle-like auditory ossicle and along several vertebral segments it is but a thin transparent membrane, closely connected with and united to the ossicles and vertebræ. Opposite the opening of the duct into the bladder the membrane again becomes thick and opaque white. This coat alone is connected with the auditory ossicles, and to its thickness, as well as to its constituents, it owes some of its stiffness.

The inner coat is very thin and membrane like, and is conformed to the walls of the various chambers. Between the median walls of the posterior chambers is a single wall due to the fusion of the two outer coats. The outer coat also surrounds and enters closely into the constrictions of the openings of the posterior chambers into the anterior one.

The outer coat is formed of connective tissue fibres and elastic fibres. The former are long, needle-like, and whitish as if calcified. The stiffness of the outer coat is due wholly to these fibres. When put into dilute acetic acid for several hours they swell up into a jelly-like mass. These fibres are arranged in every direction, but for the most part longitudinally, then transversely. The longitudinal fibres are generally outside. In acetic acid the jelly mass shows stringy portions arranged parallel, not constantly, however. The second set, or elastic fibres, are very numerous, and show an extensive branching and inter-communication sometimes surrounding, sometimes penetrating, the bundles of gelatinous matter.

The inner coat, the membranous wall of the bladder cavities, consists of a layer of flat hexagonal cells, and outside this a fibrous layer. The flattened epithelium is disposed alike over the inner surface and does not differ in development over the capillaries, as has been described to be the case in other fishes. The contents of each cell are clear and the nucleus is round and conspicuous. The mucous layer beneath consists of connective tissue fibres not very closely arranged. No elastic fibres were found. No muscle fibres could be made out either plain or striated.

The blood supply of the air-bladder is obtained from the *arteria cœliaca*, the vessel entering the organ at the origin of the duct, and, after giving several branches to the outer coat, it enters the inner membranous coat, and is there ultimately distributed. It divides into two main branches and several smaller ones; the main branches pass one to each side on the walls of the posterior chambers, while the smaller ones traverse the walls of the anterior chamber. Each branch is accompanied by a vein arranged both in such a manner that the two are in parallel course and side by side. Both branch simultaneously, and the different branches are again connected after some distance by capillaries. It also often happens that the area supplied by one branch also possesses some of the capillaries and finer twigs of a second branch. Usually each fine arterial branch has a region set apart, and there it ultimately divides into fine anastomosing capillaries which are drained by various capillaries also originating in the same way.

The larger venous branches are very often varicose, appearing often like sinuses.

There is no blood-gland in the air-bladder of *Amiurus* in the sense in which that word is used.

The blood of the air-bladder is collected in the mesenteric veins and carried onward to the heart.

# THE BLOOD-VASCULAR SYSTEM,

## DUCTLESS GLANDS, AND URO-GENITAL SYSTEM OF *AMIURUS CATUS*.

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The object of the present paper is to complete, as far as possible, the description of the anatomy of *Amiurus*. The works of Stannius[1], Owen[2] and Wiedersheim[3], have furnished the basis for the points described, but special papers have also been consulted.

### I. THE BLOOD-VASCULAR SYSTEM.

This has been carefully worked out in the different groups of fishes, and as the parts and relations in *Amiurus* are in the main similar to those of other *Teleostei*, such general knowledge is assumed.

#### THE HEART.

The heart is situated entirely in front of the first vertebra. The *pericardium* which encloses it, is in contact with the coracoids on the ventral side. The hyopectorales muscles which arise from the inner curved surface of the coracoids form the lateral boundaries, and coming together anteriorly give a triangular shape to the cardiac space. Above, it is covered by the floor of the mouth and the copulæ of the posterior branchial arches or their equivalents. The posterior boundary is formed ventrally by the upward curve of the posterior border of the coracoids, and dorsally by the aponeurotic membrane. The stout coracoids are about 30 mm. wide in the median line, and extend from behind the sinus venosus to the upward curve of the truncus arteriosus. It is plain that no other spot in the body outside the brain-case would afford such security to this vital organ. The outer coat of the pericardium is more or less attached to the surrounding surfaces. The heart lies free within the pericardium, which is attached anteriorly to the truncus and posteriorly to the dorsal and

[1] Handbuch der Anatomie der Wirbelthiere.

[2] Anatomy of Vertebrates.

[3] Lehrbuch der vergl. Anat. der Wirbelthiere.

ventral surfaces of the sinus venosus and ductus Cuvieri, and continued over their anterior surfaces.

The *sinus venosus* lies between the pericardium and the 'aponeurotic wall,' and is but little larger than the sinus-like vessels of which it is the termination. Its anterior surface is attached to the posterior surface of the atrium in the median line of the body. The opening between them is guarded by a pair of large semi-lunar valves which not uncommonly become united at their extremities and present the appearance of a diaphragm with a central opening, the ordinary slit, 3·5 mm. in length, being reduced to a more or less rounded passage as small as 1 mm. in diameter.

The *atrium* is a flattened chamber, 14 mm. long and nearly as broad at the posterior end. It lies to the left and over the dorsal surface of the ventricle, extending from behind its apex to the anterior extremity of the bulbus. The thick rounded posterior border of the atrium is divided into two lobes; laterally and anteriorly the chamber thins out to an edge and narrows anteriorly to a blunt apex. The wall is formed of connective tissue and is very thin. To this wall the *trabeculæ carneæ* are attached and run in various directions along the wall and across the chamber, leaving, however, several free spaces. The largest of these spaces is opposite the opening into the ventricle, and the muscle-bundles which surround it are directed toward this point and expel the blood by drawing the wall of the atrium toward the opening, while by the same contraction they expand it. The wall of the atrium surrounding the *ostium atro-ventriculare* is strengthened by a muscular ring and thickening of the connective tissue. The union of the atrium and ventricle is effected by the attachment of the outer surfaces of the connective tissue of each wall. Where this takes place the connective tissue sends strong interlacing processes into the muscular ring and the muscles of the ventricle. At places muscular tissue also passes from one to the other. Where not interrupted by these muscles the connective tissue of the wall joins similar tissue covering the inner surface of the muscular ring to which the pair of vertical semi-lunar valves closing the opening are attached.

The *ventricle* is somewhat cylindrical in form and slightly curved towards the dorsal surface. The connective tissue-coat is as thick as that of the atrium. The muscular tissue is divided into two distinct portions, an outer layer, the muscles of the wall, and within this the muscles of the trabeculæ. Processes from the connective tissue layer pass in among the muscles of the wall, and, uniting again, form an inner layer to which the muscles of the trabeculæ are attached. The fasciculi of the latter resemble those of the atrium, but are placed more closely together. Their arrangement leaves a central cavity which extends from behind the atro-ventricular opening to the bulbus, and many smaller spaces as well. The surface of the ventricle is smooth, and between the two sets of muscles there are no lymph-spaces as described by Kasem-Beck and J. Dogiel[1] in their investigations on the heart of *Esox* and *Acipenser*. There *are* large spaces in the inner connective tissue layer toward the apex, opposite the *ostium atro-ventriculare*, but they are blood-cavities connected with the other spaces of the ventricle. While I have not attempted to demonstrate the endothelial layers described by the above-mentioned investigators, I doubt the existence of the inner one in *Amiurus*, for at points the muscle-fibres of the one layer pass into the other as do also the connective tissue fibres, except at the spaces. In comparing the structure of the ventricle with that of the atrium the only difference is that the former has á dense muscular layer without blood-spaces developed between the connective tissue layer and the *trabeculæ carneæ*, which greatly strengthens the wall. The heart of such fishes as are supposed to possess double walls should be further studied, and especially its development.

The base of the *bulbus* is provided with a narrow neck which is inserted into the central cavity of the ventricle to which it is attached by its outer surface. At this opening a pair of valves is attached to the muscles of the ventricle similar to those attached to the atrium. Their extremities, however, extend forward as ridges upon the wall of the bulbus to strengthen them. Curving upward the bulbus passes into the *truncus arteriosus*, which runs almost at right angles to the axis of the ventricle.

The walls of the bulbus, ventricle and atrium are well supplied with blood-vessels. An artery passes along the dorsal surface of the bulbus to the ventricle; where it divides in two stems which distribute themselves on each lateral surface. Another artery runs along the ventral surface of the bulbus and ventricle and gives off a branch on the former to the dorsal surface of the latter. The veins pass back-

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[1] Beitrag zur Kennt. d. Structur u. Function d. Herzen d. Knochen-fische, Zeit. für wiss. Zoo. Vol. XXXVII., p. 247.

wards over the atrium and sinus venosus. These vessels are confined to the connective and muscular tissue of the walls, the main stems lying wholly in the connective tissue layer.

THE BRANCHIAL SYSTEM.

The *branchial arteries* to the third and fourth arches arise from the truncus arteriosus by a single stem which runs backwards and upwards to the anterior end of the median ventral ridge of the triangular cartilage uniting the fourth and fifth arches. Over this it divides into two stems, which immediately divide again, the anterior divisions curving forwards and outwards to the third arch, and the posterior pair backwards and outwards to the fourth arch. This arrangement is not uncommon among Teleosts according to Stannius.[1] The truncus passing forward gives off the arteries to the second and first arches, not in pairs, but alternately from the dorsal surface, first to the right and then to the left, ending in the left stem of the first arch.

The general features of the *branchial arches* have already been described by Prof. McMurrich in his paper on the osteology of *Amiurus*.[2] I shall therefore content myself with following the course of the blood through them, without attempting a description of their histological structure, which has been exhaustively done for other Teleosts by Riess,[3] Hyrtl, Dröscher,[4] &c.

The *art. branchiales* enter the gills upon the posterior side of the arch, nearly 10 mm. from the termination of the filaments which are continued forwards upon the membrane, in posterior arches beyond the attachment of the adjacent arch. To supply these filaments with blood the artery sends back a branch after entering the canal. In the canal the branchial artery is placed farthest from the bottom of the groove, beneath the rudimentary diaphragm, and gives off a branch to each filament of the double row. The artery passes outwards upon the inner side of the filament, while the vein, which gathers the blood from the capillaries, returns upon the outer side and passes around the branchial artery to enter the branchial vein which lies along the bottom of the groove. The branchial nerve lies directly between the artery and vein.

[1] *Loc. cit.*, p. 240. [2] *Vide*, p. 292.

[3] Arch. für Nat., 1881, Jahrg. 47, p. 582.

[4] Arch. für Nat., 1882, Jharg. 48, Heft. I. & II.

The *venæ branchiales* leave the gills at the dorsal end of the arch much as the arteries entered at the ventral end. Both the artery and vein of the first arch are straight vessels entering and leaving near the termination of the filaments, and so not requiring a branch. The fourth vein leaves the gill below the bend in the arch.

Each branchial vein sends a branch backwards to the hyoid and mandibular regions while yet within the gill.

### THE ARTERIAL SYSTEM.

The course and relation of the branchial veins (Pl. VIII., Fig. 1, I., II., III., IV.) are as follows. The first branchial vein runs at right angles to the longitudinal axis of the skull, and near its base gives off two branches (*c. ex.* and *c. in.*), which I have called the external and internal carotids. It then turns backwards along the ventral surface of the anterior cardinal, and is joined by the second branchial vein. The vessel thus formed unites with its fellow from the opposite side to form the *aorta descendens.* An artery to the pharynx, &c., springs from it at varying points. The vessels formed by the union of the third and fourth branchial veins enter from each side immediately below.

The first branch from the descending aorta, after the junction of all the branchial veins, is a small impair artery from its median ventral surface to the 'head-kidney.' (Fig. 1, *hk.*) Immediately behind it, arises the *arteria cœliaco-mesenterica* (Fig. 1, *cm*), a large single stem which supplies all the viscera, except the kidney. It passes downward between the air-bladder and the head-kidney, and to the right of the œsophagus. The first branch supplies the air-bladder, the second the œsophagus and stomach, the third is the hepatic artery, the next branches pass to the anterior end of the intestinal tract, and then the splenic artery is given off. Here the mesenteric artery divides into two stems which follow respectively the right and left walls of the mesenteric fold and supply by many nearly parallel branches each its own half of the intestine.[1] The left *vis.* that branch situated upon the attached portion of the mesentery is the larger, and from it springs the genital artery near the anterior end of these organs.

One other impair artery is given off into the body cavity at its

[1] For the distribution in the various organs of the branches of the arteria cœliaco-mesenterica, xcepting the splenic and genital arteries, see Mr. Macallum's paper.

posterior end. This vessel passes directly downward through the substance of the kidney to the mesentery, and anastomosing with the left mesenteric artery is distributed with it to the rectum.

The descending aorta behind the origin of the cœliaco-mesenteric artery enters a deep groove (Pl. IV., Fig. 7) on the ventral surface of the fourth vertebra to pass the attachment of the air-bladder. Throughout the rest of its course in the body-cavity it lies upon the rounded surfaces of the centra. In the tail as the *art. caudalis* it occupies the bottom of a groove on the centra, and is further protected by the hæmal arches and by the short spines which arise from the sides of the groove between these arches. A longitudinal dorsal ridge projects into its lumen as in some other forms.

The arteries given off to the trunk and tail arrange themselves in three sets, *neural*, *lateral* and *hæmal*. Each pair of neural and lateral branches arise by common stems, which, passing around the vertebra, give off the lateral arteries about the middle of the centrum, and are then continued upwards along the posterior surface of the neural spine as the neural arteries.

The *lateral* arteries pass outwards by the division in the lateral trunk musculature along the 'lateral line,' giving branches to these muscles.

The *neural* arteries divide into branches which run between the lateral muscles and supracarinales, and branches which pass upwards in the median line between the supracarinales.

The *hæmal* arteries have similar relations to the ventral muscles. They arise independently, and run upon the anterior surface of the hæmal spine. Throughout the length of the body cavity these arteries (*intercostales*) run with the nerves between the peritoneal lining and the muscles of the body wall.

These vessels present the same irregularity in *Amiurus* as is found in other *Teleostei*. A large number have entirely disappeared or been greatly reduced in size, and the blood is distributed by large single stems, now from the right side and now from the left, giving branches to both sides of the body and spreading over from two to five myomeres.

The lateral arteries and the hæmal arteries of the body cavity can, from their position, supply only one-half of the body, and consequently present greater regularity than the others.

The *art. cuadalis* terminates by dividing beneath the second last centrum into two branches, which pass upwards and backwards on the sides of the last centrum beneath its hæmal spines, which are widened by being attached to small lateral processes on the lower portion of the body so as to afford space and protection for these vessels. A horizontal ledge of bone which projects from each side of the spine *A* (Fig. 5, Pl. II.) almost closes a bony foramen with the spines. As a rule, the right branch distributes itself entirely at this point by dorsal and ventral branches to the deep muscles of the caudal fin, and branches along the surface of the flat spines to its intrinsic muscles. The left branch, however, after giving off similar vessels sends a large branch along the dorsal surface of the bony ledge and thence in the median line between the spines B and C, (Fig. 5, Pl. II.) to the tail-fin.

The fin rays consist of two separate halves, each half being convex on its outer surface and deeply grooved on the inner. They are attached by their base on each side of the flat spines of the bodyless vertebræ, and so form an arch in which a canal runs the entire width of the fin. The artery upon entering this canal divides into a dorsal and a ventral stem, from which a branch passes out between the halves of each ray, or several of these branches may arise by a common stem. The artery in the ray usually divides into two which run parallel to each other.

In sections of the fin a layer of connective tissue is seen to occupy the median plane passing between the halves of the rays where it forms a median canal for the arteries and two lateral canals for the veins.

The short rays of the dorsal margin are supplied by the arteries to the muscles mentioned above. The dorsal and ventral fins, with their musculature, are supplied by two or three of the ordinary spinal arteries somewhat enlarged at these points.

The *art. renales* are given off from the hæmal vessels passing around the kidney, of which there are usually three or four pairs specially enlarged. The most posterior of these is continued to the pelvic fins entering on the posterior surface. A large branch is also continued forward to the muscles attached to the pelvic arch. The arrangement of the vessels in the caudal fin may be taken as representative of what occurs in the others.

The *subclavian* arteries are the largest and most anterior pair of the *intercostales*. They arise from the dorsal surface of the aorta descendens in the groove upon the fourth vertebra, and issue by foramina between it and the third. They pass outwards along the anterior surface of the transverse processes of the fourth vertebra beneath the strong peritoneal continuation of the aponeurotic membrane. Each artery gives off two branches to the muscles of this region and then turns forwards, over the head-kidney and downwards to the median spine of the scapula, at which point it distributes itself. Three or four branches to the anterior portion of the ventral musculature of the trunk; a branch to the pectoral fin and its muscles, which also sends a strong branch backwards on the outer surface of the muscles of the wall, and a branch which passes forwards beneath the girdle and anastomoses with certain of the hyoidean arteries are supplied by it.

The arteries of the head have already been mentioned. It remains to add a short description of their relations and distribution.

A few small twigs arise at the junction of the branchial veins for the aponeurotic wall and the fatty tissue on the base of the skull.

An artery from the united first and second branchial veins, which I shall designate as pharyngo-branchial, passes down around the pharynx, which it supplies with blood, and also gives branches to the posterior *lev. branchiales,* and in some cases the *pharyngo-branchiales.* Small arteries for the anterior *lev. branchiales* arise from the first branchial vein near the origin of the carotids.

The *A. carotis externa* arises from the dorsal surface of the first branchial vein at the angle where it turns backwards to join the second. (Pl. VIII. Fig. 1, *c. ex*). There is neither *carotis communis* nor *circulus cephalicus* in *Amiurus.* It passes upwards over the lateral surface of the *N. trigeminus* on to its dorsal surface and along the ramus mandibularis towards the eye. A large branch supplies the abductor mandibulæ turning backwards beneath the muscle and also sending a branch through the mesethomoid bone to the nasal sac. A second branch passes beneath and behind the eye, also terminating at the nasal cavity. After giving a branch to the antero-lateral portion of the roof of the mouth, the remainder of the artery turns outwards, beneath and slightly anterior to the eye, and divides into a branch to the large maxillary barblet and another to the mandible.

The latter divides and sends a branch backwards and another forwards along the outer dorsal surface of the mandible.

The *A. carotis interna* (Pl. VIII. Fig. 1, *c. in.*) arises from the anterior surface of the first branchial vein close to the *carotis externa*, and passes forwards along the side of the skull. A short distance from its origin it thickens into a gland-like structure (*p s*) nearly 8 mm. long and 3 mm. wide in the middle and tapering towards both ends. This organ is exposed from the roof of the mouth by dissecting away the adductor arcus palatini from its attachment to the side of the skull. From this surface (ventral) the channel of the artery is distinctly seen passing directly through it from end to end Transverse sections show that the wall of the vessel is thickly perforated throughout the length of the organ by small openings of vessel-like passages (Fig. 2, *b*), which are quickly lost in the fine interspaces of the connective tissue of which the thickening is formed. Scattered through it are seen the small arteries by which the blood is again collected from the interspaces (Fig. 3, *a*). An examination of the position and relations of this structure leaves no doubt but that it is the remains of the *pseudobranchia* which has become reduced to a mere *rete mirabile.* It is worthy of note in connection with its reduced state in *Amiurus*, that Owen mentions *Silurus* as one of those fish in which it is entirely absent. That it is the pseudobranchia is shown by the fact that the *arteria ophthalmica magna* (Fig. 1 *a. o. m*,) arises from its anterior dorsal surface which is in contact with the optic nerve, in company with which the artery passes to the eye.

Three small arteries arise from the same surface, posterior and medial to the former, and immediately enter the braincase. These are the *encephalic* arteries, and their origin from the pseudobranchia is unknown among other *Teleostei.*[1] In this point, however, as also in the structure of the organ *Amiurus* shows a singular agreement with *Acipenser.*[2]

As far as I am aware the pseudobranchia has not the peculiar direct relation to the carotid, described above, in any other fish, but is situated upon a branch of that vessel even in the sturgeon.

The internal carotid supplies the *adductor arcus palatini*, a branch to the posterior part arising behind, and those to anterior part after

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[1] *Dr. F. Maurer*—Ein Beitrag z. Kennt. d. Pseudobranchien d. Knochentische. Morph. ahrb. Bd. IX. Taf. XI.

*Owen—l. c.* Vol. I. p. 489.

the vessel passes through the pseudobranchia. It then enters the wide flat anterior portion of the brain cavity as the nasal artery (Fig. 1, *n*), and joins the olfactory tract at the bulb, from which point dividing it distributes itself to the nasal sac, and also gives a strong lateral branch to the large maxillary barblet. It is difficult to understand why the internal and external carotids should cross their branches in order to supply these two parts.

The three arteries to the brain may be designated as anterior, medial and posterior. (Fig. 1, *ant. med. post.*)

The *anterior* runs at first beneath and then along the posterior surface of the optic nerve direct to the optic chiasma, where a transverse stem unites it with its fellow of the opposite side. The union of this pair and also the posterior pair in the median line closes a *circulus cephalicus*, but within the brain-case. From this connecting stem a small anterior and a posterior artery are given off to the perilymphatic tissue of the brain-case. From the point of junction the arteries run backwards parallel to one another upon the dorsal surface of the optic tract, turn upwards behind the cerebral commissure, and enter respectively the right and left cerebral hemispheres at their base, where they distribute themselves.

The *median* and smallest lies behind the optic nerve and runs backwards about the angle of the floor and side of the skull, lateral to the hemispheres, and divides into a stem to the thalamencephalon and another to the lobus inferior.

The *posterior* and largest lies above the former, behind and slightly above the optic nerve and runs backwards along the side of the skull in the same plane. It passes inwards along the anterior margin of the fourth nerve and gives off a branch which is continued along this nerve behind the optic lobes to the anterior under surface of the cerebellum, which it enters at its base. The artery turning slightly forwards passes under the brain and joins its fellow in the median line immediately behind the *saccus vasculosis*, to which a vessel is at once supplied. From this point a single median stem runs backwards and ends on the medulla oblongata. Three branches from this median artery pierce the floor of the ventricle and form centres of distribution to the median and posterior parts of the brain. The first gives off three pairs of branches : an anterior to the inner surface of the *tecta optica*, a median to the *tori semiculares* distributed upon the surface covered by the *tecta optica*, and a posterior passing backwards to the lateral walls of the internal cavity of the cerebellum. The second supplies a pair of arteries to the *tubercula acoustica* and a second pair which divide before entering the *lobi trigemini*. The third gives off a set of four branches to the parts behind the cerebellum.

The median stem also gives a pair of lateral branches to the auditory labyrinth.

The artery from each half of the first branchial arch turns forward and passes through a foramen in the hypohyal, and then turns backwards and outwards along a groove on the dorso-lateral margin of the ceratohyal. On reaching the epihyal it divides itself into three branches. A large branch returns along the mandible supplying it and the appended barblets; a second branch crosses the outer surface of the epihyal to supply the branchiostegal rays; and a third passing onward to the attachment of the operculum distributes itself upon it.

The arteries from the other three pairs of arches show considerable irregularity in anastomosing and giving off independent branches, but the tendency is to unite in a large median stem between the pericardium and the copulæ of the arches. From this hyoidean plexus all the surrounding parts are supplied. The *coronary artery* divides into two stems, a dorsal and ventral, which enter the wall of the bulbus at the point of attachment of the pericardial membrane.

The *thyroid artery* is usually a branch of the coronary.

A pair of large arteries to the *hyopectorales* and another pair more posterior to the *pharyngo-claviculares* are the more important stems to the muscles.

All the arteries of the trunk and tail, except those to the organs within the body cavity, and those to superficial parts of the head, end in a rich capillary network in the subcutaneous connective tissue of the skin. The ability shown by these fishes to live for a considerable time out of water is no doubt due to aeration of the blood in these capillaries while the mouth and gill-cavity are kept closed. If the skin be moistened artificially this period can be greatly prolonged.

## THE VENOUS SYSTEM.

The *vena caudalis* arises in the tail-fin, usually by two vessels of unequal size having the same course as the arteries. It runs forward in the hæmal canal beneath and in contact with the caudal artery The two posterior trunk vertebræ have short and broad hæmal arches united by a transverse piece. The caudal vein turns downwards over the posterior face of the second (sometimes the first) and enters the kidney, which extends back over these arches. It then passes downwards and forwards through the substance of the kidney and near the ventral surface gives off two branches, first a right and then a left *vena renalis advehens*, which, passing forwards and outwards, distribute their blood to the kidney.

The caudal vein, leaving the kidney, is attached to the mesentery which unites the genital glands and becomes the portal vein, running straight forward beneath the air-bladder to the liver. This arrangement has not been described for any of the *Teleostei*, as far as I am aware, and if Nicolai and Hyrtl are correct does not occur in other Siluroids. According to these observers the entire vein distributes itself to the kidney as the *vena renalis advehens*. The former arrangement was constant in all specimens of *Amiurus catus* examined by me.

The posterior cardinals (*venæ vertebrales posteriores* of Stannius) arise in the kidney and run forward on each side of the vertebral column. As in other Teleosts the left vein is very small in comparison with the right, which, by a median stem, drains almost the entire kidney, and issuing upon its anterior concave surface passes upward and to the right, to the side of the vertebral column, where it forms a large sinus-like vessel. The left cardinal receives only a few branches from the horn of the kidney upon that side. Upon reaching the fourth vertebra they narrow to pass through a triangular foramen formed by the body of the vertebra at the side, the transverse process above and an oblique bony ledge below. Having passed through they turn downwards through the head-kidney and join the anterior cardinals.

The veins which drain into the *vena caudalis*, do not require any special description, but when this vein leaves its position beneath the aorta upon entering the body, it causes its branches to vary also from the branches of the latter.

The *portal* vein receives the *genital* veins in its passage between these organs. It then passes above and in contact with the spleen receiving the *splenic* veins. This point also forms a sort of nucleus for the entry of a number of veins from the left mesenteric fold. Those on the right unite into a *mesenteric* vein which in some specimens curving upwards and backwards crosses and joins the portal at this nucleus; in others, however, it continues straight forward on the right of the stomach and joins the portal vein near its termination in the liver.

The *venæ intercostales* opposite to the kidney enter that gland near its ventral margin, but those more anterior consist of a dorsal and ventral branch which unite in a horizontal stem on a level with the ventral surface of the air-bladder. This stem consists of an anterior and a posterior branch, which unite into a transverse stem across the mesentery covering the ventral surface of the air-bladder, the right to the right mesenteric vein, and the left to enter the portal vein immediately in front of the spleen. The most anterior pair of intercostal veins enter the head-kidney at its dorso-lateral angle.

The portal vein continues forward to the median side of the left posterior lobe of the liver, to which it gives a branch and continues to give off branches as it passes around the posterior margin of the gland below the œsophagus to terminate in two branches to the right lobe. The gastric veins from the stomach enter the portal vein at various points as it curves around between the stomach and the liver. Sometimes they miss the portal vein and enter the liver direct.

The *hepatic* veins arise by small branches opening directly into large sinus-like vessels which run downwards and forwards to meet in the median line and pierce the aponeurotic membrane just above the coracoids, where it is in contact with the *sinus venosus*. The latter has but a single opening for the hepatic veins, but the division between them extends quite up to the aponeurotic membrane.

The neural and lateral segmental veins above the body cavity unite in a vein in the neural canal, which discharges itself into the posterior cardinals by a pair of vessels between the transverse processes of the fourth and fifth vertebræ. The highly modified region between the dorsal fin and the skull has special venous connections which will be described below.

The veins from the fin-rays enter a venous sinus or large vessel in the canal at the base, from which the blood is drained by several of the ordinary veins.

The *anterior cardinals* arise by branches from the mandible, maxilla, M. adductor mandibulæ, the operculum, and dorso-lateral surface of the skull generally. These branches enter at the orbit, and uniting, run along the ventral surface of the R. mandibularis trigemini. It receives a large branch from the nasal region as well as small branches from the roof of the mouth. Reaching the skull it turns backwards, as a large sinus-like vessel, along its side above and closely attached to the branchial veins, and medial to the M. lev. branchiales, from which it receives three or four small veins.

The cavity of the skull is drained by a pair of veins which arise in the nasal sac and pass inwards to unite by a transverse stem before passing back along the dorso-lateral line of the wall. Usually one of these veins—sometimes the right and sometimes the left—becomes greatly reduced, and even disappears posteriorly to the transverse stem. They again unite over the anterior end of the cerebral hemispheres. and, continuing backwards, receive a number of veins and unite a third time on the posterior wall, completing a second venous circle. This circle receives a pair of veins from the auditory labyrinths, and a median impair vein from the dorsal surface of the spinal cord.

The veins leave the brain-case, along with the *rami laterales trigemini*. through the supraoccipital and turn at once downward along the lateral surface of its spine. As it issues from the brain-case each vein receives a vessel from the dorsal musculature as far back as the spine of the fourth vertebra. Again, at the transverse process of the supraclavicle, it receives a vessel, which, arising in the dorsal fin, descends along the anterior surface of the spine of the fourth vertebra. and runs forward above the latter. The vein then turns outwards and forwards, and enters the anterior cardinal.

At this point the anterior cardinal turns outwards and downwards upon the anterior surface of the aponeurotic membrane to join the posterior cardinal immediately upon its leaving the head-kidney, and from the *truncus transversus* or *ductus Cuvieri*. The ductus runs downwards and slightly forwards upon the membrane and beneath the œsophagus to meet its fellow in the median line, and form with the hepatic veins the *sinus venosus*.

The vein draining the hyoidean region, called by Stannius[1] *vena jugularis inferior*, arises in the branchiostegal rays and runs forwards along the median margin of the epi- and ceratohyals. Anteriorly to the pericardial chamber the veins of both sides usually unite in a single vein on the left side, surrounded by the thyroid gland, but, in passing around and above the pericardial chamber, a small vein

[1] *Loc. cit.*, p. 249.

drains the right side, and, like its fellow, enters the *ductus Cuvieri* at the *sinus venosus.*

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## THE DUCTLESS GLANDS.

### THE SPLEEN.

This organ lies in *Amiurus*, between the posterior end of the stomach and the anterior end of the genital organs. It is in contact with the peritoneum covering the ventral surface of the air-bladder, and is itself surrounded by peritoneum. The long axis of the gland which is parallel to the same axis of the body, measures when the organ is distended 20 mm., the short diameter 13 mm. It is slightly divided into two lobes, a posterior large lobe and an anterior small lobe. The surface next the air-bladder is concave, the ventral surface convex. The right margin, which lies near the median line of the body, is thick and rounded, but the gland thins out toward the left margin where the points of the lobes nearly touch the left body wall. The hilum is on the concave dorsal surface where the artery and veins enter together, and run side by side throughout the gland until the finer branches are reached. This arrangement agrees with that of the higher Vertebrates, but it is not universal in fishes, *e. g.*, *Anguilla*[1], in which the arteries lie across the veins. The vessels spread themselves out, fan-like, from three or four trunk-stems, but these in the case of the veins do not unite into a single splenic vein but enter separately the portal vein, which runs in immediate contact with the surface of the gland. Indeed, one commonly finds three or four patches of small openings close together in the wall of the portal vein, the larger branches of each centre having entered without joining. A small vein usually arises from the ventral surface of the anterior lobe, and may enter the portal vein direct or join one of the mesenteric veins just before its junction with the portal.

The surface of the spleen presents a perfectly smooth appearance in some individuals, while in others raised papillæ are visible to the naked eye. In the former granular-looking nodules can be seen thickly imbedded in a clear, reddish matrix, while in the latter they are much less distinct. The reason for this difference will be better understood after a description of the internal structure.

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[1] *C. Phisalex*—Structure et texture de la rate, chez l'*Anguilla communis*. Comptes Rendus 1884, Vol. XCVII., p. 190.

In a section through the spleen of a young fish, (one year old, judging by its size), it is seen to be surrounded by a delicate connective tissue capsule (Pl. VIII., Fig. 4, *c*). At a few points delicate processes pass into the substance of the gland. In the gland substance the *Malpighian corpuscles* (Fig. 4, *m.c.*) varying in size and form according to the direction in which they are cut, occur evenly and thickly throughout, surrounded by a very openly reticulate pulp tissue. The larger veins and arteries lie together, and in many instances the artery lies wholly within the lumen of the vein, appearing as if attached to the inner surface of its wall. A most noticeable feature is the small patch of brown pigment in the majority of the Malpighian corpuscles to which they are strictly confined, *never being found in the pulp.*

When we examine the pulp-tissue with a power of about 600 dia., it is seen to consist of large plate-like nucleated cells, (Pl. VIII, Fig. 7, *a*) which unite with one another by branched processes enclosing large vesicular spaces (Pl. VIII., Fig. 5, *v. s.*) To their surfaces are attached a few lymphoid cells similar to those of the corpuscle, besides adherent blood-cells. This reticulate tissue is continued through the corpuscles and attached to the vessels, although this is difficult to make out, because in the Malpighian corpuscles the spaces are almost completely filled with lymphoid cells, except next the artery (Fig. 5, *x*), where there are often spaces as in higher forms.

The lymphoid cells of the Malpighian corpuscles vary greatly in size and shape (Fig. 7, *d*), but the bulk of the tissue is made up of very small cells with a nucleus which nearly fills the interior. This tissue seems to accompany and surround all the branches of the artery.

The brown pigment consists of amorphous granules which may attain a size of 12.4 $\mu$, but are usually smaller. These pigment granules are formed in cells which when full of pigment measure about $15{\cdot}5\mu$. It is only in a few cases that the surrounding cell can be seen; as a rule it has disappeared, leaving the granules adherent in a mass, (Fig. 7, *b*) or allowing them to be scattered in the tissue, (Fig. 5, *g*).

So marked is the difference between a section of the spleen of a young fish and that of an old one, that at first sight they would scarcely be recognized as from the same animal. The place occupied by the pulp (Fig. 4), has been filled by a dense connective tissue stroma which divides the gland into lobules as seen in section.

These lobules appear to represent the Malpighian corpuscles. In the angles between them the connective tissue fibres separate so as to leave small spaces in which a few blood-cells are to be seen. (Fig. 6, *i*). The brown pigment patches have increased in size so as in many instances to entirely conceal the tissue surrounding the artery, and render its nature difficult of determination. In places where there is no pigment, (Fig. 6) the endotheloid cells are visible, covered by only a few lymphoid cells, and so they rather resemble the pulp. The thickness of the stroma between the lobules varies from 6·4 to 55·8$\mu$, and the average diameter of the enclosed spaces is 220 $\mu$.

This connective tissue forms a thick layer beneath the outer capsule, from which it is easily distinguished by its lesser density. As its fibres pass inwards between each outer Malpighian corpuscle, they draw the capsule slightly after them and give in section a wavy outline and the appearance of minute papillæ on the surface, referred to above. The difference in transparency is readily accounted for by the difference between connective tissue and large numbers of vesicular spaces filled with blood.

I regret that the short time at my disposal for the preparation of this paper has prevented my preparing sections from a large number of specimens so as to examine the steps in the change. Fig. 4, *st.*, shows a trace of the beginning in the pulp. The difference was also noticeable in making preparations of the vessels, for while in the one case the substance of the gland was readily removed by a camel's hair brush, in the other it was tough and difficult to clear away.

The most marked difference between the spleen of *Amiurus* and the same organ in higher *Vertebrata* is the absence of any structure corresponding to the *trabeculæ*.

### THE THYROID GLAND.

In *Amiurus* this organ occupies the exact position described for it by Stannius[1] in the Ganoids and many Teleosts, viz., beneath the copulæ of the branchial arches and surrounding the anterior end of the branchial artery. It is an impair structure extending in the median line from the origin of the vessels to the first pair of gill arches to a short distance behind the origin of the single stem for the third and fourth pairs of arches. Although richly supplied with blood it appears of a whitish colour contrasted with the blood vessels.

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[1] *Loc. cit.*, page 255.

among which it lies. The frame work of the organ consists of loose connective tissue which does not form a limiting membrane, but simply passes over into the like tissue sheathing the adjacent parts and the vessels which it surrounds. (Pl. VIII., Fig. 8.) The usual vesicles of the thyroid are scattered throughout this connective tissue, showing a tendency to arrange themselves in short rows. They vary in size from 15 $\mu$ to 210 $\mu$ in diameter, and are filled with the usual colloid substance. A few, however, contain a granular substance with nuclei, showing nucleoli scattered through it, while others are part filled with the granular and part with the colloid matter. In the preparation from which Fig. 8 was drawn the colloid matter did not completely fill the vesicles which was probably due to the action of the reagents.

The wall of the vesicle consists of a single layer of columnar epithelium resting on a basement membrane formed from the surrounding connective tissue. The epithelium is readily made out in the young fish, but in the gland from which the section is figured it had almost entirely disappeared. A few brown pigment granules were observed.

In the youngest specimens (15 mm. long) of which I have sections the gland is very small, and the connective tissue is unattached to any of the neighbouring structures. The vesicles are confined to a few spots and form only a single row.

### THE THYMUS GLAND.

Considerable interest has centred in the question of the existence of a thymus gland in fishes. Following Stannius' description of its position in the haddock,[1] careful search was made for the gland by dissections on adult fishes but without success. It was afterwards observed and figured by Prof. Wright in sections through the head of a young fish (Pl. IV., Figs. 12 and 13, *Th.*), where it is quite a conspicuous object. This spot was again examined in the adult, and a slight thickening discovered upon the inner surface of the lining membrane of the gill-chamber, in most cases presenting the appearance of fat-tissue. As, however, it is impossible to define the gland by dissection on the adult, a description will be given from transverse sections of a young fish.

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[1] Müller's Archiv, 1850, p. 504.

The gland lies between the epithelium and connective tissue of the lining membrane of the gill-chamber in its posterior dorsal portion. The bulk of the organ lies above the dorso-median angle of the chamber extending upwards as a lobe between the *trapezius* and *lev. branchiales* muscles, and attaining a thickness of 700 $\mu$, or eighteen times that of the epithelium, and one-tenth of the vertical median diameter of this part of the head. From this thickening the gland thins out laterally and medially terminating on a line with the floor of the brain-case. Its anterior margin is on a line with the third branchial arch, and it terminates behind, slightly in front of the transverse process of the supraclavicle. The cavity in the gland, shown in the figures, is a mere split in the tissue and without a limiting membrane.

The substance of the gland consist of connective tissue fibres mostly parallel to the epithelium and small round nucleated cells not larger than 4 $\mu$. They are readily distinguished from the epithelial cells with which they are in contact by their smaller size and the deeper stain imparted to them by various reagents. There are no blood spaces and the tissue is homogeneous throughout, except that it is looser toward the centre of the gland where the split occurs.

The gland was secured in the adult by removing the entire membrane and examined by cutting sections. The greatest thickness observed in four specimens was exactly that given above for the young fish, and it may be safely stated that in the full grown fish it is absolutely smaller. The connective tissue covering it above contains fat cells, and at places exceeds the gland in thickness. It sends processes through to the epithelium at right angles to its surface. This reticulate connective tissue appears to gradually increase while the cellular elements decrease, and in places undergo fatty degeneration.

The thymus gland in *Amiurus* is, therefore, an embryonic structure, while the thyroid developes and is functional in the adult animal. The former is, no doubt, developed as a diverticulum from the epithelium of the branchial cavity as the latter is from the mouth.

It is interesting to find a member of such an old family as the Siluroids possessing all those structures (pseudobranchia thyroid thymus and head-kidney) which are not, according to our present knowledge, constant in their occurrence in fishes, and have been frequently confounded. The condition of the pseudobranchia and thymus in the adult would suggest the probability that an examination of the embryonic and young stages of those fishes in which they have not been found would show rudiments to be present.

### THE SUPRARENAL BODIES.

In view of the relationship of these bodies to the sympathetic nervous system as established by the studies of Leydig, Semper and Balfour on their development, an apology is due for placing them in relation to what are considered blood-glands. The sympathetic system, however, has not been examined, nor yet the relation of these bodies to it; and further, many persons still hold that their function is to effect some change upon the blood. This point will be noticed further on.

The suprarenal bodies occupy in *Amiurus catus* a position similar to that which Hyrtl[1] found obtaining in other Siluroids. They are represented by a single pair lying one on each side of the kidney imbedded in its lateral surface, where they are readily distinguishable as small white spots in the dark red gland. Sometimes, however, the kidney substance having pressed in between them and the body-wall they are entirely concealed. No definite position can be assigned to these bodies with reference to the surface of the kidney, but they always lie near a pair of renal arteries which vary their course upon the middle third of the lateral wall. One series of sections showed the suprarenal body lying in a fork of the artery, with its capsule so intimately joined to the wall of the latter that their limits could not be defined. A branch from this artery supplies the organ with blood.

It is not uncommon to find instead of a single body two or even three bodies on one or both sides. I regard these as divisions of the simple one, because they are always smaller and are related to branches of the same artery. Further, when a suprarenal body has been macerated in Müller's fluid it shows a tendency to divide into two or three parts. These division lines were seen in section as processes of connective tissue from the capsule. It would appear, however, from the observations of Stannius that these structures may vary greatly in number in individuals of the same species, and arise in an

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[1] Das uropoetische System der Knochenfische. Sitz. Wiener Akad. 1851.

independent manner. The form varies from round to oval, and the size ranges from 1 mm. to nearly 3 mm. through the long diameter.

The suprarenal bodies are separated from the substance of the kidney in which they lie not only by their own capsule but also by that of the kidney, the two being however united as one throughout almost the whole extent of surface lying in contact. This double wall does not measure more than 10·8 $\mu$ at the thickest part. As mentioned above, it sends in at various points processes in which the stems of the blood-vessels run.

The interior of the organ is made up of lobules or alveoli, each one being enclosed in a delicate but distinct fibrous capsule joined to those adjacent so as only to appear distinct in certain angles. This partition wall does not average more than 1·5 $\mu$ in thickness. The lobules are more or less oblong in form, from 26·4 to 66·2 $\mu$ thick and 200 $\mu$ as greatest length. The diameter varies in the same lobule, and they are frequently bent upon themselves at one end. No part of the body is marked off from the rest either by the form, size, or arrangement of the lobules. If these correspond to the divisions of the cortex in the suprarenal of higher vertebrates the medullary portion is entirely absent.

The contents of the alveoli are granular nucleated cells of varying form and size (Pl. VIII. Fig. 11), the longest being nearly 40 $\mu$ and frequently reaching from wall to wall. After studying a number of sections, I am forced to the conclusion that the large and the small cells have no fixed relations.

Some alveoli appear to be composed entirely of long cells arranged parallel to one another, with spaces between their outer pointed ends; others show an almost homogeneous granular matrix containing nuclei, the limits of whose cells can rarely be defined. A combination of these is the commonest arrangement, where the long cells being arranged as before with the axis at right angles to the long axis of the alveolus, the smaller cells are fitted in between. A comparatively regular row of nuclei around the margin gives in many instances the appearance of a lumen and epithelial lining, especially in teased preparations, but in section the true structure is easily discerned.

In the alveoli of the lateral portion of the body, where the cell limits were least defined, a number of small round, oval or triangular cells were distributed, principally upon the margin. (Pl. VIII. Fig.

11, *B*). They stain deeply and evenly throughout like the nuclei of the blood cells or the nucleoli of the ordinary suprarenal cells, but are larger and more irregular in form. They are most probably small ganglion cells.

The blood-vessels of the bodies are small and the capillaries do not seem to be abundant, which explains their pale color. The blood supply seems no more than sufficient for the nourishment of functionally active organs of their size.* Mr. Weldon[1] lately suggested that these bodies are probably related to the kidney and perform some function in connection with the elaboration of the blood. My observations upon *Amiurus*, although imperfect, are opposed to such conclusions. The smallness of the blood supply, the absence of ducts and of all stored up remains of its action, such as the brown pigment of the kidney, head-kidney and spleen, or the colloid matter of the thyroid, and also its structure, mark it off from the other blood-glands. He further remarks: "In *Teleostei* suprarenals are at all events frequently absent; or, as I would rather suggest, they are represented by the greatly metamorphosed head-kidney described by Balfour. In other cases where suprarenals have been detected, they have always been attached to the surface of the kidney." In regard to the first point, we have in the cat-fish a well developed head-kidney in which the metamorphosis can be traced and which preserves its relation to the renal-portal system, and presents the characteristics of a blood-gland. The position upon the surface of the kidney is no doubt due to the development of the latter causing it to press upon the body and carry it outward upon its surface. It is certainly neither connected with the kidney nor yet with its blood-vascular system in the adult, whatever may be its developmental relationships.

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Certain other gland-like structures are attached to the walls of the veins in the body cavity. They were observed in sections of the head-kidney surrounding the cardinal vein, but are specially abundant on the portal vein between the spleen and the liver. They are small white bodies varying in size and form, sometimes appearing small and rounded upon the side of the vessel, sometimes forming a

* NOTE.—In teased preparations the blood cells bear a very small proportion to the other cells.

[1] Quart. Jour. Mic. Sc., N. S., Vol. XXIV., p. 176.

complete ring around it. The largest and most constant of these bodies lies on the right side between the gall-bladder and spleen and close to the mesenteric artery. It does not surround any large vessel, but like the rest of these bodies is well supplied with blood.

Where these bodies were cut in sections through the head-kidney and spleen they closely resembled the suprarenal bodies in their histological structure, but in sections through others the difference was quite marked. The most important feature was the presence of spaces surrounded by a connective tissue wall, and having either a process or a central mass of the ordinary tissue connected by small processes with the surrounding wall. The blood-vessels pass to the centre through these. The interspaces seem to be occupied by a loose unattached tissue.

It seems probable from the relationship of these structures to the surface of the veins that they belong to the lymphatic system, and as I am unable at present to investigate this part of the vascular system of *Amiurus*, I shall say nothing further in regard to them.

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## THE URO-GENITAL SYSTEM.

### THE KIDNEY.

The kidney has been carefully described in a number of Siluroids by Hyrtl[1]. Although this organ in *Amiurus* agrees closely with these—especially with that of *Silurus glanis*—it will not be out of place to give a somewhat detailed account of it in this paper.

It is divided into an anterior lymphatic portion, the 'head-kidney' and a posterior portion, the functional or true kidney. These two divisions are separated by the entire length of the air-bladder, around the anterior and posterior ends of which they mould themselves. These three organs fill the entire dorsal portion of the body cavity from the aponeurotic membrane of the pectoral girdle to its posterior extremity, and present a smooth level ventral surface covered by peritoneum.

The *head-kidney* (*pronephros*), is a paired organ, the two halves of which are joined by a bridge of gland substance crossing beneath the first, second and third vertebræ. The bulk of the gland lies above this bridge, filling the space between the transverse process of the

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[1] Sitz. Weiner Akd. 1851.

supraclavicle and the transverse process of the fourth vertebra. From this thick rounded dorsal portion it gradually thins out ventrally and curves backward upon the surface of the air-bladder, thus becoming convex upon the anterior, and concave upon the posterior surface. The aponeurotic membrane, which covers it anteriorly, forms a strong capsule for it by sending its shining fibres into the peritoneum, which stretches backwards along the œsophagus so as to cover it ventrally, and passing over its dorsal surface, is attached to the transverse process of the fourth vertebra, and then continued downwards between the air-bladder and the gland. The lateral lobes of the liver insert themselves between the membrane covering the head-kidney and the body wall. It is also covered by a delicate connective tissue membrane of its own, well supplied with blood-vessels.

The artery to the head-kidney referred to above enters the connecting portion and divides into two branches, one to each half of the gland. Judging from their size they cannot do more than supply nourishment to the gland substance, while the vein from the body wall which enters at the outer dorsal angle furnishes the blood to be acted upon. The veins which drain the blood into the posterior cardinals appear out of all proportion in number and size to the afferent vessels. More than twenty openings of these vessels, many of them quite large, can be counted on the inner surface of the right cardinal.

The frame work of the gland consists of a finely reticulate connective tissue. The interspaces are in places filled with the lymphoid cells of the glandular pulp, and at others serve as blood spaces. The areas occupied by the lymphoid tissue and the blood spaces are about equal. (Pl. VIII., Fig. 9.) Brown pigment patches, exactly similar to those seen, but in greater abundance in the spleen and kidney, are irregularly scattered through its substance, and increase with the age of the gland.

The change from the kidney to the lymphoid structure[1] was not completed in the youngest specimens of which sections were cut, for a few epithelial lined tubules remained in the neighbourhood of the cardinal veins. A section through the head-kidney, near its anterior surface, showing these has been drawn by Prof. Wright. (Pl. IV., Fig. 14, *hk.*) The figure is reversed and the large right cardinal vein appears on the left, near the centre of the lobe, surrounded by the tubuli.

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[1] *Balfour*—Quat. Jour. Mic. Sc., N.S., Vol. XXII., Jan., 1882.

No portion of the kidney in *Amiurus* lies above the air-bladder. The only connection between the head-kidney and the posterior part is the cardinal veins. Ignorance of the change of function in the former, no doubt, led Hyrtl[1] to state that the ureters also served to connect them, but the fact is that all trace of the ureters beyond the posterior part has disappeared before the metamorphosis of the gland itself is completed.

The functional kidney (*mesonephros*) is a single gland measuring in large specimens of *A. catus* 25 mm. across the ventral surface behind the air-bladder; 35 mm. from its apex to the surface of the air-bladder; 25 mm. to the posterior point of the air-bladder in the median line. A dorso- and a ventro-lateral horn fills up the space between the rounded posterior end of the air-bladder and the body-wall. The length along the ventro-lateral edge from the apex of the gland to the point of the horn is 45 mm.

The only indication of the paired character of the gland is to be found in its ducts and blood-vessels. There is a pair of ureters which by their numerous branches drain the right and left half of the kidney respectively, and unite as they leave its posterior point just at the urinary bladder. In most cases they appear to unite sooner, even as far forward as the middle of the gland, but in all specimens examined, the adjacent walls were found to persist as a partition as far as the bladder.

The urinary bladder is apparently a mere diverticulum of the ventral wall of the urinary canal. As it always lies upon the right side of the genital organs and rectum, it must represent the right horn of the bladder, but there is no rudiment of a left horn present as found by Hyrtl in *Silurus glanis*. Its length is about double its width, but the actual size varies in different individuals. It opens into the wide urethra, which is about 12 mm. in length, and opens on a papilla behind the anus.

The large vessels and ducts of the kidney, to which reference has already been made, occupy the following relative positions: The caudal vein passes downwards between the ureters, and then gives off its branches which lie near the ventral surface. Above these are the paired ureters, and still more dorsal the impair median vein to the right posterior cardinal. The histological structure of the gland

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[1] *Loc. cit.*

does not appear to present any peculiarities. and nothing further need be said regarding it.

### THE GENITAL ORGANS.

I have not studied any details in connection with these organs, and will merely note a few of their general features. They are paired glands, 65 mm. long, lying along the ventral surface of the kidney and posterior part of the air-bladder, and attached by a median continuation of the peritoneum which surrounds them, to the mesentery close to its junction to the peritoneum covering the kidney and air-bladder.

The ovaries of the female are cylindrical in form, bluntly pointed at both ends. The ova-duct is a large passage in the centre around which the ova are developed from the entire wall, but more abundantly along the median side. The ova, seen through the thin transparent membrane of the organ, give it a bright yellow color.

The testes are greyish-white in color, flattened in form, with a straight median edge along which the vas deferens lies, while the lateral edge is broken into a great many small lobes.

The genital ducts join to form a common median duct. In the female this opens on a papilla between the urinary opening and the vent, but in the male it joins the urethra and opens with it on a common uro-genital papilla.

These papillæ, upon which the openings of intestine and the urinary and genital-ducts are situated, arise in a longitudinal median depression, 15 mm. in length and very shallow. The papillæ and the surrounding depression are remarkable for the richness of their blood supply.

The above arrangement of the uro-genital ducts is exactly similar to that described by Wiedersheim as most common among the *Teleostei.*

The blood supply to these organs has already been referred to. The trunk stems run in the median line, giving off, at intervals, lateral branches, which run parallel to one another across the attaching peritoneum to the glands. The vessels divide into a dorsal and ventral stem which supplies or drains respectively these halves of the organs.

## PLATE VIII.

Figs. 2, 3, 5, 6, 9, 11, 12, Hartnack *Ob.* 8, *Oc.* 2, *cam. luc.* Figs. 4, 8, *Ob.* 4. Fig. 10, *Ob.* 2.

FIG. 1.—I., II., III., IV., 1st, 2nd, 3rd and 4th branchial veins; *c. ex.*, external carotid; *c. in.*, internal carotid; *ps.*, pseudobranchia; *n.*, branch of internal carotid to the nasal cavity; *br. c.*, cut edge of the floor of brain case removed to show (*ant.*, *med.*, *post.*) anterior, median and posterior arteries to brain; *sc.*, artery to pharynx, &c.; *ao. des.*, aorta descendens; *h. k.*, artery to head-kidney; *c. m.*, cœliaco-mesenteric.

FIG. 2.—Pseudobranchia—*a.*, part of wall of internal carotid; *b.*, openings into the surrounding tissue; *c.*, artery.

FIG. 3.—From the same section—*a.*, arteries; *b.*, spaces from which they arise; *c.*, blood-cells in interfibrillar spaces.

FIG. 4.—From a section of spleen of young fish—*c.*, capsule; *m. c.*, Malpighian corpuscle, with *m. a.* its artery; *pg.*, pigment granules; *p.*, pulp.

FIG. 5.—Same as the last—*a.*, artery; *x.*, spaces between artery and tissue of Malpighian corpuscle, *m.*; *p.*, pulp; *v. s.*, venous sinuses of pulp; *g.*, pigment granules.

FIG. 6.—Malp. corp. from spleen of old fish—*a.*, arteries; *i.*, interconnective tissue of M. corpuscles, with blood-cells in its interspaces.

FIG. 7.—Cells of spleen from Müller's fluid prep.—*a.*, adenoid connective tive tissue cells; *b.*, pigment cells with granules; *c.*, blood-cells; *d.*, lymphoid cells of Malp. corpuscles.

FIG. 8.—From section of thyroid gland—*tr.* is placed in lumen of truncus arteriosus, cut at the origin of the stem of the 3rd and 4th pairs of branchial arteries; *v.*, veins; *vc.*, vesicle with granular contents; *vc'.*, vesicle filled with colloid matter; *p.*, pigment.

FIG. 9.—From section of head-kidney to show the pulp tissue and the venous sinuses.

FIG. 10.—Section of *s. r.*, suprarenal body imbedded in the substance of the kidney, *k.*

FIG. 11.—Lobules of suprarenal body—*A.* to show the common form and arrangement of the nucleated granular cells; *B.* lobules with indistinct cellular outlines, but distinct nuclei, and deeply stained structures (figured black) usually pointed triangular, supposed to be ganglion cells.

FIG. 12.—Cells of lobule, Müller's fluid prep.


m
pe
cl
s
p
pc
1
cl
pap
p
pc
fc
ac
2
pap
3
pc
4
5
6
7
sc
ot
8
ap. post
12
ap. ant
CB
TA
LV
N VII
N VIII
Vag X
16
Olf. Tr
N II
CH
N V+VII
N. VIII ant
N. VIII post
N. IX
N. X
14
R lat V
R ot
R op s.
R op. p
N IV
R c
N III
R. max-mand. + Fac
N VI
N sp I
R op p
R os
R ot
CB
R. lat V.
SL
IM
N. VI
Fac
TA
LV
N VIII.
15
9
10
n: ant
n post
11
CH
LO
CB.
LT
TA
LV
13
R c
R lat
R os
R op
IM
17

R.R.W. Del

# EXPLANATION OF THE PLATES.

## PLATE I.

FIG. 1.—Vertical section of the skin of *Amiurus* from the lateral region of the trunk.

Zeiss D, Oc. II., cam. luc.

*pc.* pigmentary layer of corium.

*p.* palisade cells of epidermis.

*s.* spindle-shaped intermediate cells.

*cl.* clavate cells.

*p.e.* interepithelial pigment cells.

*m.* mucous cells.

FIG. 2.—Vertical section from skin of dorsal surface of head. Zeiss A, Oc. II., cam. luc. *fc.* fibrous ; *ac.* adipose layer of corium ; *pap.* papillæ ; *cl.* points to a clavate cell projecting beyond the level of the epidermis.

FIG. 3.—Vertical section of abnormally thickened skin as described in text. *pap.* points to one of the branched papillæ.

FIGS. 4, 5, 6.—Dorsal, ventral and lateral aspects of cephalic end of young *Amiurus* to show the openings of the mucous canals.

FIG. 7.—Vertical section of supraorbital mucous canal of young *Amiurus* (25 mm.) Zeiss H. I. $\frac{1}{8}$th, Oc. II., v. Text.

FIG. 8.—Horizontal section through a macula acustica neglecta from a fish of similar size under same enlargement. *ot.* otolith ; *sc.* spindle-celled cartilage ; *v.* vessel.

FIG. 9.—Auditory labyrinth from medial aspect. *a.s. a.h. ag.* ampullæ of the sagittal, horizontal, and frontal semicircular canals ; *lap. as. sag.* lapillus, asteriscus and sagitta in the recessus utriculi, lagena cochleae, and sacculus respectively.

FIG. 10.—The same from lateral aspect—osmic preparation—showing the branches of the Rr. anterior and posterior of the auditory nerves.

1. Ramus ampullæ sagittalis.
2. R. amp. horizontalis.
3. R. recessus utriculi.
4. R. neglectus.
5. R. amp. frontalis.
6. R. lagenæ.
7. R. sacculi.

FIG. 11.—Partes inferiores of both sides, with the amp. front. from above to show the relation of the R. sacculi to the duct. endolymph (*d.e.*) and sinus impar. (*s*).

FIG. 12.—Right nasal sac, natural size, opened from above. *ap. ant.* and *post.* anterior and post narial apertures.

PLATE I.—(*Continued*).

FIG. 13.—Dorsal aspect of adult brain.

FIG. 14.—Ventral aspect of adult brain.

*CH.*—Cerebral hemispheres.

*LO.*—Optic lobes.

*CB.*—Cerebellum

*TA.*—Tuberculum acusticum.

*LT.*—Lobus trigemini.

*LV.*—Lobus vagi.

*LI.*—Lobus inferior.

1, 2, 3, &c., indicate the planes of the sections of the brain numbered 1, 2, 3, &c.. on Plate V.

*Olf. Tr.*—Olfactory tract.

*N. II.. III., IV., &c.*—Optic, third, fourth nerves, &c.

*N. VIII. ant.* and *post.*—R. ant. and post. of auditory nerves.

*N. sp. I.*—1st spinal nerve.

*R. lat. V.*—Ramus lateralis trigemini.

*R. ot.*—Ramus oticus.

*R. op. s.*—Ramus ophthalmicus superficialis.

*R. op. p.*—Ramus ophthalmicus profundus.

*R. c.*—Ramus ciliaris.

*R. max-mand.* and *fac.*—R. maxillo-mandibularis and facial.

FIG. 15.—Lateral aspect of brain to show origin of nerves. Additional lettering:

*R. b.*—Ramus buccalis.

*SL.*—Supero-lateral strand of trigeminal complex.

*IM.*—Infero-medial strand of trigeminal complex.

*G. IX.. G. X.*—Ganglia of the glossopharyngeus and vagus respectively.

FIG. 16.—Lateral aspect after removal of the Gasserian ganglion to show points of emergence of the roots of the fifth.

*Vag. I.*—Anterior root of the vagus group.

FIG. 17.—Medial aspect of the Gasserian ganglion with its branches *in situ*.

$\delta$—Smaller dorsal branches of the trigeminal complex.

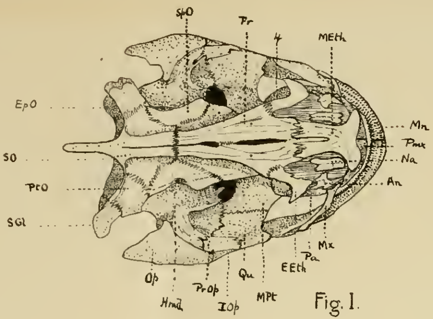
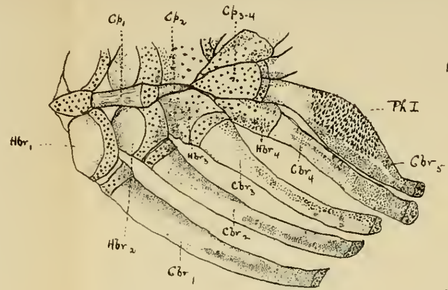


Fig. 1.



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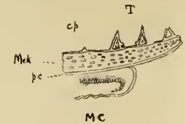

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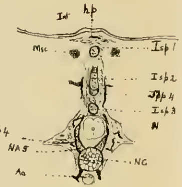

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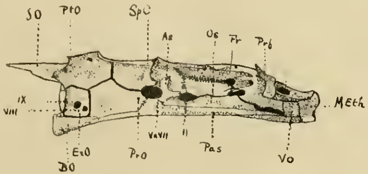

Fig. 2.

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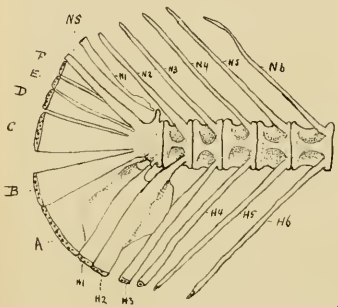

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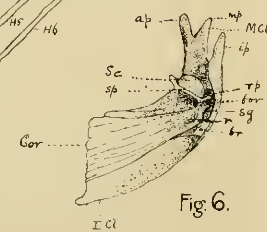

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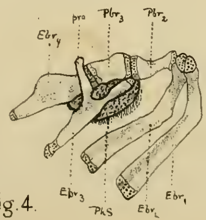

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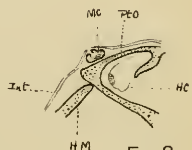

Fig. 8.

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## PLATE II.

FIG 1.—Surface view of skull of *Amiurus catus*. *An*=adnasal, *Eeth*=ectethmoid, *EpO*=epiotic, *Fr* = frontal, *Hmd* = hyomandibular, *IOp*=interoperculum, *MEth* = mesethmoid, *Mn*=mandible, *MPt*=metapterygoid, *Mx*=maxilla, *Na*=nasal, *Op* = operculum, *Pa* = palatine, *Pmx*—premaxilla, *PrOp*=preoperculum, *PtO*=pterotic, *Qu*=quadrate, *Scl*=supraclavicle, *SO*=supraoccipital, *SpO*=sphenotic, *H*=membrane bone in fascia of add. arc. pal.

FIG. 2.—Cranium of *Amiurus catus* seen from the side and slightly from below. In addition to certain letters used in Fig. 1, there are the following :—*As*=alisphenoid, *BO*=basioccipital, *ExO* = exoccipital, *PaS*=parasphenoid, *Prf*=ectethmoid, *PrO* = proötic, *VO*=vomer, *VIII.*=foramen for glossopharyngeal, IX.=foramen for vagus.

FIG. 3.—Lower half of left branchial arches of *Amiurus nigricans*. $Cbr_{1-5}$=ceratobranchials 1–5, $Cp_{1-4}$=copulæ 1–4, $Hbr_{1-4}$=hypobranchials 1–4, *PhI*=pharyngeum inferius.

FIG. 4.—Upper half of right branchial arches of *Amiurus nigricans* from above. $Ebr_{1-4}$=epibranchials 1–4, $Pbr_{2-3}$=pharyngobranchials 2 and 3, *pro*=process of epibranchial 3, *PhS*=pharyngeum superius.

FIG. 5.—Posterior vertebræ and arches of *A. nigricans*. $N_{1-6}$=neural arches and spines, $H_{1-6}$=hæmal arches and spines, *A* and *B*=two lower hæmal arches without centra, *C*. *D*, *E* and *F*=four upper hæmal arches without centra, *NS*=osseous sheath of notochordal filament.

FIG. 6.—Pectoral arch of *A. catus*. *MCl*=mesoclavicular portion ; *Icl*=infraclavicular portion; *Cor*=coracoid ; *Sc*=scapular portion ; *ap*, *mp*, *ip*=anterior, median and inferior process of mesoclavicle ; *up*=rod-like process of coracoid ; *for*=foramen between coracoid and scapula ; *sg*=semicircular groove on mesoclavicle for first ray ; *r*=ridge in coracoid ; *br*=bridge-like process on coracoid which articulates with infraclavicle ; *sp*=bridge-like spiculum.

FIG. 7.—Anterior ray of pectoral fin of *A. catus*. *Sr*=semicircular ridge, ; *tps* and *tpi*=superior and inferior terminal processes.

FIG. 8.—Transverse section through the pterotic region of a very young *A. catus*. *POt*=pterotic cartilage ; *Int*=integument ; *Hc*=horizontal semicircular canal ; *HM* = hyomandibular cartilage ; *MC*=mucous canal with a ring of bone around it.

FIG. 9,—Longitudinal section through the anterior portion of the mandible of a very young *A. catus*. *Mck* = Meckel's cartilage ; *T*=teeth ; *cp*=cement plates ; *Pc*=perichondral bone ; *MC*=mucous canal with ensheathing bone.

FIG. 10.—Transverse section througn a very young *A. catus*, immediately in front of the dorsal fin. The lateral musculature has been omitted. *Int*=integment ; *hp*=anterior portion of horizontal plates of dorsal fin (1st ray) ; $Isp_{1-3}$=interspinalia 1, 2 and 3 ; $Spp_4$=spinous process of fourth vertebra ; $Tp_4$=expanded transverse process of fourth vertebra ; *NA5* = neural arch of fifth vertebra ; *NC*=notochord ; *N* = nervous cord ; *Ao* = aorta ; *Msc*=muscle.

## PLATE III.

FIG. 1.—Head of *Amiurus Catus*, after removal of the integument and superficial fascia. *Pmx* = premaxillæ ; *Na* = nasal ; *AnA* = adnasal ; *Eth*=Mesethmoid ; *Prf*=Ectethmoid ; *Fr*=Frontal ; *SO*=Supraoccipital ; *Pal*=Palatine ; *Mx*=Maxilla ; *Mn*=Mandible ; *Qu*= Quadrate ; *Op* = Operculum ; *Brst*=Branchiostegal rays ; *E*=Eye ; *S. Ob*=Superior oblique ; *E. R.* & *S. R.*=External and Superior Recti.

*AM*=Adductor mand. ; *AT*=Add. tentaculi ; *LAP*=Lev. arcûs pal. ; *LOp*=Lev. operc.

FIG. 2.—Same as preceding, but with add. mand. removed. In addition to certain letters in preceding figure the following occur : *EcPt*=No. 4 ; *MPt* and *EnPt*=portions of the Metapterygoid ; *Pf*=Sphenotic; *PtO*=Pterotic.

*AdT*=Add. tentaculi ; *Dil. Op.*=Dilat. operculi.

FIG. 3.—Under surface of head of *A. Catus*. *GH*=Geniohyoideus ; $Hh^1$ = upper yortion of Hyohyoideus ; $Hh^2$ = lower portion of Hyohyoideus ; *Im* = Intermandibularis ; *ti* and $ti^1$ = tendinous bands to extremities of which tentacles are attached.

FIG. 4.—Under surface of branchial arches of *A. Catus*, the hyoid being removed. *UHy*=Urohyal ; *HyH*=Hypohyal ; I., II., III., IV., V.=Branchial arches.

*HyP*=Cut ends of the Hyopectoralis ; *HBr*=main portion of Hyobranchialis ; $HBr^1$ = slip of same to Ceratobr. iii. ; $HBr^2$ = slip to Ceratobr, iv. ; $HBr^3$ = slip between Ceratobrs. iii, and iv. ; $HBr^4$ = slip between Ceratobrs. iv. and v. ; $TV^1$ and $TV^2$ = anterior and posterior Transv. vent. ; *PhEx*=Pharyngo-clav. externus ; *PhIn*—Pharyngo-clav. internus ; $ObV^1$ = and $ObV^2$ = first and second Obliqui Ventrales.

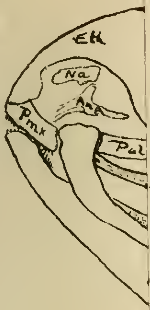
FIG. 5.—Transverse section (partly diagrammatic) through the pectoral arch, slightly ventral to the articulation of the fin. (This and the succeeding figure are in reversed position, ths clavicle should be below.) *Cl*=Clavicle ; *Cor*=Coracoid : the letters point to the bridge articulating with the Clavicle ; *sp*=Spiculum on Coracoid forming a bridge over Add. prof. ; $AbP^1$ = first portion of Abd. prof. ; $AbP^2$ = second portion of same ; $AbS^1$ = first portion of Abd. Sup. ; $AbS^2$ = second portion of same ; *AdP*=Add. prof.

FIG. 6.—Transverse section of pectoral arch some distance nearer the median line than fig. 5. Letters same as in preceding figures.

FIG. 7.—Ventral musculature of ventral fin. $VM^1$ and $VM^2$ = median and external portions of ventral musculature of the trunk ; *VA*=aponeurosis of ventral musculature of trunk ; *AdS*=adductor superfic. pelvis ; *C*=cartilaginous horseshoe of pelvic arch ; *VF*= ventral fin.

FIG. 8.—Superficial and intrinsic muscles of the caudal fin. *Cd*=dorsal continuation of caudal fin ; *It*=intrinsic muscles ; $My^1$ and $My^2$ = upper and lower prolongations of myocomma ; *f* = fascia ; *LL*= lateral line.

FIG. 9.—Deep muscles of the caudal fin. *D*=dorsal portion ; $V^1$ and $V^2$ =upper and lower divisions of ventral portion ; *ct*=connective tissue.

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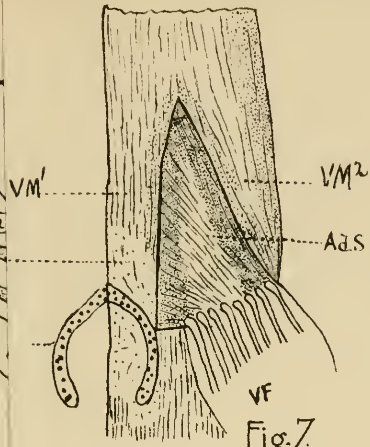


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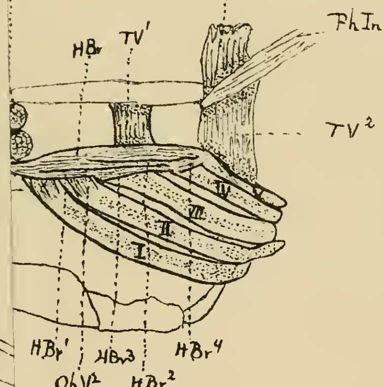


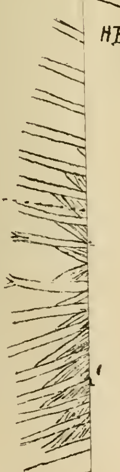


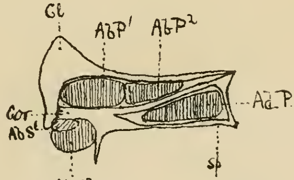


Fig. 5.



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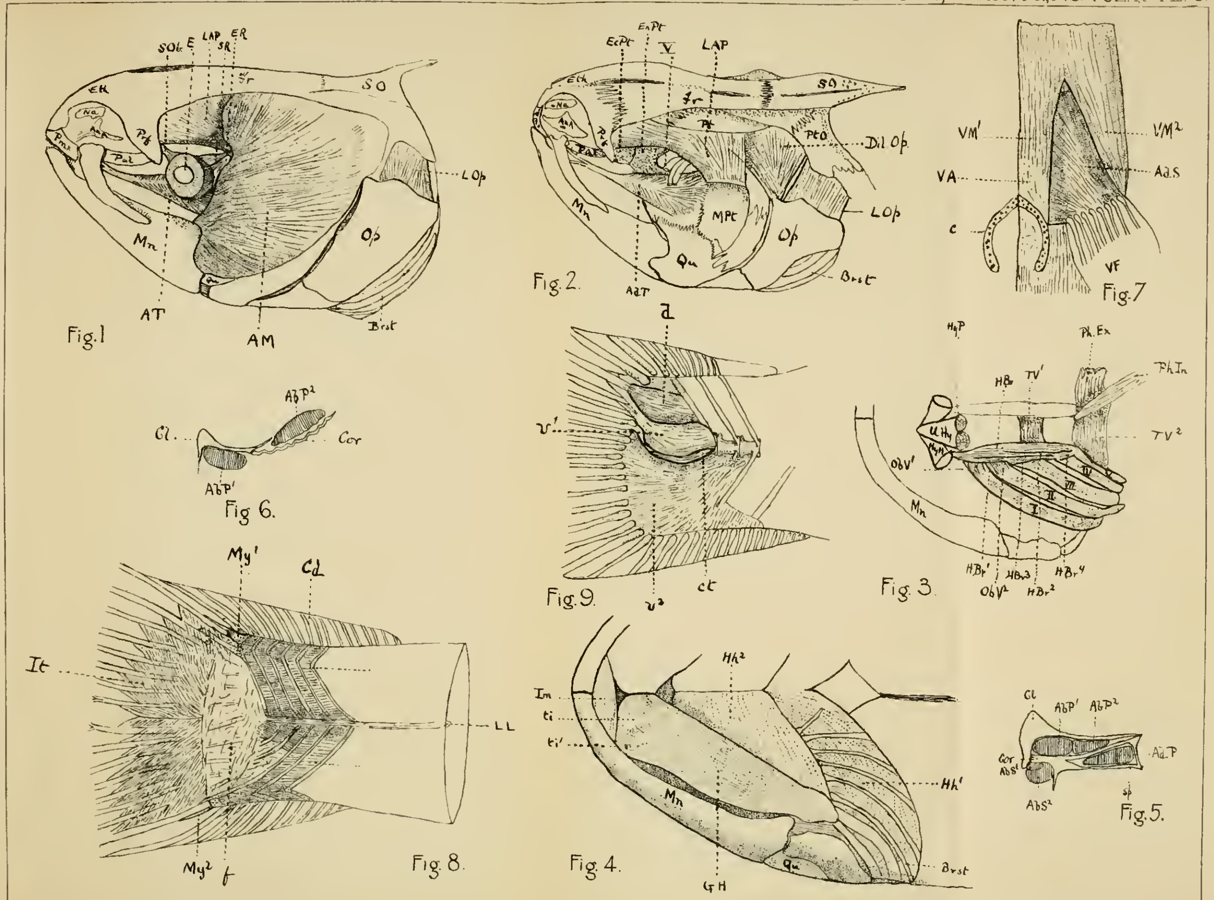




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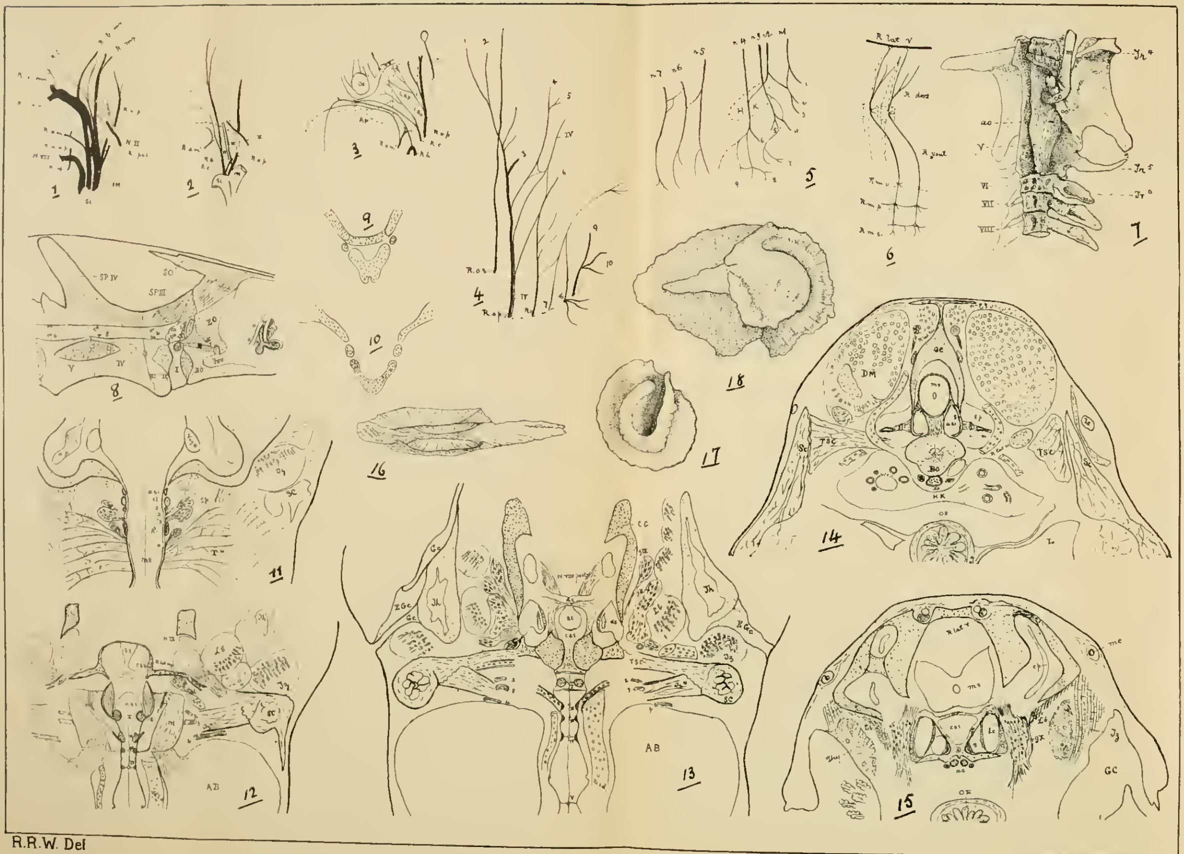


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## PLATE IV.

FIGS. 1, 2, 3, represent dissections of the fifth nerve of the right side from the roof of the mouth, of which 1 is the most superficial (ventral), and 3 the deepest (most dorsal). To expose the 3rd and 6th nerves and the ramus buccalis, as seen in Fig. 2, it is necessary to cut the supero-lateral and infero-medial strand, turning forwards the nerves to which they give origin. In Fig. 3 the 3rd and 6th nerves have been removed to show the cutaneous branches of the Rr. add. mand. and buccalis, as well as the branches of the R. ciliaris and opthal. profundus. The dotted lines in Fig. 3 indicate the boundaries of the adductor mandibulæ, *AM*; levator arcus palatini, *LAP*; and dilatator operculi, *DO*.

FIG. 4.—Dissection of same nerves represented in Fig. 6 from dorsal surfaces.
1. Branch of R. oph. prof. to middle line nose. 2. Along medial border nasal sac. 3. To nasal barblet. 4. Along outer border nasal sac. 5. To fat, &c., in front of eye under origin of lev. arc. pal. 6. Is the chief branch of R. ciliaris. 7. The cutaneous branch of R. buccalis. 8. Of R. add. mand., with which are connected the muscular branches for lev. arc. pal. and dil. op. 9. Branch for muscle of maxillary barblet. 10. For add. mandib.

FIG. 5.—Diagram of brachial plexus.

$N^1$, $N^2$, $N^3$, $N^4$, &c. 1st, 2nd, 3rd, 4th, spinal nerves, of which the first four enter into the formation of the brachial plexus. Description of branches in text.

FIG. 6.—Diagram of Rr. dorsales and ventrales of the spinal nerves. Two vertebræ are represented by dotted lines.

*Rmv.* Branches for ventral musculature.

*Rmp.* & *s.* Branches from plexus supplying the deep and superficial muscles of the anal fin. The infracarinales are supplied by branches similarly derived to those marked *R.m.s.*

FIG. 7.—The first 8 vertebræ from the latero-ventral aspect.

*ao* points to the aortic canal opposite the point of junction of the 4th and 5th vertebræ. *o.o.*, the oblique, *c.o.*, the crescentic ossifications referred to in the text. *Tr.*, the transverse processes or costiferous pedicles of the anterior vertebræ. V., VI., VII., &c. Bodies of the fifth, sixth and seventh vertebræ.

FIG. 8.—Longitudinal vertical section of adult near middle line.
I., II., III., &c. Centra of 1st, 2nd, 3rd, vertebræ. *E.O.*, exoccipital. *B.O.*, basioccipital. *S.O.*, supraoccipital spine. *Sp. III.* & *IV.* Neural spines of the 3rd and 4th vertebræ. 1, 2, 3, 4, &c. Points of emergence of the 1st, 2nd, 3rd, &c., pairs of spinal nerves. *Fov.*, in the fovea sacculi; directly above it is the opening into the cavum sinus imparis, on the osseous roof of which I stands. The black spot above *BO* indicates the apertura interna of the atrium sinus imparis. The membranous roof of the cavum being removed shows the stapes and claustrum in the position indicated in 8*a* to the right of the figure.

FIGS. 9, 10, 11, 12, 13, are horizontal sections through the cephalic end of a fish of 3-4 cm. in length, of which 9 is the most dorsal. 9 and 10 are merely intended to show the relations of the claustral cartilages to the cartilaginous cranium and roof of the spinal canal.

Fig. 11.—*Tz*, M. trapezius. *Sc.*, supraclavicle. *Tsc.*, transverse process of supraclavicle. $Tr^4$., transverse process of 4th vertebra. *Sp.*, saccus paravertebralis. *Asi.*, atrium sinus imparis.

PLATE IV.—(*Continued*).

*Cl.*, claustrum. *S.*, 'stapes.' 2, 3, 4, dorsal roots of 2nd, 3rd and 4th spinal nerves with their respective ganglia. 1 the position of the first spinal ganglion which does not appear in this section. $A^3$., the arch of the 3rd vertebra. *Ms.*, medulla spinalis. *Ap.*, Ampulla frontalis.

Fig. 12.—*Th.*, thymus. *Lb.*, most posterior of the levatores branchiarum. *R. lat. vag.*, points to the root of the vagus in connection with which is seen the portion of the ganglion trunci which gives off the ramus lateralis. *Si.*, sinus impar. or saccus endolymphaticus. *Csi.*, in the cavum sinus imparis pointing to the osseous lateral wall of the cavum. *i.*, the 'incus.' *m.*, the 'malleus.' *Asi.*, points to the atrium sinus imparis, as bounded by the spoon-shaped process of the 'stapes' *s.*, and lies on the thickened patch of dura mater which is seen in vertical section in Fig. 14. I., II., III., IV., stand on the middle points of the centra of the 1st, 2nd, 3rd and 4th vertebræ. *Ab.*, in the cavity of the air-bladder points to its union with the posterior end of the malleus. *Vcid.*, vena cava inferior dextra.

Fig. 13.—*Gc.*, the gill cavity and its opening on the left side. *EGc.*, epithelium of the roof of the gill cavity. *De.*, duct. endolymph. *As.*, asteriscus in the lag. cochleæ. *Csi.*, in the cavum sinus imparis points to the basi-occipital and the exoccipital cartilages resting on it. *G. IX. & X.*, ganglia of glossopharyngeus and vagus.

Figs. 14 and 15, are from vertical sections through fish of same age as the foregoing horizontal sections, of which 15 is the more anterior.

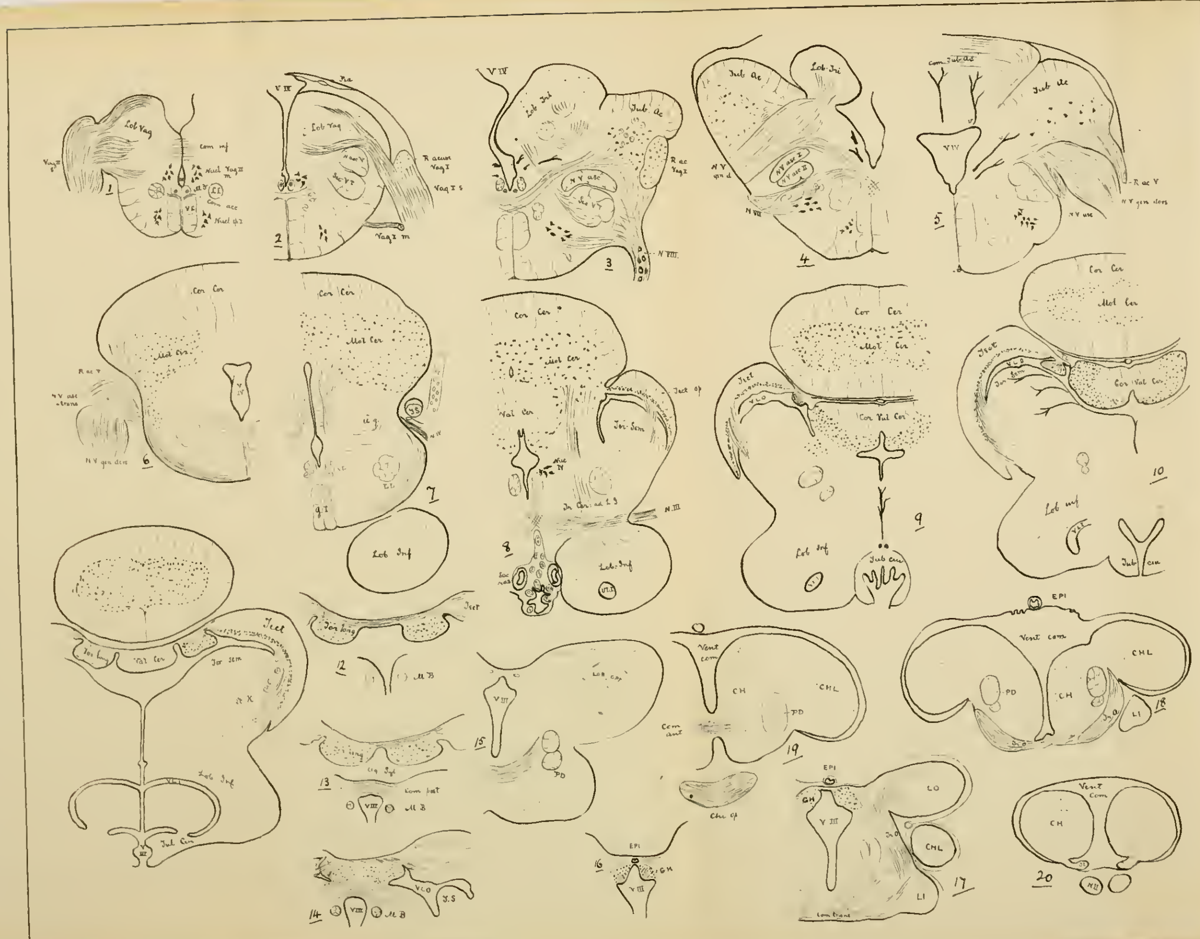
*Œ.*, œsophagus. *Mc.*, mucous canal in postfrontal. *R. lat. V.*, ram. lateralis trigemini. *Cp.*, canalis frontalis. *Lc.*, lagena cochleæ. *S.*, sacculus. *Ao.*, aortæ at sides of which are the sympathetic ganglia, The sections are slightly oblique, so that the right sides represent planes somewhat posterior to the left. The thymus is seen on the one in continuity with the epithelium of the gill cavity, on the other its posterior end is seen wedged in between the trapezius muscle and the levat. branch. post.

Additional letters in 14.

*Lc.*, lateral mucous canal in section. *Hk.*, head-kidney. *L.*, liver. *R. lat. va.*, ram. lat. vagi in section as it crosses the transverse portion of the supraclavicle. *Bo.*, Basioccipital. *Oc.*, occipital cart., above which is the supraoccipital spine. *D.M.*, dorsal musculature attached to the posterior surface of the skull on either side of the foramen magnum.

For additional lettering, see foregoing figures.

Figs. 16, 17, 18.—The otoliths, sagitta, asteriscus and lapillus, × 6.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## PLATE V.

Represents 20 frontal sections through brain of adult *Amiurus*, the planes of which are indicated in Figs. 13 and 14, Plate I. The anterior sections are slightly oblique.

*Aq. S.*—Aqueduct of Sylvius.
*C. H.*—Cerebral hemisphere.
*C. H. L.*—Lateral lobe of hemisphere.
*Com. acc.*—Commissura accessoria of Mauthner.
*Com. ant.*—Commissura anterior.
*Com. cer. inf.*—Commissura cerebri infima of Haller.
*Com. post.*—Commissura posterior.
*Com. trans.*—Commissura transversa Halleri.
*Cor. Cer.*—Cortex of Cerebellum.
*Cor. Val. Cer.*—Cortex of valvula cerebelli.
*Epi.*—Epiphysis.
*G. H.*—Ganglion Habenulæ.
*G. I.*—Ganglion interpedunculare of Gudden.
*Lob. Tri.*—Trigeminal lobes.
*Lob. Vag.*—Vagus lobes.
*L. I.*—Lobus inferior.
*L. L.*—Lateral longitudinal fasciculi.
*L. O.*—Lobus opticus.
*M. B.*—Bundles of Meynert.
*M. F.*—Fibres of Mauthner.
*Mol. Cer.*—Molecular layer of cerebellum.
*N. II.*—Opticus.
*N. III.*—Oculomotorius.
*N. IV.*—Trochlearis.
*N. V. asc.*—Ascending root of fifth.
*N. V. gen. d.*—Dorsal geniculated root of fifth.
*N. VII.*—Facialis.
*N. VIII.*—Auditory.
*Nucl. Sp. I.*—Nucleus of 1st spinal.
*Nucl. Vag. II. M.*—Nucleus of motor root of posterior part of vagus group.
*Ol.*—Olfactory tract.
*Op. Chi.*—Optic chiasma.
*Pd.*—Peduncle of cerebral hemisphere.
*R. ac. V.*—Root of fifth from tuberculum acusticum.
*R. ac. Vag. I.*—Root of vagus group from tuberculum acusticum.
*Sec. V. T.*—Secondary vago-trigeminal fasciculus.
*T. L.*—Torus longitudinalis.
*T. O.*—Tectum opticum.
*T. S.*—Torus semicircularis.
*Tr. O.*—Optic tract.

PLATE V.—(*Continued*).

*Tr. Cer. ad LI.*—Tractus cerebelli ad lobum inferiorem.

*Tub. Ac.*—Tuberculum acusticum.

*Tub. Cin.*—Tuber cinereum.

*VLI.*—Ventriculus lobi inferioris.

*VLO.*—Ventriculus lobi optici.

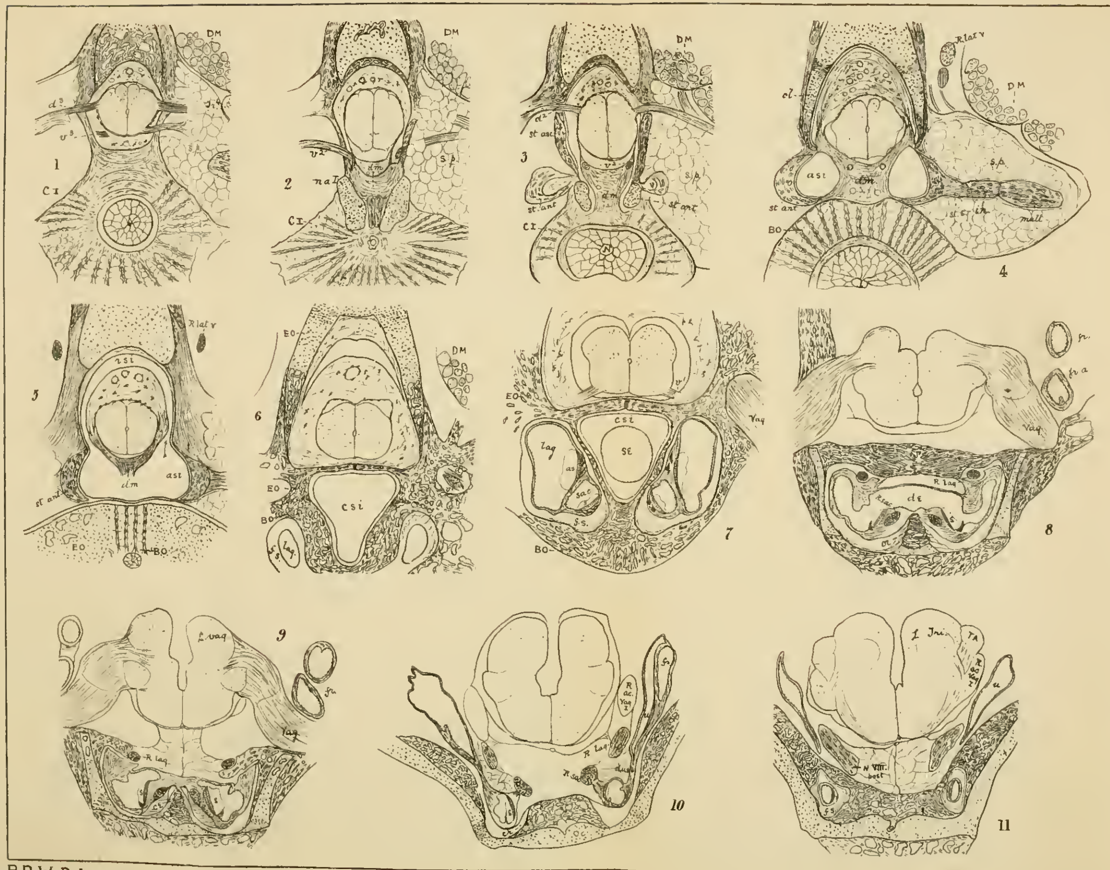
*V. III.*—Ventriculus tertius.

*V. IV.*—Ventriculus quartus.

*Vent. com.*—Ventriculus communis.

*Vag. I. & II., S. & M.*—Sensory and motor roots of the first and second parts of the vagus group.

*Val. Cer.*—Valvula cerebelli.

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## PLATE VI.

*BO.*—Basi-occipital.
*C. I.*—Centrum of 1st vertebra.
*D M.*—Dorsal musculature.
*E O.*—Exoccipital.
*L. tri.*—Trigeminal lobes.
*L. vag.*—Vagus lobes.
*N. VIII. post.*—Posterior division of auditory nerve.
*R. ac. vag. I*—Acustic root of vagus.
*R. lag.*—Ramus lagenæ cochleæ.
*R. lat. V.*—Ramus lateralis trigemini.
*R. sac.*—Ramus sacculi.
*T. A.*—Tuberculum acusticum.
*Vag.*—Vagus nerve.
*as.*—Asteriscus.
*asi.*—Atrium sinus imparis.
*cr.*—Crest of basi-occipital between foveæ sacculi.
*cl.*—Claustrum.
$d^{1\ 2\ 3}$—Dorsal roots of 1st, 2nd and 3rd spinal nerves.
*de.*—Ductus endolymphaticus.
*dm.*—Patch of dura mater on basi-occipital and upper surface of first vertebra.
*dus.*—Wall of ductus utriculo-saccularis.
*fr.*—Frontal semi-circular canal.
*fr. a.*—Ampulla of semi-circular canal.
*fs.*—Fovea sacculi.
*in.*—Incus.
*lag.*—Lagena cochleæ.
*na I.*—Neural arch of 1st vertebra.
*mall.*—Malleus.
*s.*—Sagitta.
*sac*—Sacculus.
*sc.*—Saccus endolymphaticus.
*sp.*—Saccus paravertebralis.
*st. ant.*—Anterior spoon-shaped process of stapes.
*st. art.*—Articular process of stapes.
*st. asc.*—Ascending process of stapes.
*st. t.*—Tendon attaching incus to stapes.
*u.*—Utriculus.
$v^{1\ 2\ 3}$—Ventral roots 1st, 2nd and 3rd spinal nerves.

Figs. 1-11 represent selected sections from a frontal series through the part surrounding the central nervous system of *Amiurus* from the posterior face of the first vertebra as far forward as the suture between the ex-occipital and the prootics.

Fig. 1.—The dorsal and ventral roots of the third spinal nerve piercing the membranous wall of the neural canal, which is lined by the dura mater vertebralis, while the spinal cord is closely invested by

PLATE VI.—(*Continued*).

the dura mater medullaris. Between these two membranes is the characteristic loose adipose tissue. The roof of the neural canal is here formed by cartilage which has largely undergone ossification both from the centre and the perichondrium It is invested on the outside by the membrane bone in continuity with the third spinous process. The dorsal musculature lies above the anterior part of the tranverse process of the fourth vertebra and the saccus paravertebralis which contains the malleus. (*Vide* Fig. 4).

Fig. 2.—Through the ventral roots of the second nerve (further back than the dorsal) (*vide* Fig. 8, Pl. IV.) which emerge behind the ascending processes of the stapes (right side is somewhat further backwards). Between the neural arches of the first vertebra is the thickened patch of dura mater which furnishes the membranous wall of the neural canal as well as the dura mater medullaris.

Fig. 3.—Shows the dorsal roots of the second spinal nerve emerging above the ascending processes of the stapes. The neural arches of the first vertebra are seen as the articular processes of the stapes. The ventral roots of the second are seen in a canal of dura mater in their backward course towards their foramina. The anterior spoon-shaped process of the stapes is caught just behind the atrium sinus imparis.

Fig. 4—Is through the middle of the atria sinus imparis, the partition between which is formed by the thickened dura mater which is in continuity with the connective tissue surrounding the stapes, and that on the outside of the claustra. The separation of the layers of dura mater is less complete, but in the dorsal part of the spinal canal the medullary can be distinguished from the vertebral layers and between them the rest of the membrane is continuous with the loose adipose tissue. The tips of the claustra project slightly from above into the atria sinus imparis. The whole of the saccus paravertebralis containing the oily reticular tissue is seen in section, the malleus and incus being connected to the stapes by tendon.

Fig. 5.—The basi-occipital is here only exposed for a small portion in the middle line owing to the ex-occipitals abutting on it. The section passes through the communication between the *cavum* and *atria sinus imparis*, the partition (dm. of last figure) being only caught above. The atria open above into the reservoir (*rsi*). The lateral wall of the neural canal is formed by the connective tissue separating the *claustra* from the ex-occipitals.

Fig. 6.—The reservoir appears in this section, which passes through the foramen magnum, slightly bilobed. The dorsal and the ventral roots of the first nerve are caught in the bony canal through which they emerge. The cavum sinus imparis is cut behind the saccus endolymphaticus. It contains only fluid like the atria and reservoir, no reticular tissue. The posterior surface of the lagena cochleæ is just caught. The osseous roof of the cavum thins out before it joins the patch of dura mater.

Fig. 7.—Just behind the vagus foramen, and through the strong ventral roots of the first spinal nerve, the membranes of the brain have here the features characteristic of the cranial cavity. The osseous roof of the cavum sinus imparis is somewhat thicker, its walls much thinner. It contains here the thin walled *saccus endolymphaticus*. In the *foveae sacculi* is the section of the *pars inferior*

PLATE VI.—(*Continued*).

of the labyrinth, in which the outlines of the asteriscus (*as*) and sagitta (*s*) are shown resting on the *macula acustica lagenæ cochleæ* and *macula acustica sacculi*.

FIG. 8.—Is through the ductus endolymphaticus which connects the *sacculi*. It lies in the entrance to the cavum sinus imparis whose osseous root here slopes downwards so as partly to close the entrance. The sacculi communicates here with the *lagenæ cochleæ*. The wall of the labyrinth below is attached to the crest separating the foveae sacculi. The relative position of lagenar and saccular branches of the auditory nerve is well seen. The right side of the section is immediately behind the vagus foramen, and catches the ampulla of the frontal semi-circular canal.

FIG. 9.—Shows the section of the sacculi in front of the ductus endolymphaticus ; the anterior wall of the ductus is also attached to the crest. The ventral surface of the medulla oblongata is separated from the labyrinth by a layer of adipose tissue. The solid wall of the labyrinth in which the ductus sacculo-utricularis is excavated stretches upwards and outwards along the thickened exoccipital.

FIG. 10.—Cuts the labyrinth immediately behind the ductus sacculo-utricularis (*dus*). On the lateral wall of the utriculus is one of the *maculæ neglecta*. The crest separating the foveae sacculi is now much wider.

FIG. 11.—For the region of the brain in the section *vide* Fig. 3, Pl. V. The utriculus is cut behind the recessus utriculi. The posterior division of the auditory nerve with its interpolated ganglion-cells is not yet subdivided into Rr. lagenæ and sacculi. The anterior tips of the sacculi are about to enter the small cavities in the prootics which receive them ; they are surrounded by delicate tubes of dura mater.

## PLATE VII.

Eigs. 1–12 are from *Amiurus catus*; Fig. 13, from *A. nigricans.*

FIG. 1.—Epithelium of the mucous membrane of the mouth, the section being from near the tongue; *a*, a clavate cell; *b*, slime cells. Magnified about 400 diameters.

FIG. 2.—A transverse section of the wall of the œsophagus showing the arrangement of its coats. Low power.

FIG. 3.—Superficial epithelium of œsophagus isolated by maceration in a mixture of serum and Müller's fluid. Magniffed 440.

FIG. 4.—Epithelium and glands of the stomach, hardened in Müller's fluid. Magnified 235.

FIG. 5.—A peptic gland of young cat-fish four hours after swallowing food. Treated with osmic acid and alcohol. Magnified 590.

FIG. 6.—Superficial epithelium of pylorus; *a*, crypt forming one of the so-called pyloric glands. Hardened in Müller's fluid. Magnified 235.

FIG. 7.—A transverse section of the wall of the midgut showing the various coats; *s*, the *serosa*; *mo*, the outer or longitudinal muscular coat; *mi*, the inner circular layer of muscle fibres; *sm*, the *submucosa*; *mm*, *muscularis mucosæ*; *m*, the *mucosa*. Low power.

FIG. 8.—Superficial epithelium of the midgut isolated fresh in serum. Oc. 4, Imm. obj. H, Zeiss.

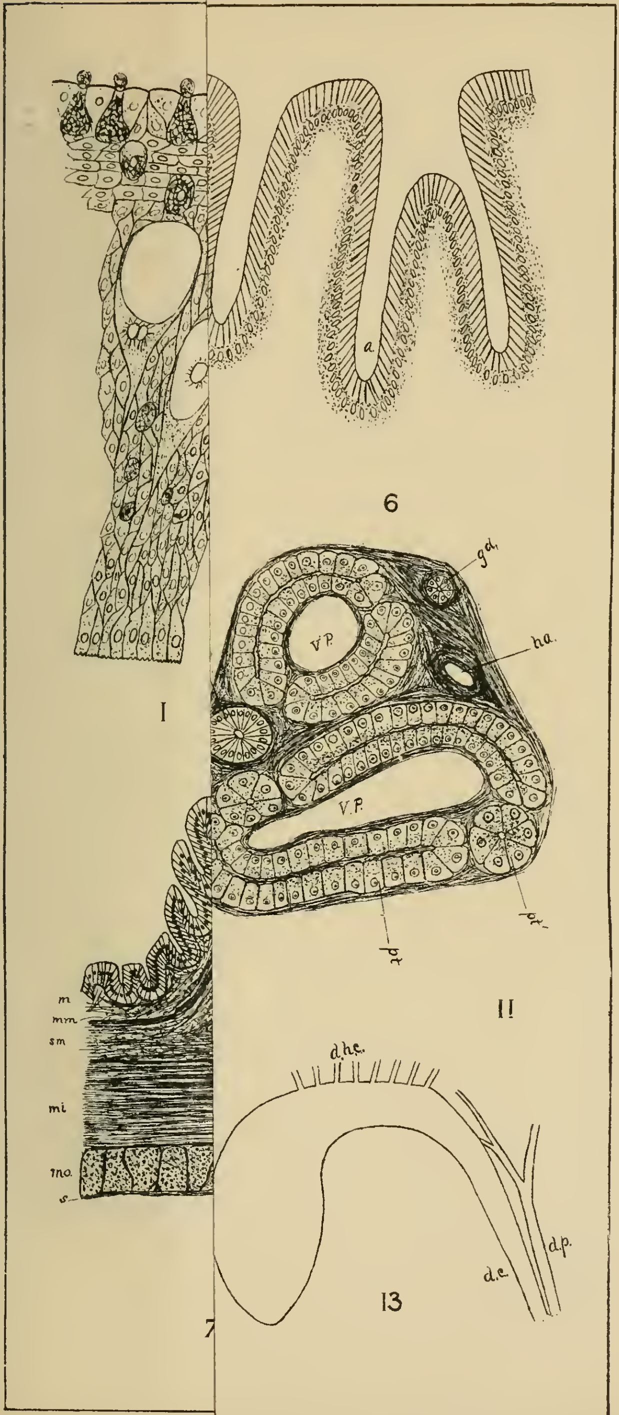
FIG. 9.—Fresh epithelium of endgut teased out in serum. Oc. 4, obj. H, Zeiss.

FIG. 10.—A portion of a section of the liver showing the radial capillaries cut transversely; *gc*, gall capillary filled with indigocarmine by natural method, and shown here by the broad black line; *rv*, radial vessels of the lobule; *gt*, a hepatic cylinder surrounded by the radials and their transverse branches, with the gall capillary in the centre. Magnified 590.

FIG. 11.—A section of a smaller division of the portal canal; *V.P.*, interlobular veins; *gd*, gall ductlets; *ha*, hepatic artery; *pt*, pancreatic tubules. Magnified 440.

FIG. 12.—A pancreatic tubule showing the condition some time after food is taken. Magnified 590.

FIG. 13.—Diagram showing the relation of the gall-bladder and duct to the pancreatic duct; *dhc*, hepato-cystic ducts; *dp*, pancreatic duct; *dc*, ductus choledochus.

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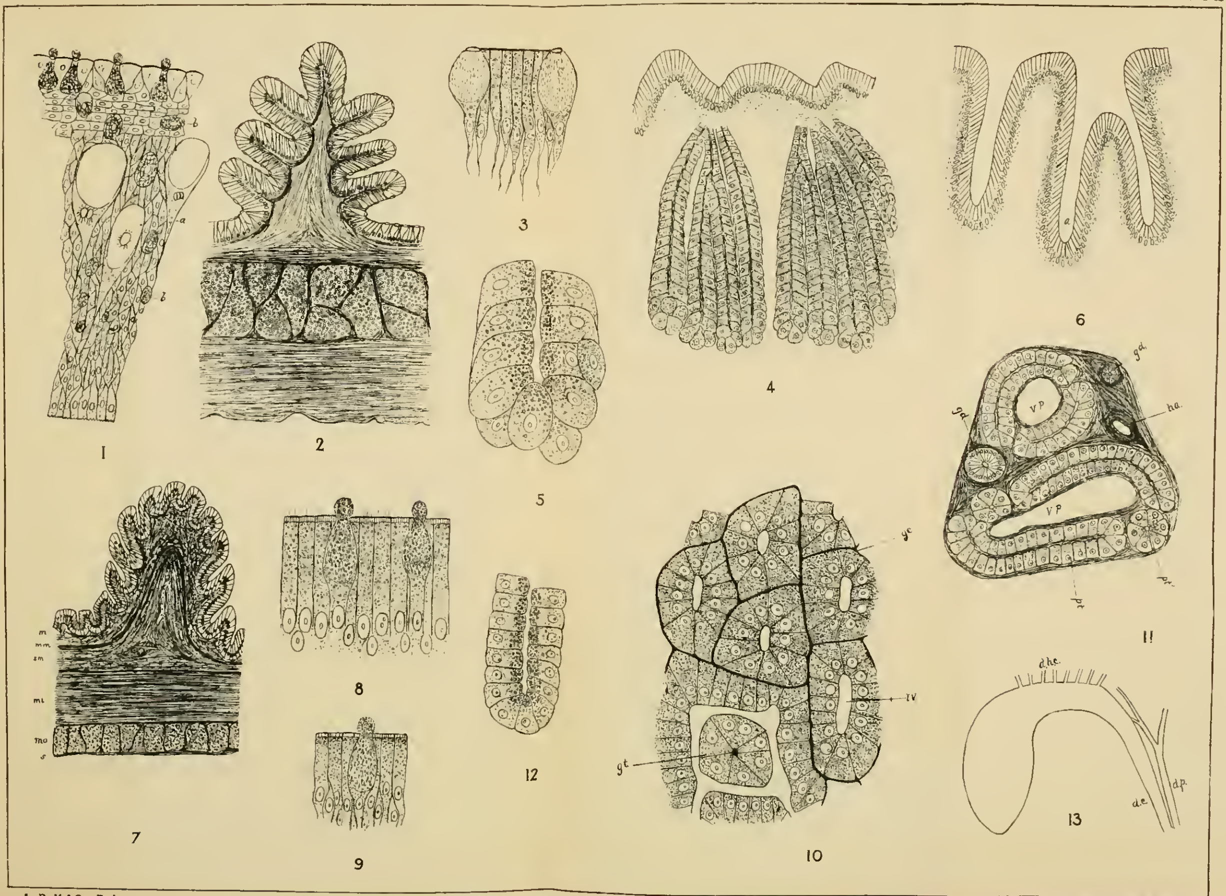


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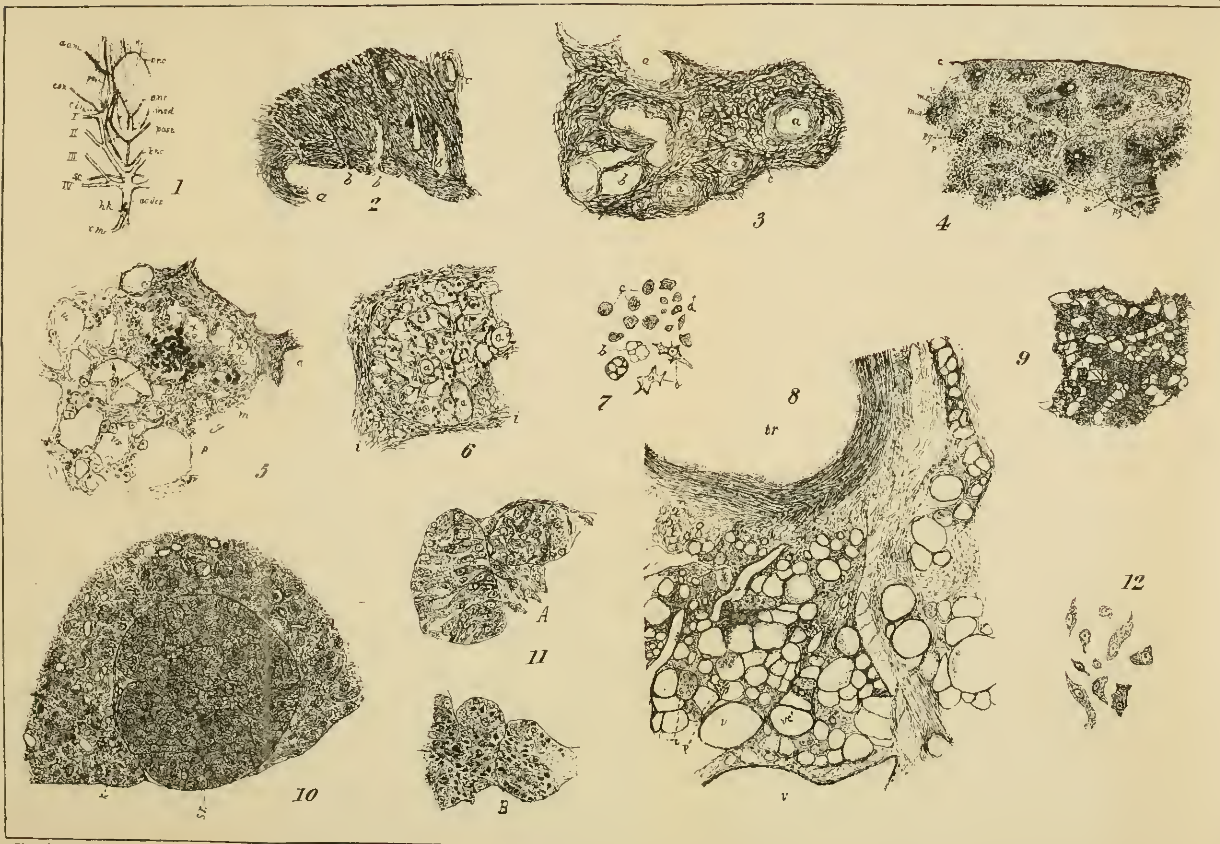


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