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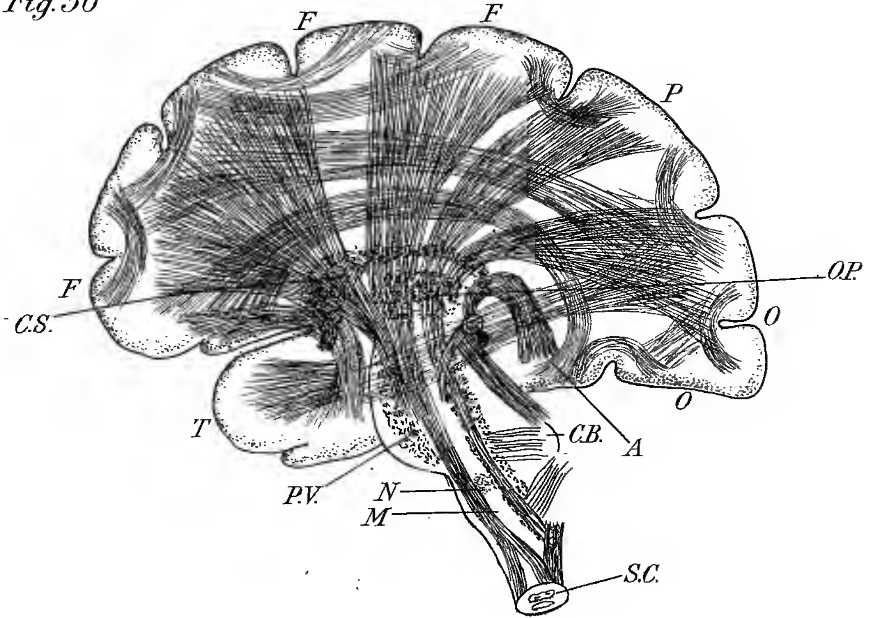

Fig. 36.—Diagram to illustrate the course followed by some of the nerve fibres which pass upwards from the spinal cord and downwards from the brain into the cord, represented by the black lines. The red lines indicate the course of some of the principal bundles of *association* fibres. The blue dots represent the *cortex* of the hemispheres of the brain.

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HUMAN SPEECH

A STUDY IN THE PURPOSIVE ACTION OF LIVING MATTER

BY

N. C. MACNAMARA, F.R.C.S.

FELLOW OF KING'S COLL., LOND.; SURG.-MAJOR, INDIAN MEDICAL SERVICE, RETD.,
AUTHOR OF "HIST. OF ASIATIC CHOLERA," ETC.

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PREFACE

The object of the following work is to explain the nature and action of the living matter of those parts of our bodies, by means of which we gain ideas concerning the external world, and are able to express our thoughts in intelligent speech.

The first part of this volume, therefore, is devoted to the consideration of the fundamental properties possessed by all forms of living matter, because it is necessary to gain correct ideas regarding the nature of this substance before we can comprehend how it is able to perform work such as that above mentioned. Reasons are given for adopting the opinion that living matter acts as a special transformer of non-vital into vital modes of energy, and that the phenomena exhibited, as a whole, by this substance cannot be shown to exist apart from this form of matter. In support of this opinion, I refer to the work carried on by the living matter which forms the bodies of the simplest classes of organisms; such, for example, as its power to assimilate nutrient matter and thus renew its used-up elements, and to pass on its characters to succeeding generations of beings. The source of the working energy of living matter as well as its sensitivity and adaptability to the action of incident forces is discussed.

It is then shown how living matter, in response to energy received from various sources; has come to produce structures which enable unicellular organisms to exist and to multiply in a constantly varying environment. Structures thus developed, in the course of many succeeding generations become hereditary characters, and under the action of natural selection those species of organisms which have arrived at the most complete harmony with their environment survive, and develop into higher orders of beings.

From the study of the properties displayed by the living substance of unicellular organisms, I proceed to explain how this matter has produced structures and organs in invertebrates adapted for their preservation in their struggle for existence, and illustrate my meaning by referring to the functions performed by the living matter of the cells which constitute the bodies of sponges, polyps, and the jelly-fish; in the latter class of animals, sense-organs and a muscular and nervous system are shown to have been produced from the substance of the cells which form the outer layer of the animal's body.

The nervous system of the starfish, flat-worms, sea-mouse, and crayfish, together with that of some insects, are described, in order to demonstrate the fact that in proportion to the perfection attained by their cephalic sense organs corresponding areas of the nervous matter of their brains have become developed, and consequently their intellectual capacities. In some of these animals masses of nervous matter exist in connection with their brains, which appear directly to control their intellectual capacities.

The knowledge acquired from a study of the subjects above referred to is applied to explain the functions performed by the sense-organs, in conjunction with the nervous and muscular systems of the higher classes of animals, including man. The constant flow of energy received through the cephalic sense-organs stimulates the living substance of definite areas of the brain and leads to its structural and functional development, and in this way to modes of life adapted to promote the well-being of the organism as a whole.

The reason why the words uttered by birds are almost meaningless is explained, and also why apes and certain idiots are unable to formulate any but rudimentary ideas, or to express their imperfect mental processes in articulate language. We are thus led step by step, through the aid of comparative biology, to realise the nature of the forces which have led to the gradual evolution of mental process, culminating in the power possessed by human beings of expressing their thoughts in intelligent speech.

In conclusion, it is shown how knowledge regarding the properties and potentialities possessed by living matter can, with advantage, be employed to enable us to form sound ideas regarding the methods best calculated to develop the intellectual powers of young people.

The contents of the ninth and following chapters of this work are those which will probably most interest the general reader. But, until we have become acquainted with the nature of the living matter which forms the "organ of speech," and of the psychical areas of our brains, it is difficult for us to understand the processes by which we formulate ideas and come to express our thoughts in silent or in spoken language; consequently I have devoted the earlier chapters of this volume to the subject.

It is hardly necessary to remark that a subject, such as the one I have attempted to explain in this work, must be attentively studied before its full meaning can be appreciated by persons unacquainted with the science of biology. But the subject is a fascinating one, and is well worth the serious consideration of all educated persons. This volume has at any rate one quality to recommend it to the general reader—it is brief; and so far as the study admits, the use of complicated technical terms has been avoided in its pages.

My sincere thanks are due to Dr A. Dendy, F.R.S., Prof. of Zoology at King's Coll., Lond., and Professor B. Moore, Prof. of Bio-Chemistry at Liverpool University, for their valuable suggestions and criticisms while this volume was in MS., and to Mr R. H. Burne, B.A., Assistant Curator of the Museum of the Royal College of Surgeons of England, for the kind assist-

ance he has given me in preparing my work, and correcting the proofs; but none of these gentlemen are in any way responsible for the matter or for the opinions enunciated in its pages. For these I alone am responsible.

I have also to thank Sir Edwin Ray Lankester, Professors E. B. Wilson, A. Fischer, and other well-known scientists for the permission they have given me to copy drawings from their books for the purposes of this work—and the President of the Royal College of Surgeons of England for the loan of the blocks used in Figs. 32 and 33. My powers as an artist are extremely limited, and I am convinced, that if I had attempted to produce original drawings from my own specimens, they would have been much less satisfactory than those which I have copied from standard works on Physiology and Zoology.

At no distant period I hope to produce a second part to this work, my object being to follow the evolution of living matter from its simplest purposive forms, up through matter having instinctive functions, to that of the fully developed nervous matter which regulates the inherited characters possessed by human beings. This subject is one of perhaps even greater interest and importance than the development of man's intellectual capacities.

N. C. MACNAMARA.

THE LODGE, CHORLEY WOOD, HERTS,
August 1908.

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CHAPTER I

The prevailing ideas regarding the nature of matter and of energy are referred to—Living matter in virtue of the numerical and proportional arrangement and motion of its elements acts as a specific transformer of energy—This action results in the manifestation of certain phenomena which collectively we call life.

THE purpose of this work is to describe the nature and functions performed by those parts of the living matter of our bodies by means of which we gain ideas concerning the external world, and are enabled to formulate and express our thoughts in intelligent speech. The lines we propose following in our investigation into this subject, lead us in the first place to consider the nature of the fundamental properties possessed by living matter, and then to lead up through comparative biology to the higher functions performed by the nervous matter of the brain culminating in human speech.

The word "biology" or the science of life was first employed by Treviranus in his voluminous work published in Göttingen in the year 1802, entitled "Biology or the Philosophy of Living Nature." It was a new thing to regard the study of living nature as a science by itself, worthy to occupy a place by the side of natural philosophy, and it was therefore necessary to vindicate its claims to such a position. Treviranus commends biology to his readers as a study which, above all others, "nourishes and maintains the taste for simplicity and nobleness; which affords to the intellect ever new material for reflection, and to the imagination an inexhaustible source of attractive images."[1]

In the year 1809, Lamarck completed his work "Philosophie Zoologique," which attracted much attention from the scientific world of that period. He believed in the spontaneous generation of living beings from inorganic matter; and that life is an order and state of things, which permits of organic movements, and these movements are the result of the action of a stimulating cause which excites them. He held that a progressive change from lower to higher orders of beings had been and was constantly taking place, and that to effect these changes, "*time* and favourable conditions are the two principal means which nature has employed in giving existence to all her productions."[2] He states that the essential cause of the variation of genera and species "arises from the influence, and from all the environing media; from the diversity of local causes, of habits, of movements, of actions, finally of means of living, of preserving their lives, of defending themselves, of multiplying themselves, etc. Moreover, as the result of these different influences the faculties, developed and strengthened by use, become diversified by the new habits maintained for long ages, and by slow degrees the structure, the consistence, in a word the nature, the condition of the parts and of the organs consequently participating in all these influences

[1] Inaugural Address by Prof. J. S. Burdon-Sanderson to the British Association, 1893.

[2] Lamarck, "The Founder of Evolution," by A. S. Packard, M.D., pp. 168, 233.

became preserved and propagated by generation" (heredity).[1]

Treviranus taught that the series of phenomena displayed by living organisms were the result, in part, of physical laws, but mainly depended on the action of what he termed vital laws. He defined life as consisting of the reaction of living matter to external influences, and he contrasts the uniformity of the vital reaction of organisms with the variety of their exciting causes. He was of opinion that the activities carried on by the various constituents of a living organism were all adapted to promote its wellbeing as a whole.[2]

Towards the middle of the last century, biologists working with improved microscopic lenses, advanced beyond the knowledge possessed by Treviranus regarding the structure and functions of cells, which, either separately or collectively constitute the bodies of living beings; they came to recognise the fact that however complicated the conditions may be under which vital phenomena become manifest, they may be split up into processes which are identical in their nature with those taking place in non-living matter.

With the issue by Darwin of his "Origin of Species" in 1863, and during the same year of the First Part of Herbert Spencer's "Principles of Biology,"[3] and last but

[1] Lamarck's definition of what is meant by a species of animals or plants is quite up to date—"every collection of similar individuals perpetuated by generation in the same condition, so long as the circumstances of their situation do not change enough to produce variations in their habits, character and form." A. S. Packard's Lamarck, p. 184.

[2] Biologie, oder der Philosophie der lebenden Natur, vol. i. published in 1802, and vol. vi. in 1822.

[3] H. Spencer's definition of life is given on pages 80 and 60 of his "Principles of Biology," vol. i.

not least of Huxley's "Man's Place in Nature," a great impetus was given to the scientific study of the properties and potentialities possessed by the matter which forms the essential part of all living beings.

The late Prof. Burdon-Sanderson in his address to the British Association in the year 1893 states, that in his opinion the definition of life as above quoted from the work of Treviranus held good, and that *action* is not an attribute of the organism but of its essence—that if, on the other hand, protoplasm is the basis of life, life is the basis of protoplasm.[1] At the present time we are invited to consider living organisms as chemical machines, consisting essentially of colloidal materials, which possess the peculiarity of automatically developing, preserving, and reproducing themselves.[2]

As our work from first to last deals with living organic matter, it seems desirable before entering into details concerning its properties, to state briefly some of the prevailing ideas regarding the arrangement and motion of the elements which form matter, and to refer to energy as that which has the power of changing the properties of bodies. Whenever a body changes its condition, its motion, temperature, volume, chemical composition, etc., there energy is in action. Energy has been defined as "the capacity for doing work."[3]

[1] "Nature," Sept. 14, 1893, p. 464.

[2] Prof. A. Findlay on "Physical Chemistry and its applications to Medical and Biological Science," p. 9, states that colloidal materials are those which do not readily diffuse through living animal membranes, such as those which form the outer layer of many cells.

[3] Text-books of Physical Chemistry, edited by Sir William Ramsay. "Chemical Statics and Dynamics," by J. W. Mellor, p. 20. Also Prof. W. B. Hardy, who states that "there is no lack of evidence to prove the life-like characteristics of colloidal matter, its capacity for storing impressions, the elusiveness of its chemical and physical

By the aid of reagents and the balance, we may learn much regarding the arrangement of the atoms or ultimate elements which form the molecules or atom-clusters, of which it is held both organic and inorganic matter is constituted. We know that these elements have a fixed capacity for union with one another, and that this capacity has its numerical expression. An atom of hydrogen unites with one other atom only; that of oxygen may combine with two; that of nitroger with three or five, while carbon has a capacity for four. All union of atoms to atoms within a molecule are governed by conditions of this order, and the limitations thus imposed determine the possibilities of combinations in a given class of compounds.

The prevailing idea regarding the nature of the ultimate elements of matter is, that it consists of portions of a universal substance which is simple in structure, and occupies not only our Universe but also the utmost limits of space. This substance is known as the Ether, and portions of it are in irrotational motion transmitting the undulations of light, etc.; while other portions in rotational motion have become separated from the rest of the medium, and by reason of their motion have gained a certain amount of rigidity. These vortices of the all-pervading ether are known as electrons, and are supposed to form the ultimate elements of matter.[1] These electrons are

states, are due to the fact that an exceptionally large fraction of its energy is in the form of surface energy," p. 193. "Science Progress," October 1906, p. 193. See also Annual Report of the Smithsonian Institution, 1903, p. 282. The Intra-Atomic Theory, by M. Gustave Le Bon.

[1] In making use of the term "element" we mean something that we cannot decompose into anything simpler.

charged with electricity. A number of electrons aggregate round a centre or nucleus and form an atom of matter. Atoms in their turn are supposed to accumulate about a centre of attraction, and constitute a molecule of matter.[1] Each form of organic or of inorganic substance possesses a specific numerical and proportional arrangement of molecules and atoms, the latter being charged with electrons in perpetual motion. Dr Larmor, in his well-known work on "Æther and Matter," is disposed to consider it likely that the chemical atoms are built up "of positive and negative electrons interleaved or interlocked in a state of violent motion, so as to produce a stable configuration under the influence of their centrifugal inertia and their electric forces." It is from elements of this description that we are led to suppose all material bodies are formed.

The tendency of the elements forming matter is to fly apart from one another, but to a large extent they are restrained from doing so by certain forces of attraction which hold them together, an equilibrium being established between the disruptive and the conservative forces at work in these elements, whereby they are retained in position so long as these forces balance one another. But this equilibrium is readily disturbed by the action of more potent forces than those which hold the elements of matter in position;

[1] At the recent meeting of the British Association, Lord Kelvin made the following statement regarding atoms: "It seemed, indeed, almost absolutely certain that there were many different kinds of atoms each eternally invariable in its own specific quality, and that different substances, such as gold, silver, etc., consisted, each of them, of atoms of one invariable quality, and that every one of them was incapable of being transmuted into any other."

its molecules may then, within restricted limits, alter their position in relation to one another and their motion. The structural arrangement of matter under these conditions, and its functions or the work it performs, become modified in character.[1]

Dr Gustave Le Bon, after a long course of experimental research, has arrived at conclusions which are summarised as follows, by his translator—that all matter is radio-active in the same manner as uranium, radium, and the other so-called radio-active metals, and that this radio-activity is but a step in the process by which it gradually sinks back into the ether from which it was originally formed. To this he has lately added the corollary that, in the course of this disintegration, energies of an intensity transcending anything of the kind previously observed are very slowly and gradually liberated.[2]

Dr Le Bon illustrates his meaning regarding the dissociation of matter by reference to the emission of abundant particles from bodies discoverable by the sense of smell. The sense of smell is infinitely superior in sensitiveness to that of the balance, since in the case of certain substances, such as iodoform, the presence, according to M. Berthelot, of the hundredth of a millionth of a milligramme can be easily revealed by it. His researches lead him to conclude that one gramme of iodoform only loses one milligramme in a

[1] The properties of various bodies are functions of the masses of their respective atoms. Review of Mendeléeff's Law. Brit. Med. Journ., p. 1723, Dec. 1906. Also June 9, p. 1335, Dr T. Claye Shaw on Mind and Matter.

[2] "The Evolution of Matter." By Gustave Le Bon. Translated into English from the 3rd edition. Also Dr Le Bon's "The Forces of Nature," *The International Scientific Series.* Vol. xci.

hundred years, though continuously emitting a flood of odoriferous particles in all directions. M. Berthelot adds, that if, instead of iodoform, musk were used, the weight lost would be very much smaller, "a thousand times perhaps." This scientist also remarks "that there is hardly any metallic or other body which does not manifest, especially on friction, odours of its own," which, as Le Bon remarks, is simply saying that all bodies slowly evaporate.[1]

These experiments give us an idea of the immensity of the number of particles which are contained in an infinitesimal quantity of matter. From the recent researches of Rutherford, Thomson, and other scientists, we are led to believe that one cubic millimetre of hydrogen would contain 36,000 billions of molecules.

The elements forming the atoms of a molecule are supposed to be in excessively rapid rotation on their axis and round a centre. It is to their speed Le Bon assigns the vast store of energy they contain; and also their stability. But when under the influence of chemical or other influences their speed of rotation falls below a certain critical point, the equilibrium of the particles becomes unstable, their kinetic energy increases, and they may be expelled from the system, a phenomenon which is the commencement of the dissociation of the atom.[2]

The enormous amount of intra-atomic energy

[1] P. 237, "The Evolution of Matter," by Dr Gustave Le Bon.

[2] When a sheet of gold and lead are brought into contact their particles mingle perceptibly though only very slowly, which demonstrates the constant dissociation of the elements of which they are constituted. This subject is clearly dealt with by Mr W. A. Shenstone, F.R.S., in his work "The New Physics and Chemistry." Messrs Smith Elder, 1906.

liberated during the dissociation of matter can be appreciated when it is stated that these particles possess a velocity of 100,000 kilometres per second, their speed being such as to drive them through a plate of ebonite half a centimetre thick.[1]

Professor Ehrlich has advanced a theory regarding the nature of the molecules constituting living pro-

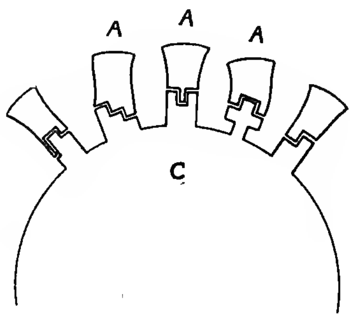

FIG. 1.—Diagram of: *C*, central group with side chains; *AAA*, atoms which fit on to the side chains.

toplasm which enables us to some extent to realise their action. His idea is that each molecule of this matter is formed by a central aggregation of atoms which have a strong affinity for one another. The function of this central group of atoms consists largely in fixing to itself certain side chains of atoms. The central group of atoms with its side chains constitutes a molecule. (Fig. 1, C.) The side chains of the molecule possess a certain degree of independent action, the bond of union being less between them than that

[1] "The Evolution of Matter," pp. 36, 38, 42, 416.

which unites the central group of atoms; so that atoms composing side chains may become detached, or modified in character, without disturbing the atoms forming the central group. (Fig. 1, A.) For instance, we can imagine that certain of the side chains of molecules of protoplasm concerned with the nutritive processes of living matter, may attach to themselves certain atom-groups of food-stuff which have precisely corresponding side chains, the two fitting to one another as a key to its own lock. The relationship, therefore, of corresponding groups of side chains, that is in the above imaginary case of nutritive protoplasms, the elements forming the side chains of the living molecule, and those derived from the food stuff brought in contact with it must coincide, otherwise they would not be able to unite with one another. We can thus picture to ourselves the taking on, and the throwing off capacity of the molecules constituting living organic matter.

Energy, as we have stated, is defined by Dr J. W. Mellor as "that which has the power of changing the properties of bodies," or the capacity of doing work.[1] As this author remarks, changes are continually taking place in the properties of bodies around us. Changes of position, chemical composition, motion, temperature, volume, are among the myriad changes associated with bodies in general. "As a first approximation, every change may be supposed to be due to the action of some external agent which is called *Energy*." Whenever a body changes its condition, there energy is in action.

[1] "Chemical Statics and Dynamics, including the theories of chemical change, catalysis and explosions," by J. W. Mellor, D.Sc. (N.Z.), Longman, Green & Co., 1904.

Energy is the cause, change of condition the effect. Matter has been referred to as being "the vehicle of energy,"[1] and as changes in the atomic and molecular arrangement of matter can only occur when the power which holds them together is withdrawn, in overcoming this resistance energy must be expended. Whenever change takes place in opposition to a force resisting that change, *work* is said to be performed. Work is therefore done at the expense of energy.

We have come to know that the various forms of energy with which we are familiar, heat, chemical action, etc., are all different forms of one distinct entity —energy; and can be transformed directly, or by intermediate steps, the one into the other. When any quantity of one form of energy is made to disappear, an equivalent quantity of another form of energy reappears under the action of laws known as those of "The Conservation of Energy." Professor J. Clerk Maxwell when discussing the subject of Matter and Energy states "that all we know about matter relates to the series of phenomena in which energy is transferred from one portion of matter to another, till in some part of the series our bodies are affected, and we become conscious of a sensation. By the mental processes which are founded on such sensations we come to learn the conditions of these sensations, and to trace them to objects which are not part of ourselves, but in every case the fact that we learn is the mutual action between bodies." He further adds, "the transactions of the material universe appear to be conducted, as it were, on a system of credit. Each transaction consists of the transfer of so much credit or energy from

[1] J. W. Mellor, p. 24.

one body to another. This act of transfer or payment is called work."[1] He might have added that all the physical changes which take place in the Universe, including those which are inseparably associated with the thoughts as well as actions of living beings, are merely transformations of energy.[2]

If we apply the principles above referred to to the phenomena presented by living matter, we arrive at the conclusion that this substance consists of matter which acts as a transformer of chemical and other non-vital forms of energy, into biotic (living) energy.[3] As above explained, by a transformer of energy we mean a substance, which by its structural arrangement is specially adapted for promoting certain energy exchanges, and which may be quite inert with regard to other exchanges. Professor B. Moore remarks as to some energy transformers that they possess the property shared by all forms of matter of acting as transformers, although varying in degree, while in others the property is specific, and associated with some special arrangement of matter. Thus all metals possess electrical conductivity, and in inverse proportion act as transformers for the conversion of electrical energy into heat energy. The chlorophyll of green plants, on the other hand, has the specific power of converting light energy into chemical, and here acts as a peculiar energy-transformer. Similarly all enzymes are energy trans-

[1] "Matter and Motion," by the late J. Clerk Maxwell, pp. 92, 93.

[2] "The Unseen Universe," by Professors B. Stewart and P. G. Tait, sixth edition, p. 116.

[3] "Recent Advances in Physiology and Bio-Chemistry." Edited by Dr Leonard Hill. Article by Dr B. Moore, Professor of Bio-Chemistry in the University of Liverpool, p. 5.

formers limited and specialised in range of action for the transformation of chemical energy.[1]

Again iron, by some special structural arrangement, is specially adapted to act as a transformer in the case of magnetic energy, effecting its conversion into electrical or mechanical energy, or *vice versâ.* It is only necessary to lightly touch an iron wire in order to cause it at once to become the seat of an electric current. A thread of platinum is so sensitive that it reacts, by a variation of electric conductibility when struck by a ray of light having an intensity so feeble, that it can produce an elevation of temperature amounting to only one hundred millionth of a degree. Hertzian waves having travelled over hundreds of miles, and therefore being extremely feeble, nevertheless modify the structure of the metals that they reach so as to produce marked changes in their electric conductibility. It has been shown that metals become for the time being less sensitive after constant excitation, but regain their irritability after an interval of repose; their action may be excited or depressed, or even abolished by chemical substances.[2]

Some bodies are transparent and transmit radiant light and heat unaltered, while others are opaque and transmute the energy into other forms. In the same

[1] "Recent Advances in Physiology and Bio-Chemistry," edited by Dr Leonard Hill, p. 5. Article by Dr B. Moore, Prof. of Bio-Chemistry in the University of Liverpool. *Enzymes*, or soluble ferments, are chemical substances secreted by living protoplasm, and may be extracted from the cells in which they have been formed. We may mention the pepsin of the gastric juice as an example of an enzyme: this substance breaks up complex albuminous products into simpler substances, and thus fits them for digestion.

[2] Annual Report of The Smithsonian Institution for the year 1903, p. 286.

way the living protoplasm of cells, on account of its peculiar structure and constitution, is a transformer of energy specially adapted for the intermediate conversion of chemical, and other modes of energy presented in certain suitable forms into biotic (vital) energy, and for its final conversion into other forms, such as mechanical energy and heat.[1] We have only to show that energy phenomena exist in living matter, which as a whole do not exist apart from it, in order to prove that this kind of matter is a peculiar energy transformer.

As Prof. B. Moore argues, it does not militate against the existence of this discrete form of energy that it is only produced from other forms of energy, and passes back again into other forms. It must be so, or the balance of which the laws of conservation of energy is the expression would be broken. Hence the fact that vital phenomena arise from the expenditure in the cell of chemical energy, and that the phenomena are accompanied by the development of heat, electricity, and other forms of energy, are no arguments that such vital phenomena are not characteristic of a type of energy found only in living matter. "*It is the linking of one reaction with another, and the using of the free energy of one to run another which specially characterises the cell, and differentiates the cell from the enzyme.*"[2]

The essential substance of each organism or cell, therefore, consists of living matter which in virtue of the numerical and proportional arrangement and motion of its elements acts as a specific transformer of energy; this action results in the manifestation of certain

[1] Dr B. Moore, "Recent Advances in Physiology and Bio-Chemistry," edited by Dr Leonard Hill, p. 5.

[2] Dr B. Moore, p. 135.

phenomena which collectively we term *life*. In other words life is the result of chemical and other forms of energy acting on a specific structural arrangement of matter; if this arrangement and motion of these elements is destroyed they cease to act as a transformer of non-vital into vital modes of energy.

No reliable evidence exists of the conversion of dead into living matter unless through the action of pre-existing living organisms. Living matter exists only in the form of living organisms. As to the time or conditions under which inorganic elements assumed the structure and functions of living protoplasm, or it may be of some simpler form, we know absolutely nothing; but this substance could only have come into existence after the temperature of the earth's surface had cooled down to a certain point, and in some of the early paleozoic strata a living population of lowly organised beings flourished on our earth, and were divided as at present, into protistoid, vegetable, and animal beings.

There is good reason to believe that the molecules of the jelly-like proteid material which constitute living protoplasm, are of a large size as compared with those of other forms of matter, and that their structural arrangement and motion are of a vastly complex character. It is in consequence of this extreme complexity and size of living molecules that their ultimate elements are capable of becoming gradually modified in character by the various forms of energy which act upon them.[1]

H. Spencer, referring to the gradual adaptative advance in the structural arrangement of ascending orders of

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Lamarck, in his "Système des Animaux sans Vertèbres," observes that "I could here pass in review all the classes, all the orders, all the animals, remarks—"that along with the gradual evolution of organisms having some activity, there grows up a kind of equilibration that is relatively direct. In proportion as the activity increases, direct equilibration plays a more important part. Until, when the neuro-muscular apparatus becomes greatly developed, and the power of varying actions to fit varying requirements become considerable, the share taken by direct equilibration rises into co-ordinate importance." By direct equilibration, Spencer means "that there go on in all organisms certain changes of functions and structures that are directly consequent on changes in the incident forces; inner changes by which the outer changes are balanced, and the equilibrium restored." "Principles of Biology," vol. i. pp. 442, 468. He states that indirect equilibrium either destroys such members of species as are least capable of resisting it, or fostering such of the members as are most capable of resisting it, or fostering such of the members as are most capable of taking advantage of it," or the survival of the fittest. "Biology," vol. i. p. 463.

The precise chemical composition of living matter cannot be ascertained, but when dead it consists of a semi-fluid substance formed principally of water and albuminous substances, of which the white of an egg is a familiar example. These albuminous (proteid) compounds are never absent from living matter, and are never formed by anything but that which is alive, or has been produced by the agency of living matter. Various other substances occur in small quantities in living protoplasm such as salts, and phosphorised fatty

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genera and species of animals which exist, and make it apparent that the conformation of individuals and of their parts, their organs, their faculties, etc., is entirely the result of circumstances to which the race of each species has been subjected by nature." See Lamarck "The Founder of Evolution," by Dr. A. S. Packard, p. 234.

matter. In cells which possess a nucleus, a proteid-like compound rich in phosphorus, known as nuclein, exists.

Having thus briefly stated the prevailing ideas concerning the nature of the ultimate elements of living protoplasm, and the power it possesses as a transformer of energy, we may pass on to consider some of the peculiar energy phenomena which it displays in its simplest known forms.

CHAPTER II

The structure and the functions performed by the living matter which constitutes the bodies of the simplest unicellular beings is described in order to demonstrate the nature of the fundamental properties common to all forms of this substance—Reference is made to the separation of this non-nucleated matter into reproductive and somatic elements under the action of energy derived from its environment.

Bacteria.—Among the simplest forms of living things we find a class of beings known as the Bacteria. Each one of these organisms consists of a minute mass of protoplasm, or living matter, enclosed in a cell wall or membrane, and containing granules of various kinds. In the most numerous and widely spread group of bacteria each being consists of a single cell; but in the higher forms of these organisms the cells join on end to end and produce a filament which is sometimes provided with a sheath, and may throw out branches; but the minute structure of the elements comprising these filaments is analogous to that of the units constituting the simpler class of organisms.[1] (Fig. 2.)

The bacteria are associated in the minds of most people with the microbes of diptheria, phthisis, cholera, and other diseases; but these organisms are by no means all harmful in their action, on the contrary, a vast group of them are constantly at work in effecting putrefactive and fermentative processes in dead animal

[1] "Manual of Bacteriology," by Profs. R. Muir, and James Ritchie, second edition, p. 1.

and vegetable substances. In this way they act as the scavengers of the world; beyond this, bacteria perform many other important functions in the economy of nature. Our interest in these beings however, is principally concerned with the transmutations effected by their living matter of chemical into other forms of energy. We have to inquire how it comes to pass that their protoplasm, while it is constantly at work and therefore subject to ceaseless wear and tear, nevertheless maintains during the life of the organism its form, working power, and capacity to reproduce its like. The minute particle of protoplasm which constitutes a bacterium is one of the most prolific kinds of matter in existence. Under favourable conditions it has been calculated that some of the bacteria in the course of one day might, if unchecked, rejoice in a progeny of sixteen hundred trillions.[1]

The Structure of the living matter of Bacteria.—When we examine living bacteria under high powers of the microscope they appear as pale, almost homogeneous masses, containing granules of matter of stronger refringency; in some of the larger organisms spaces or vacuoles may be defined in the soft semi-transparent protoplasm forming the body of the cell. (Fig. 2.)

After bacteria have been properly stained and fixed on

[1] "The Structure and Functions of Bacteria," by Prof. A. Fischer, translated into English by A. Coppen Jones, pp. 2, 17. The author of the present work has for many years past been engaged in the study of these simple forms of organisms; his first published work on the subject appeared as far back as the year 1869, in "A Treatise on Asiatic Cholera," written in Calcutta. Long before the cholera bacillus had been defined he had arrived, from the history and nature of this disease, at the conclusion, that it was spread by the dejecta of human beings, principally through contaminated drinking water, and that its specific cause consisted of living matter.

a glass slide we are able, in the larger forms of these beings, to see that they consist of a minute mass of protoplasm which is enclosed in a structureless cell wall or membrane. The protoplasm is arranged in the form of a mesh-work, the interspaces being occupied by a semi-fluid substance. Particles of what are probably protein materials may be seen dispersed through the protoplasm. Some of the granules stain with what are known as nuclear dyes, and probably consist of matter allied to nuclein.

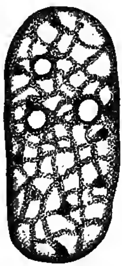

FIG. 2.—Chromatum okenii, one of the sulphur bacteria, greatly magnified. (After E. B. Wilson, "The Cell," p. 39.)

We are therefore justified in stating that a bacterium is formed of a minute mass of protoplasm containing granules, surrounded by a cell wall. Vacuoles may be seen in the protoplasmic basis substance, which, during life, are filled with cell sap. Bacteria do not contain a nucleus, but traces of a substance allied to nucleo-albumen (mycoprotein) exists in their protoplasm.[1]

The tension of the cell wall of bacteria is maintained, like that of other vegetable and animal cells, by the osmotic pressure exercised from within outwards by the contents of the cell. The water contained in the cell holds in solution mineral salts and organic compounds; the living matter which lines the interior of the cell wall is readily permeable to pure water, but is almost impermeable to the substances held in solution by the cell sap. As a result, these bodies exert a strong pressure from within outwards, and force the protoplasmic contents of the cell against the comparatively

[1] Fischer on "Structure and Functions of Bacteria," p. 53.

unyielding cell wall; our object in referring to this fact is in order to demonstrate the difference that exists in the physical state of living and of dead protoplasm. For no sooner is the life or specific molecular arrangement of matter of the cell abolished, than the protoplasm loses its impermeability, and presents no hindrance to the escape of the substances held in solution.[1] Dr J. O. Wakelin Barrett in his researches into the subject of chemiotaxis in *Paramoecia* finds "that an essential difference exists between the staining reaction of the cell-protoplasm of living and dead paramoecia, when both are exposed to the action of acids and alkalies." He states that the action of acids and alkalies upon living protoplasm is of a different order from that on dead protoplasm.[2]

Assimilation carried on by the living matter of Bacteria.—The living matter which forms the essential part of a bacterium is constantly at work during the life of the organism, and this entails the wearing out and disintegration of some of its component elements, which then become detached from their molecules. But as the organism during its life retains its form and functions, it is evident that this effete matter must be replaced by materials derived from the external world; and as the living matter of a bacterium is enclosed by a cell wall, nutrient materials can only gain access to the protoplasm in a state of solution.

Even the largest bacteria are of such a minute size that under the highest powers of the microscope it is

[1] "Physical Chemistry and its Application to Medical and Biological Science," by Prof. A. Findley, pp. 12, 19. Also Fischer, p. 53.

[2] *British Medical Journal*, 18th July 1904, p. 1413 of "Scientific Grants Committee" (Supplement).

almost impossible to follow any changes taking place within these organisms. In some of the lowest forms of algæ however, which are structurally allied to bacteria, we observe that when starved their protoplasm assumes a transparent appearance, and shrinks into a small mass within the cell. But if these same cells are supplied with suitable food and kept at a proper temperature, their protoplasm spreads and fills the cell, and that part of it which immediately surrounds the vacuoles in the living matter at the same time becomes crowded with minute granules of materials known as enzymes. These enzymes are catalysts of a colloidal nature, and obey the usual laws of catalytic phenomena.[1]

A catalyst is a body which by its presence accelerates (or in some cases retards) a chemical reaction, a conspicuous character of living matter, analogous to the action of a minute quantity of finely divided platinum in effecting the rapid combination of oxygen and hydrogen to produce water. *Colloids* are jelly-like substances composed of large molecules possessing slow movement (inertia), and at the same time chemical mobility, p. 181, *Science Progress.*

Enzymes are produced by living protoplasm. We might almost venture to say they are a part of its colloidal substance, for they retain one of its characteristic functions of performing a large amount of work without loss of substance, and with the expenditure of a comparatively small amount of energy. Enzymes are in fact a form of matter having specific properties as transformers of energy, by means of which they break up the food-stuff brought to the vacuoles of the cell into simpler compounds, and some of these after undergoing

[1] "The Nature of Enzymes," by W. M. Bayliss. "Science Progress," edited by N. H. Alcock, M.D., and W.G. Freeman, No. 2, p. 305.

further change are capable of becoming a veritable part of the living substance of the cell. It is therefore through means of the processes set up by the action of enzymes, that food-stuff taken into the cell is converted into a form capable of being *assimilated* by the living substance of the cell, and thus of replacing its worn-out protoplasmic elements. These non-living substances thus become a part of the living working substance of the organism.[1]

Professor Huxley, when referring to the power possessed by living matter of changing the character of certain substances which are brought into contact with it (known as metabolism), in terms not altogether metaphorical, observes that the atoms which enter the substance of living cells are for the most part piled up in heaps, and tumble down into smaller heaps before they leave it. The energy which is set free in the tumbling down of these atoms is one of the sources of active power of the organism.[2] This must be the case, for the latent energy contained in the raw food brought

[1] It is well to notice that there is a difference in the effects produced by chloroform and ether on living protoplasm and on enzymes. The activities carried on by living matter being completely suspended so long as the organism is subjected to the influence of a weak anæsthetic, but in the case of enzymes their action is not prevented by dilute solutions of chloroform, although in certain cases it has a more or less retarding action.

[2] The action of the various kinds of enzymes is in the first place to produce proteids from the raw materials brought under their influence; the proteid molecules are smaller than those of the original albumin and are known as albuminoses. The next stage is the formation of still smaller molecules of peptone, and finally the peptone breaks up into simple crystalline materials of known composition, which no longer give the typical proteid reaction. See British Med. Journal, Jan. 27, 1906, p. 221. An able resumé of this subject by J. Reynolds Green is published in *Science Progress*, No. 3, Jan. 1907, p. 427.

into the cell is liberated when its elements are broken up into simpler compounds by the action of the enzymes. The latent energy thus liberated is transformed by the living matter of the cell into work, such as that of building up the substance it receives into the space left vacant by its worn-out atoms.

The amount of nutrient matter entering a bacterium or one of the lower forms of algæ would seem to be regulated by its requirements.[1] The living matter of the cell, as we have stated, in performing its functions uses up a portion of its energy and sheds its effete matter; it then shrinks into a small compass, and is, we presume, in an exhausted condition. In contracting, the protoplasm allows of the ingress of a fresh supply of albumin and other substances, which is tantamount to a renewal of its energy, and so to its power of resuming its functions. But in order to carry on this work the effete protoplasmic materials, and much of the refuse substances formed from the action of the enzymes must be removed from the organism, otherwise its living matter would speedily be clogged and unable to carry on its work.

Respiration.—Bacteria are divided into two main groups, the *Aerobes*, in which the process of respiration is carried on in the same way as in all ordinary organisms, by the absorption of oxygen and the extrusion of carbonic acid and moisture. The other groups consist-

[1] An idea of the extent and complexity of this subject may be formed when it is stated that the most recent work on it extends over three large volumes of closely printed matter. But even this work is not intended as a "complete study in normal metabolism, and still less in physiological chemistry." P. i. vol. i., *Metabolism and Practical Medicine. By Carl Von Noorden. (English issue under the editorship of Professor T. Walker Hall.)*

ing of *Anaerobic* bacteria are found everywhere in nature where air cannot penetrate or where it is replaced by other gases—in the deeper layers of the soil, at the bottom of the sea, and so on, where they set up active fermentation and putrefactive processes, and so effect the disintegration and removal of dead animals and plants.

The physico-chemical processes involved in the oxidation of the effete matter contained in the cells of the aerobic bacteria is a complex subject, and beyond the scope of this work, but the final result of these processes is carbonic acid and water, which are extruded from the cell. It appears, however, that a portion of the oxygen which enters the cell passes into relations with its molecules, which in their turn readily transfer it to refuse substances formed from the living matter, which are thus directly oxidised. Chemical changes of this nature are attended with the liberation of energy, which is one of the principal sources of the supply of latent force with which the living protoplasm of the cell is charged. All energy set free in the body of the organism leaves as heat, in so far as energy of work is not transferred outwards.[1]

The structural arrangement and motion of the elements forming the living protoplasm of all organisms are not identical in character.—We presume it is in consequence of modifications in the relation of the atoms forming its molecules, that this matter is capable of being adapted to alterations in its environment; alterations thus established become hereditary characters of the different kinds of protoplasm. This fact is

[1] P. 185, vol. i., "Metabolism and Practical Medicine," by Carl Von Noorden.

illustrated in reference to the two groups of bacteria. The living matter of one group flourishes in our atmosphere while the other group is destroyed by it. The living matter of both groups of organisms is composed of the same elements, but these elements have a different arrangement and motion in the one group of bacteria to that which prevails in the other group. Mr Hardy illustrates this point in reference to two chemical substances, each composed of seven atoms of carbon, five of hydrogen, and one of nitrogen. There is a small difference in the arrangement of these atoms; and this slight difference in the molecular architecture of these two substances completely alters their characters; the one being a harmless aromatic fluid, and the other an offensive poison.[1] And so it is with relation to the structural arrangement and motion of the elements forming the living matter of the two groups of bacteria, a slight alteration in this respect probably alters their properties. Beyond this, alterations of the molecular arrangement of living matter of the kind referred to, become in the course of time a fixed character, and are transmitted from one generation to another in these orders of beings.[2]

[1] *Science Progress*, October 1906, p. 196. The substances referred to are known as benzonitrile and phenylisocyanide.

[2] This fact seems to be substantiated by observations made on the egg of an Ascidian by Prof. Calkins. He describes the protoplasm of this egg as consisting naturally of differently coloured protoplasms, each of which gives rise to a different kind of structure in the body of the animal which is derived from this egg. The deep yellow protoplasm produces the animal's muscular system, the light grey the brain, the transparent the skin, and so on. This egg, therefore, contains different kinds of protoplasm distinguishable by their optical differences, but not structurally, so far as our microscopes enable us to define their arrangement.—*Journ. Exp. Zool.*, ii. 1905.

Changes in the molecular structure of the living matter of bacteria are not to be regarded as a sudden transition from one kind of proteid to another; on the other hand we may trace upwards a progressive advance from the living substance forming the bodies of bacteria occupying the lowest rung of the ladder of life, till we reach those which respire in the same manner as ordinary plants and animals. For instance the nitrifying bacteria form a group of beings constantly at work in the soil of every part of the world, preparing food for plants; the materials from which they build up their cells are obtained from inorganic compounds of the simplest character, carbon dioxide, and ammonia, or nitrous acid, with a few mineral salts. The energy necessary for the processes of life is gained by the nitrifying bacteria from oxidation of ammonia, or nitrous acid. The building up of their proteids, therefore, is of the simplest conceivable nature. From this group we pass to that of the bacteria, whose living matter can only carry on its work at the bottom of the ocean, or in other places from which our atmosphere is excluded, to a host of bacteria representing every gradation as to their supply of oxygen, some existing with a very small amount and for a time with none at all; until we arrive at the group which can only carry on their work with a plentiful supply of oxygen.[1]

Circulation carried on by living matter.—A free circulation of water through the substance of the living matter of all forms of bacteria is essential to their existence. It is by the interchange of the external and internal fluid of the cell that nutrient materials gain access to the protoplasm, and the by-products formed

[1] Fischer, pp. 61, 106.

from its effete elements escape externally. In fact, the functions of this matter can only be carried on by means of a free circulation of water through its substance.

Sensitivity or Irritability of living matter.—In the previous chapter we referred to the fact that Hertzian waves after passing over hundreds of miles, and whose energy therefore must be extremely feeble, nevertheless profoundly modify the structure of the metals they reach, since they change in a marked degree their electric conductibility. This extreme sensitiveness or irritability of matter and its consequent motile properties are marked characters of living matter.

The agent or form of energy which excites the living matter to action is known as a *stimulus*; movement or other work thus effected by living matter is described as being a *response* or reaction to the stimulus.

For instance if the upper surface of the leaf of a growing sensitive plant is lightly touched or stimulated, the living matter of its cells, from the point of contact, responds by a movement which folds up the leaf. The stimulus applied to the upper surface of the leaf passes from the point touched to the surrounding living matter of the cells forming its upper sensitive surface; a portion of the latent energy of this matter is thus liberated, and becomes manifest in the motion of the leaf. It is to be observed that motion of this kind is suspended if the leaf is exposed to the action of chloroform or ether; and after repeated and rapid application of the stimulus and movement of the leaf, its latent energy for a time becomes exhausted, and it then ceases to respond when irritated, until it has gained a fresh supply of working energy derived from the constant chemical processes going on in the cell.

The locomotor apparatus of bacteria consists of one, or it may be many slender filaments of protoplasm extending outwards from the living matter which constitutes its body. These filaments of living matter are known as *cilia*, the longer ones are called *flagella* (Fig. 3).

In a healthy, well-fed bacterium its cilia are constantly in motion, and it is by means of their action that the organism is propelled through the water.[1] If ciliated bacteria are exposed to an acid medium or to one containing a minute percentage of chloroform their movements cease, but will be resumed if these same organisms are removed to a neutral solution of sugar or to one containing asparagine.

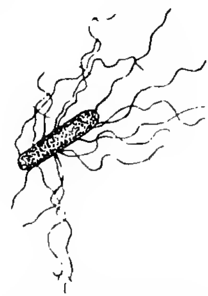

Fig. 3.—***Plectridium paludosum*, showing the body and cilia of the organism. (After A. Fischer.)**

Spore formation in Bacteria.—The living matter of a bacterium is killed if exposed to a temperature above a certain point; want of moisture, of food, and many other conditions to which these organisms are exposed destroy them; nevertheless several species of bacteria have continued to flourish from the carboniferous period up to the present time.[2] The preservation of these species, in a large measure, is attributable to the power

[1] We defer our remarks regarding the exciting causes of the motion of cilia end flagella to our fourth chapter.

[2] Fischer, p. 161.

which their living matter possesses of forming what is known as a spore or a reproductive germ, which in favourable conditions, produces a being precisely similar to the organism from which it proceeded. The process of spore formation, as we shall explain, differs from that followed in the ordinary reproduction of bacteria which in a suitable environment, consists in the division of a fully grown parent into two beings, a process which leads to a very rapid proliferation of these organisms. In many species of bacteria, spore formation only becomes active when the organisms are exposed to unfavourable conditions, and would seem therefore to indicate a tendency on the part of a portion of their living matter to become adjusted to the action of these inimical forces, and so to guard the species from destruction.[1] Before arriving at any such conclusion we must, however, take into consideration the fact that some bacteria possess a remarkable power of resisting, what to other species are destructive influences, without producing spores, and that in many other species spore formation appears to form a part of their life cycle under favourable as well as unfavourable conditions; but, as a general rule, it may be said that if bacteria are exposed to an unsuitable environment their living matter forms a spore or reproductive germ capable of resisting these inimical conditions.[2]

We may best follow the changes which occur in the living matter of a bacterium during the process of sporulation, by watching this process in some of

[1] In applying the term unfavourable or harmful conditions to an organism, we imply that its living matter is not in a state of equilibrium with the forces by which it is surrounded.

[2] See The Horace Dobell Lecture for 1904, delivered by Prof. E. Klein.

the larger species, such for instance as *Clostridium butyricum* or the *Plectridium paludosum*, Figs. 3 and 4, which are actively motile organisms, the latter inhabiting marsh water.

In these bacteria, sporulation commences by the aggregation of a minute particle of the living matter of the cell into a glistening globular mass, which at

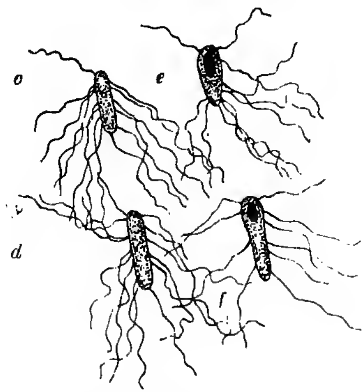

FIG. 4.—*c*, *Clostridium butyricum* in its resting, and *e*, in sporulating stage. *d*, *Plectridium paludosum* in its resting, and *f*, in sporulating stage. Magn. about 1200. (After Fischer.)

first lies loose in the cell and stains slightly with nuclear dyes.[1] In a brief space of time this mass of living matter becomes enclosed in a resisting membrane, and is then difficult to stain. That part of the bacterium in which the spore is forming bulges outwards; the rest of the protoplasm of the cell, however, retains its structure and functions; its cilia continue to act, showing that the greater part of the living

[1] See also Klein, on Micro-organisms and Disease, p. 81.

matter of the organism is still able to carry on its metabolic, respiratory, and other processes. In this stage of sporulation therefore, the living matter of the bacterium has separated into two kinds of matter the one forming the germ or reproductive substance, while the other constitutes the body or somatic elements of the organism; the function of the latter is to protect and to nourish the germ until it is fit to grow into a new being. The spore with its protective cell wall being fit to maintain an independent existence, the somatic matter or body of the cell perishes, but the germ with its living contents continues to exist until it reaches a suitable environment for its growth, when it produces a new being having the same form and functions as were possessed by the parent organism.

In the butyric acid bacteria, granulose is at first absent, but is formed when the time of sporulation draws near.[1] In that part of the bacterium, however, where the spore appears, no granulose is formed, the protoplasm staining from first to last yellow with iodine. It would seem that in these organisms there are indications of a differentiation of the living matter of the cell, one part being devoted to sporulation or reproduction, and the other portion serving as a manufactory and store-house for granulose, from which the spore may be nourished.[2]

The significance of the process of sporulation to which we have referred, as Prof. Fischer remarks, lies "not in the shape, but in the differentiation of the cell

[1] Granulose is a carbohydrate constituent of starch, which turns blue when treated with iodine; it is an important nutritive material employed by the living protoplasm in its metabolic and respiratory processes.

[2] Fischer, "The Structure and Functions of Bacteria," pp. 13, 19.

contents into two parts, one for the maintenance of life in the organism, the other subservient to reproduction." We may add that this remark applies to a non-nucleated class of beings, consisting of the simplest known kind of living matter, and further that the process of sporulation in bacteria has been repeated, from one generation to another, from the carboniferous period up to the present day.

The effect of the environment on sporulation is marked; for instance, after a number of bacteria have given origin to many generations of like organisms by reproductive processes, their descendants become weak, and in this condition are unable to produce spores. If sporulating bacteria are exposed to direct sunlight, or to a higher than their normal temperature, they may completely lose their power of forming spores so long as they are kept in one or other of these conditions. But if bacteria which have thus become sporeless are removed to a favourable environment they regain their power of forming spores.

If certain of the bacteria, which under favourable conditions produce colouring matter, are kept at a temperature a little below that which destroys them, they lose their power of producing this matter. The longer such bacteria are kept in this unfavourable environment, the greater are the number of generations their descendents (when removed to a normal temperature) take, before they regain their power of producing pigment.

Yeast cells consist of a membrane enclosing a protoplasmic body, which is said to contain a nucleus.[1]

[1] "The Nucleus of the Yeast Plant," by H. Wager. "Annals of Botany," vol. xii., Dec. 1898, p. 499.

These cells form a round or oval being usually many times larger than bacteria; they reproduce themselves by budding and not by dividing into two equal parts. Endeavours have been made, as in the case of bacteria, by a change of environment to form a sporeless variety of yeast cells. Sporulation may thus be suppressed for subsequent generations, and the fermenting powers of the yeast slightly altered. But when mixed with earth the sporeless varieties die out in a year, whereas the unaltered spore-bearing forms of the same species live, it may be, for three years under the same conditions. It would therefore seem that a general weakening of the living matter of both bacteria and of the yeast cell, is produced by unfavourable surrounding conditions which can be restored under more favourable circumstances.

But although the attempt to form sporeless varieties of these organisms has failed, we must bear in mind the fact that our experiments can only be carried on for a brief period, and may therefore be unable to bring about a lasting hereditary change in the structure of the living matter which forms the bodies of bacteria.

In the case of yeast cells it is possible to obtain races with more or less permanently altered physiological functions—"races that produce more or less alcohol than the parent form, or in which the by-products of fermentation are different or present in different proportions."[1] Mr H. M. Vernon, referring to the sporulation of certain fungi observes, that their "adaptation to a concentrated salt solution was not entirely lost, even after rearing in a normal medium,

[1] Fischer, p. 129. By physiological functions we mean the vital phenomena characteristic of the living organisms.

or was in some degree hereditary, especially in the case of adaptations produced by the growth of two or more generations in salt solutions. Doubtless the inheritance of acquired characters was due to the salt solution influencing the germ cell at the same time as the body of the cell."[1]

Reproduction of the Living Matter of Bacteria.—The

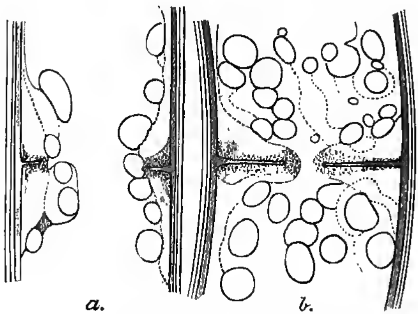

FIG. 4A.—Transverse division of an alga (*Cladophora fracta*). In Fig. *a* the new transverse cell-membrane grows out as a ring at right angles to the sides of the cell and appears (in optical section) as rod-like outgrowths from the latter, the free ends being surrounded by granular protoplasm. The large round bodies are starch grains. Fig. *b* represents an older stage, the new membrane is complete with the exception of a small spot in the centre. The figure is meant to give an idea of what probably takes place during the fission of bacteria which are too minute to allow the process to be followed. (From Strasburger.) Magn. 600. (After A. Fischer, p. 17.)

living matter of bacteria when placed in a favourable environment multiplies with great rapidity, but in consequence of the minute size of these organisms it is impossible to follow the changes which take place in their cell contents during the process of proliferation. We know that reproduction in bacteria is asexual,

[1] H. M. Vernon, "Variation in Animals and Plants," p. 378.

taking place by the division of the parent cell into the daughter cells, which assume precisely the same form and functions as the organism from which they were derived. Some of the lowest and simplest genera of algæ are structurally very like some of the bacteria; at the time of the reproduction of these beings a ring of granular matter spreads from the protoplasmic lining of the cell on the plane through which it is about to divide. This granular matter sometimes stains faintly with nuclear dyes; at other times no such reaction is produced, but whether this matter is or is not composed of some form of mycoprotein, it appears to be the agent which produces a structure like, and continuous with, that of the cell wall (Fig. 4). The structure thus produced stretches across the cell, and may split so as to divide the cell into symmetrical halves which come to form two free algæ; or the two parts of the bisected cell may remain united, and by frequent repetition of the above process form a chain of cells or a filament. In cells which become completely separated from one another fission takes place from without inwards, so that at one stage of this process the organism assumes an hour-glass shape.

From the account we have given in the preceding pages, regarding the fundamental properties possessed by one of the simplest known forms of living matter, we learn that it breaks up nutrient substances brought under its action into simpler compounds, which it *assimilates*, and so replaces its worn-out elements; in effecting these processes it gains a store of potential energy. This living matter also *respires*, and thus converts many of the by-products and the effete elements of the body of the cell into a form, capable of passing out of the cell—that is, of being *excreted*. These processes are a further source of potential energy, whereby the living matter is enabled to perform its functions. A stream of water *circulates* through this living matter, conveying nutriment to and excrementitious matter from its substance. The living matter we have referred to *reproduces* its like, is highly *sensitive* to external impressions, and, in response to stimuli, effects the active *movements* of many of the bacteria.

Whatever additional functions specialised forms of living matter may perform—that is, whether it takes the form of a nerve, muscle, or gland cell, it invariably carries on the fundamental properties to which we have above referred.

We are unable to state if there is any difference in the chemical composition of living and of dead protoplasm, but they differ essentially from one another as regards their physical properties. The elements constituting the undifferentiated living matter of the simplest forms of organisms, under the action of various modes of energy, undergo modifications whereby the internal and the external forces acting on it are brought into a state of equilibration.

Although the living protoplasm of organisms such as the bacteria has not become differentiated into special organs, it nevertheless accomplishes all the functions performed by specialised structures or organs, such as those which exist in the higher classes of beings.

The living matter forming a bacterium having grown to a certain size under the action of physical laws, separates into two parts, each of which retains all the properties inherent in the living matter from which they proceeded. These parts rapidly assume the form and dimensions of the parent organism; the characters therefore possessed by the parent bacterium are inherited by its descendants without the aid of a nucleus, or, so far as we know, of fully formed nuclein. We conclude therefore that the living matter of these organisms is the sole agent necessary for the hereditary transmission of the characters possessed by these beings, which constitute the most prolific, numerous, and one of the most ancient classes of organisms in the world.

New varieties of bacteria are constantly arising, old ones dying out and being replaced by others with recently acquired powers, but they revert, as a rule, to the original type when the action of the environment which has produced these varieties is removed, and the original conditions of life are restored.[1]

We cannot produce new species of bacteria, but this inability may be accounted for by the fact, that our experiments can only be carried on during a limited period, compared with the length of time which we have reason to believe it takes, in the natural course of evolution, to effect such stable molecular changes in living matter, as are necessary to give rise to a new species. If this difficulty could be overcome, we have still to learn the precise amount, and mode of action on living matter, of the various forces necessary to effect such modifications of its constituent elements, as would lead to the production of a new species.

[1] Fischer, pp. 25, 30, 111.

CHAPTER III

Some of the structures produced by the action of the environment on the living matter of unicellular animals are described—action of this kind must persist through many generations of these beings before they can become fixed characters—the growth of living matter.

WE may now proceed to consider how living matter, while performing its fundamental functions, has come to develop certain structures and organs. In the preceding chapter we referred to the general adaptability of living protoplasm to its environment independently of special organs. But as the habits of unicellular organisms became more complicated, we find that the living protoplasm of their cells produces definite organs or structures adapted to perform special functions. In still higher classes of beings, further modifications occur, and groups of cells come to form the organs of a complex body.

The effects caused by changes in the environment or external modes of energy on the living matter of unicellular organisms.—Lamarck, in the year 1801, states that "it is not the organs, *i.e.* the nature and form of the parts of the body of an animal which give rise to the special habits and faculties, but on the contrary its habits, its mode of life, and the circumstances in which individuals are placed, which have, *with time*, brought about the form of its body, the number and condition of its organs, finally the faculties it possesses. The circumstances which nature employs to bring about variations are principally the influence of climate, difference of temperature, the state of the atmosphere, and from all environing surroundings, from diversity of place and situation, of habitual movements, finally from that of the means of preservation, of the mode of life, of defence, of reproduction. Moreover, as the result of these different influences the faculties increase and strengthen themselves by use, diversify themselves by the new habits preserved through long periods, and insensibly the conformation, the consistence — in a word, the nature and state of the parts and also of the organs—consequently participate in all these influences, which are preserved, and propagate themselves by generation.[1]

Lamarck refers to the marked changes which follow in the form of the leaf of certain plants when grown in the water and on dry land, also of rushes and grasses; and he adds, "The same thing happens to animals which circumstances have forced to change their climate, manner of living, and habits; but for these the influences of the causes which I have cited need still more time than in the case of plants to produce the notable changes in the individual, though in the long run however, they always succeed in bringing them about."

Professor G. Henslow has paid special attention to the subject of the evolution and adaptation of plants, and has arrived at the conclusion, upon what seems to be sound evidence, that "all plants apparently have the

[1] "Système des Animaux sans Vertèbres," p. 12. See Lamarck, "The Founder of Evolution," by A. S. Packard, pp. 243, 244. Idem, p. 267.

power to vary under altered conditions of life. In nature this power shows itself in response, if not in useful adaptations, to the environment."[1]

We have already referred to the fact, that slight modifications in the relation to one another of the atoms composing certain chemical substances, cause a marked and persistent effect on the properties of these bodies. M. Perrin illustrates this action, and has shown that by the use of minute amounts of salts, we may give to the surface energy of solids a certain direction, so as to fix in this layer qualities which define its electric properties. The effect once produced cannot be undone; the salt can be removed, the effect it has caused remains. So far as we know, in the absence of active chemical intervention it will endure for all time, always exerting a directive influence upon the molecular events in its neighbourhood.[2]

Metals, such as gold or platinum, by various processes which it is unnecessary for us to describe, may be made to pass into a colloidal state; the metal passing into such a fine state of division that, in solution, it appears homogeneous under high powers of the microscope; it passes through the finest filter paper. In fact a metal when brought into this colloidal state in some respects resembles an organic compound, its activities being abolished by certain poisons. Like enzymes (p. 22) metals in this condition act by their presence alone—that is without appearing in the final product of the reaction.[3]

[1] "Vegetative Sports and Floral Freaks," J. Hort. Soc., Dec. 1906, p. 1.

[2] See note, p. 22, also *Journ. d. Chim. Physique*, ii. p. 61 and iii. p. 50.

[3] Le Bon, "Evolution of Matter," pp. 302, 303.

The very large and extremely complex molecules constituting living matter, without doubt, differ greatly in the structural arrangement and motion of their elements, from either dead proteids or inorganic matter; nevertheless, the modifications which are produced in the properties of these bodies by the action of external modes of energy enable us, to some extent, to realise those which we believe under similar conditions take place in the protoplasm of living cells.

With regard to the action of the environment on the living matter of bacteria, we have referred to the fact, that, if exposed to a somewhat higher temperature than the one in which they flourish, their power of sporulating is hindered (p. 33). Under similar conditions some of the colour-bearing bacteria fail to form pigment; the function ordinarily performed by their living protoplasm of producing colouring matter is weakened, and this incapacity continues the longer in succeeding generations, in proportion to the length of time the parent organisms have been exposed to the action of the harmful environment. Certain groups of bacteria become readily altered in form and function if exposed to a high temperature, or to a 0·1 per cent. solution of asparagine, and so on; crippled and deformed beings of this kind may be produced if grown in a medium which contains an excess of their own secretions.

The effect of the exposure to direct sunlight for even a few hours, is sufficient to weaken the characteristic functions carried on by the living matter of certain bacteria. A strong electric current kills the living matter of bacteria as it does that of all vegetable and animal cells. Under a weak current bacteria cluster round the negative pole, and structural modifications of their living matter occur under these conditions, for we notice that the positive end of the organisms becomes swollen while the negative end contracts.

It is, however, in the mutability of the functions performed by these organisms, that we notice most clearly the effects of changes in their environment on their living matter.

Bacteria possess within certain limits the power of living on different kinds of substances, the composition of which determines, in a great measure, the nature of the chemical products of these beings. For instance some of the butyric bacteria possessing specific fermenting powers, are able to break up albuminous compounds; others of this order can live in the tissues of the animal body. We find other forms of bacteria which are able to grow on non-putrefactive substances and cause them to ferment.

Certain classes of bacteria if introduced into the body of a healthy animal produce no ill effects, but other genera of these organisms after gaining access to the interior of the living body give rise to infectious diseases; they are in fact parasites living and flourishing at the expense of their host. In addition to the harmless and the parasitic bacteria a third class exist, which Prof. Klein calls "conditional parasites." These organisms when present in the body of a healthy animal are harmless, but if the tissues of the animal they inhabit become injured by disease or otherwise, they crowd into the damaged structures, and there set up it may be dangerous inflammatory action. The functions therefore performed by the living matter of these bacteria vary with the nature of its environment. As Prof. Klein states, there is evidence to show that a class of organisms exist which, under ordinary conditions are harmless, but under altered conditions may produce serious disease, and thrive on the tissues of their host.[1] We are unable to detect any structural difference in these organisms when they pass from a harmless to a parasitic condition; nevertheless, modifications in the arrangement and motion of their constituent elements must have been effected by the change of environment, otherwise their functions would not have undergone so marked an alteration as that to which we have referred. If however we assume, that a molecular change in the living matter of organisms can be effected by means of a change in their environment, we can understand why, in healthy tissues, these bacteria are harmless, while in damaged living matter they become dangerous.

Further evidence regarding the adaptation of the living matter of animals to its environment is afforded, by the power it possesses of becoming adjusted to, or tolerant of, the poison produced by bacteria and other chemical substances. For instance, if the poison produced by the diphtheritic bacteria is injected into the body of an animal in an extremely minute quantity, no appreciable effect is produced; after a few days a rather larger dose of this poison may be introduced into the body of the animal, and still no ill effects follow. By degrees the dose of the poison may be increased without causing any serious consequences, until the animal is able to tolerate a dose which would at once kill it, if it had not been previously rendered tolerant in the manner above

[1] "The Horace Dobell Lecture," delivered by Prof. E. Klein, Nov. 22nd, 1904.

described. Immunity to the action of such poisons may be acquired through structural modifications in the elements forming the living matter acted on by the poison.[1] This state of affairs we apprehend, is brought about through the slow action of an environment, generated by the chemical properties of the poison on the elements of certain parts of the living matter of the immune animal.[2]

In the case of unicellular organisms such as the sporozoa, which include many of the internal parasites, Prof. E. A. Minchin observes that they "have acquired each an organisation in harmony with certain special conditions of life, and except for a brief period of their developmental cycle, they cannot exist apart from the very definite and limited environment to which they are exclusively adapted."[3] For instance, if a human being suffering from malarial fever is bitten by an Anopheles mosquito, the gnat draws into its stomach from the patient's blood various cells and organisms which are speedily digested, with the exception of the germs or gametocytes of malaria, which continue to develop in the mosquito's stomach. After passing through definite changes in the cells lining the intestinal canal of the Anopheles mosquito, beings are produced which enter the salivary glands of the gnat; when so charged if the mosquito bites, it may be a healthy man, it introduces the malarial spore into his blood, and thus leads to an attack of this form of fever.

[1] We know how in this way people may become tolerant to large doses of opium, arsenic, and other poisons.

[2] Fischer on "The Bacteria," pp. 29, 167, 135.

[3] "Treatise on Zoology," edited by Sir E. Ray Lankester, pp. 151, 249, part i. Article on "The Sporozoa," by Prof. E. A. Minchin.

No other means of propagating malarial disease is known except through the agency of the genus Anopheles. For if a malarial patient be bitten by a mosquito of any other genus, such as one belonging to the species of Culex, the malarial spore containing cysts are at once digested in the gnat's stomach. Culex, in fact, stands in the same relation to the malarial parasites of birds as Anopheles to those of man.

We cannot discover any difference between the stomachs of these two kinds of mosquitoes; nevertheless, it is evident they differ from one another physiologically, and demonstrate the accuracy of the statement we have quoted from Prof. Minchin's work. Further, the life-cycle of the malarial parasite shows us that apparently insignificant differences of the environment in which living matter is placed, may affect not only its development but its very existence.

Prof. A. Dendy, when referring to this subject, observes that it is hardly necessary to point out that the individual organism must be in a state of equilibrium with its environment to flourish, and that any change in the environment may, if sufficiently long continued, act as a stimulus upon the organism, and cause a definite response to be made by the latter [1]—ideas which to us seem to be not far removed from those enunciated by Lamarck, p. 39, at the commencement of the last century.

Plastids and Chlorophyll-bodies.—We now come to

[1] "The Nature of Heredity," by Dr A. Dendy, F.R.S., Prof. of Zoology, King's College, University of London. See also Jour. Hort. Soc., vol. 29, Dec. 1904. Rev. Prof. Henslow on "The Heredity of acquired characters in Plants."

consider the differentiation of living matter into definite organs within the cell. When referring to the movement of the cilia of bacteria and of sensitive plants, we stated that motion of this description resulted from the action of energy liberated from the living matter of the cell in response to a mechanical stimulus; but movements of this kind are also capable of being effected by other modes of energy. For instance, the Bacterium photometricum remains at rest until it has been exposed for a short time to sunlight, when it becomes actively motile, and continues so until it is placed in the dark.[1] Again, plants such as the Mimosa, if kept in the dark for some days lose their power of movement. The leaflets of this plant fold up in the dark, and change their position gradually with the advent of full and of fading sunlight. These and many other familiar examples of the influence of light on the movements of plants show, that this form of energy exercises a direct influence as a stimulus or liberator of the energy stored up in the protoplasm of living plant cells.

In the protoplasmic substance of most plants and some unicellular animals, granular structures may be seen which vary in size and form; the smallest of these granules are known as *microsomes* and the larger ones as *plastids* (Fig. 5). These structures have been accurately described as emerging into view from the basic substance of the living matter of the cell. The protoplasm, which, as we have frequently stated is the fundamental substance of the cell, does not appear to change, although by its presence it determines, under the action of energy received from without, the produc-

[1] "Physiology of Plants," by S. H. Vines, p. 298, 523.

tion of the plastids and other structures we are about to describe.

The development of plastids has been traced by Prof. E. B. Wilson, "to apparently liquid drops in the homogeneous or finely granular basis which is itself a liquid. Some of these spheres enlarge and form the alveolar spheres, while the homogeneous basis or

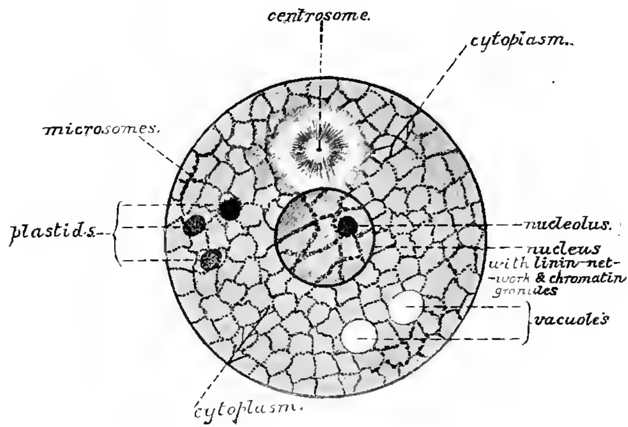

FIG. 5.—Diagram of a cell.

continuous substance remains as the interalveolar material—these elements show a continuous gradation in size—the granules being the source of all the larger elements, and in their turn emerging into view from the 'homogeneous basis' (living matter) which must itself contain, or consist of, granules still smaller."[1] Microsomes and plastids are capable of growth, reproduction, and of independent motion; their functions

[1] Prof. E. B. Wilson on "The Cell in Development and Inheritance," p. 293, also page 53.

are suspended at a temperature higher or lower than the normal, and by the same anæsthetics and chemical compounds as interfere with the action of living protoplasm.

From close observation under high powers of the microscope, we believe, that these granular structures or plastids, as Prof. Wilson states, emerge from the living basic substance of some kinds of protoplasm, and are to "be regarded as differentiations of the protoplasm substance," when it is exposed to the action of certain modes of energy.

It is well known that the colour of the leaves of plants depends on the chlorophyll or green matter which they contain. This colouring matter is formed in the granular basic substance of certain plastids. These plastids may be traced from minute colourless specks situated in the granular basis substance of the cells in which they are formed, into well-defined structures and are then known as chlorophyll-bodies.[1]

If plants are excluded from the light, the plastids contained in the cells forming their leaves and other green structures, turn a pale yellow colour, and are then found to contain a chemical compound known as etiolin, but when such plants are removed into the sunlight, provided they are kept at a certain temperature and are supplied with moisture, and a minute percentage of iron, the etiolin is changed into a green substance, that is to say into chlorophyll.

[1] Other plastids existing in the cells of plants are starch-formers, and are known as *Amyloplasts* (Wilson, p. 290). It is, however, held by other authorities on this subject that there is no evidence to show that plastids can be differentiated afresh from the general protoplasm (Prof. J. B. Farmer, F.R.S., Lankester's "Treatise on Zoology." part i. p. 25).

The chlorophyll-bodies it will be understood are formed of a living basic substance derived from the protoplasm of the cell; iucluded in this structure we find chlorophyll, a very complex chemical compound which is therefore readily decomposed. The living matter and chlorophyll in combination act as a peculiar energy transformer, that is they possess the power of absorbing the energy of certain of the rays of the solar spectrum and transmuting them into chemical energy. This latter mode of energy is employed through the agency of the living matter of the cell in forming carbohydrates from the water, and carbon-dioxide which enter the organism from without, oxygen being set free in these processes.

It is to be noticed, that the living matter of the chlorophyll-body is stimulated in the first instance into action by energy it receives from the sun, the work it is thus enabled to perform becoming manifest in the production of chlorophyll. When the fully formed chlorophyll-body is matured, it is still through means of energy it receives from the sun, that it plays so important a part in the construction of the carbohydrates from which, and other materials, substances are derived which build up vegetable structures.[1]

The movement of the chlorophyll-bodies under the influence of sunlight, is well shown by covering a portion of a leaf exposed to sunlight with some opaque

[1] It is by the action of plants that albuminoids are produced. Animals must obtain their albumen ready made; but when thus supplied their living matter makes use of it in its metabolic processes. Animal matter cannot produce the albuminoids necessary for their maintenance and reproduction. Thus the whole animal world is based on plants, p. 235. "Darwinism and the Problem of Life," by Prof. Günther.

body; on the removal of this body after a few minutes the parts covered are seen to have a deeper colour than those which were exposed. The difference of colour is due to the different distribution of the chloro-

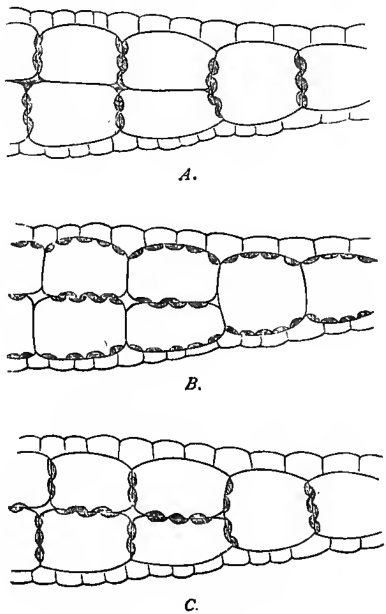

FIG. 6 (after Stahl).—Sections of the phylloid stem of *Lemna trisulca*. *A*, Position of the chlorophyll-corpuscles when the stem is exposed to intense light. *B*, Position of the corpuscles in diffused daylight. *C*, Position of the corpuscles in darkness. ("Physiology of Plants," by S. H. Vines, p. 300.)

phyll-bodies in the cells of the leaf in the two cases. In diffuse daylight, these bodies collect under the outer or free cell-walls of the superficial cells of organs consisting of several layers of cells, and on the upper and lower walls of organs consisting of only one layer of cells: whereas in direct sunlight they collect upon the lateral walls, and in darkness upon the lateral and lower walls.[1] When, however, the temperature is low, or the plant is in an unhealthy ill-nourished condition, these movements of the chlorophyll-bodies are restricted in consequence of the metabolic, and respiratory processes carried on by the living matter of the structures concerned being weakened, and its potential energy being thus lowered.

Not only are the movements of the chlorophyll-bodies in the manner above described due to the action of energy which their living matter receives from the sun, but it has been shown that their usual, if not only mode of multiplying is by division of their substance into two or more parts, under the influence of sunlight.[2]

Chromatin.—In the vast majority of plants and animals chromatin is so intimately associated with their nuclei, that we must defer much we have to say on this subject to the section we devote to the nuclei of cells. But as we hold "that all the parts of the cell arise as local differentiations of a general protoplasmic basis,"[3] it seems desirable in this place to refer to chromatin in connection with chlorophyll, and endeavour to ascertain if chromosomes (aggregations of chromatin), like the chlorophyll-bodies we have above referred to, do not arise in, and from the action of living protoplasm, and like these bodies are therefore to be considered as a form of matter which acts as a specific transformer of energy.

[1] "Physiology of Plants," by Sidney H. Vines, p. 299.

[2] Wilson, pp. 290, 327.

[3] Prof. E. B. Wilson on "The Cell in Development and Inheritance," second edition, p. 330.

Prof. Wilson, referring to this subject, observes that the "power of division shown in such protoplasmic masses as plastids, chromosomes, and nuclei, may have their root in a like power residing in the ultimate protoplasmic units of which they are made up"; he states that recent researches tend to support this conclusion.[1] This statement seems borne out in the admirable work done by Professor J. B. Farmer and J. E. S. Moore (on the "Maiotic Phase in Animals and Plants"); they state that chromosomes are to be regarded, "as the agents that are competent to produce serial changes in the protoplasm they can influence. This implies that the substance on which they work, or which they can 'activate,' must also be reckoned with."[2]

Chromatin or nuclein is a compound of proteid with a complex organic acid called nucleic acid; it differs "from a proteid, as it contains in addition to carbon, nitrogen, oxygen, hydrogen, and sulphur, 7 to 8 per cent. or even more of phosphorus in its molecule."[3] Chromatin stains with what are known as basic or nuclear dyes, whereas the protoplasm or cytoplasm of the cell stains with acid dyes. The staining reaction of chromatin depends on the nucleic acid which it contains; when the chromosomes are engaged in active work and probably contain a maximum of nucleic acid, they stain deeply.

Chromosomes appear to us to be cell organs compar-

[1] Wilson, pp. 293, 303.

[2] "The Quarterly Journal of Microscopical Science," Feb. 1905, p. 553.

[3] "Handbook of Physiology," by W. D. Halliburton, F.R.S., Prof. of Physiology, King's College, London. Seventh edition, pp. 11, 402.

able with chlorophyll-bodies, in that they act as specific transformers of energy. We hold that the nuclein of the chromosomes is produced through the agency of differentiated protoplasm, in the same way as chlorophyll is formed through the action of living plastids. The fully grown chromosomes with their living basic substance are described as passing from one to succeeding generations of nuclei; plastids also are probably propagated in this way. The chromatin, in the same nucleus, certainly varies according to its physiological condition; as Prof. Halliburton has shown, some of its constitutents are constantly being elaborated while others are breaking down into simpler products, and form a series descending from highly phosphorised bodies towards bodies such as albumins, which are specially characteristic of the cytoplasm.[1] This fact tends to confirm the idea that there is an intimate relation between the work performed by differentiated forms of living protoplasm or cytoplasm and the production of chromosomes. If this be conceded we seem able to comprehend how, that as the combined action of a living basis substance and its chlorophyll is capable of transforming energy received from the sun into a specific kind of work, so a definite form of living matter in combination with its chromatin, may perform the work manifest in the nuclear division of cells under the influence of chemical, thermal, and other modes of energy.[2]

[1] "The Chemical Physiology of the Cell," by Prof. W. D. Halliburton. Gouldstonian Lectures, British Med. Journal, 1893; also Wilson, p. 334.

[2] It is a remarkable fact that chromatin contains a large percentage of phosphorus. As we have before stated, at the time of the reproduction of bacteria, traces of this element are to be found in their protoplasm.

Centrosomes and *Centrospheres* are to be regarded like the other intracellular organs, as being produced by the action of living matter. These bodies consist of minute deeply-staining bodies, surrounded by a radiating structure or aster as it is called (Fig. 7), or it may be by an aggregation of minute particles which constitute the attraction sphere of some authors (Figs. 5 and 7). The production of centrosomes from the living protoplasm of cells may be clearly shown, at least in the lower animals, for they may be brought into existence in cytoplasm from which they were previously absent by the action of certain chemical compounds on the living matter of the cell. (Fig. 7.) Prof. Loeb finds that after treatment with magnesium chloride unfertilised sea-urchins' eggs (Abacia) may give rise to

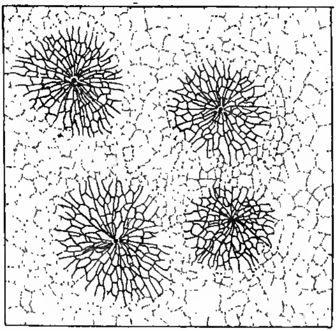

FIG. 7.—Formation of centrosomes and aster in unfertilised echinoderm egg, after being kept in sea water for six hours. (See Wilson, p. 308.)

It would therefore appear that phosphorus is present in the living matter of the cells of every description of plant and animal, and appears to take an active part (as we shall show in the following chapter) in the processes which lead to their reproduction. Dr Le Bon states that phosphorus, among other remarkable properties, is "one of the bodies with the most intense radio-activity"; its dissociation, effected it may be by chemical action going on in the living matter in the cell, might possibly assume a form of energy which becomes manifest in the changes culminating in the division of its substance into two or more portions.

perfect Pluteus larvæ—a result which places the new formation of true centrosomes beyond question (Wilson, p. 309). Thoroughly to realise the effect of changes in the environment in the production of centrosomes, it is necessary to watch not once or twice, but repeatedly

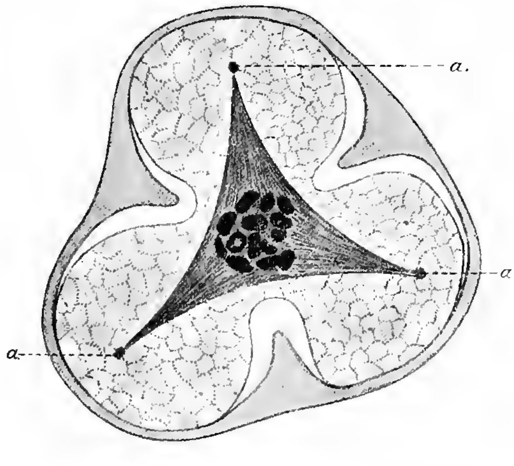

FIG. 8.—Cell of *Aneura pinguis* (species of Liverwort). *a a a*, Centrosphere with centrosomes which have formed in the granular cytoplasm of the cell. The centrosomes appear to exert tractive forces acting on the nucleus which changes its form and becomes distinctly drawn out, so that an angle of it projects to each centrosome. The dark masses in the centre of the nucleus form its chromosomes. (Profs. Bretland Farmer and J. E. S. Moore, Plate 36, Fig. 34, Quart. Jour. Mic. Science, Vol. 48.)

under varying conditions, their development out of living matter. The same conditions will not produce these bodies out of dead protoplasm.

Centrosomes, either single or paired, sometimes in considerable numbers, may be identified in the vast majority of nucleated cells (except in the higher plants) at the time of their reproduction. The centrospheres emerge from the living basic substance of the cell usually near its nucleus, but sometimes within the nucleus. They may be made to appear in considerable numbers in cells which are placed in a 1·5 per cent. solution of common salt. From the granular matter of the sphere a number of fibrils extend outwards. (Fig. 7.) Centrosomes exercise an attractive force on nuclear matter. (Fig. 8.) These bodies have been compared to the pole of a magnet, and its stellate arrangement of fibrils to iron filings attracted by the magnet; again they have been likened to a particle of radium, the granular matter and striæ representing dis-associated elements. But we possess so little definite knowledge concerning the nature of the energy and work performed by the different elements entering into the constitution of centrospheres, that it is futile to enter upon a discussion on this subject. When we come to consider the proliferation of the cells of multicellular beings, we shall have to refer to the active part taken by centrospheres in this proceeding.

The Nucleus forms the most complicated structure produced through the agency of the living matter of unicellular beings. Before proceeding to describe its development it is well to define the meaning we attach to the term nucleus.

A nucleus consists of a vesicular body, generally of a round or oval form, and it is usually situated near the middle of the protoplasmic mass which constitutes the body of the cell.[1] Nuclei consist (Figs. 5, 9):—

I. Of a nuclear membrane which, during the greater part of the life cycle of the cell, separates the

[1] There may be more than one nucleus in a cell.

nuclear contents from the surrounding cytoplasm. (Figs. 5, 9.)

II. Of a meshwork of a granular jelly-like consistency resembling in structure the cytoplasm, and like it staining with acid dyes, this nuclear meshwork is known as *linin* (thread), and is often

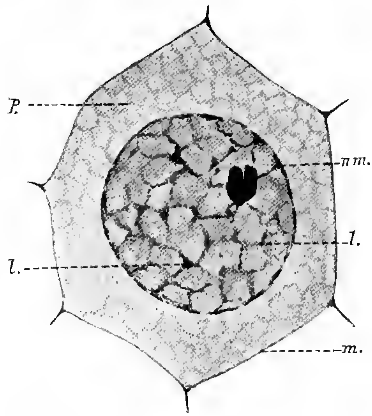

FIG. 9.—A cell about to enter on its reproductive stage. *nc*, nucleolus; *m*, cell membrane; *p*, cytoplasmic mesh-work; *nm*, membrane surrounding nucleus; *l l*, linin reticulum, in the meshes of which are chromatin granules. (Fig. taken from Fig. 8 of Prof. J. E. S. Moore's and L. E. Robinson's paper, "On Behaviour of the Nucleolus in the Spermatogenesis of Periplaneta Americana," Quart. Jour. Mic. Sc., Feb. 1905, p. 571.)

referred to as the achromatic nuclear recticulum; its meshes are filled with nuclear juice.

III. Scattered throughout the substance of the linin meshwork a multitude of granules of chromatin may be seen; some of this granular matter becomes aggregated into minute masses. So full of chromatin granules is the linin meshwork, that when an active healthy nucleus is stained with basic dyes, the deeply-coloured chromatin hides the living substance in which it is situated.

IV. Nucleoli or deeply staining bodies are found in most nuclei; these bodies play an undetermined part in the processes concerned in nuclear proliferation. Nucleoli "arise *de novo*, and not from the remains of the nucleolus present in the previous generation of cells."[1]

We may best explain the structure, and certainly one, if not the chief, function performed by the nuclei of cells, by describing their development first in a rudimentary form, such as that presented by a unicellular organism known as *Tetramitus chilomonas*.[2] This being consists of a meshwork of protoplasm, which during the resting stage of its existence contains a number of chromatin granules scattered throughout its substance. (Fig. 10.)

The protoplasmic substance of this organism is enclosed in a cell membrane or wall from one end of which four flagella extend outwards. Prof. Calkins in his work on the Protozoa states, that when a Tetramitus has reached its full growth a granular structure appears near its centre, in which a deeply-staining particle may often be detected, constituting in fact a centrosphere or attraction sphere (Fig. 10, A). So soon as the centrosphere makes its appearance in the protoplasm of the cell, the granules of chromatin leave their scattered

[1] Prof. J. E. S. Moore and L. E. Robinson, Quart. Jour. of Micro. Science, Feb. 1905, pp. 574, 579.

[2] "The Protozoa," by Prof. Gary N. Calkins, pp. 124, 251, 270.

position, and aggregate near the centrosphere, thus forming a rudimentary nucleus (Fig. 103). That such an aggregation of chromatin can only be considered as a rudimentary nucleus is evident, because the chromatin lies directly in the meshes of the protoplasmic meshwork of the cell; it is not connected with a specialised portion of this living matter so as to form a linin recticulum (Fig. 9, *l l*). Moreover, an aggregation of

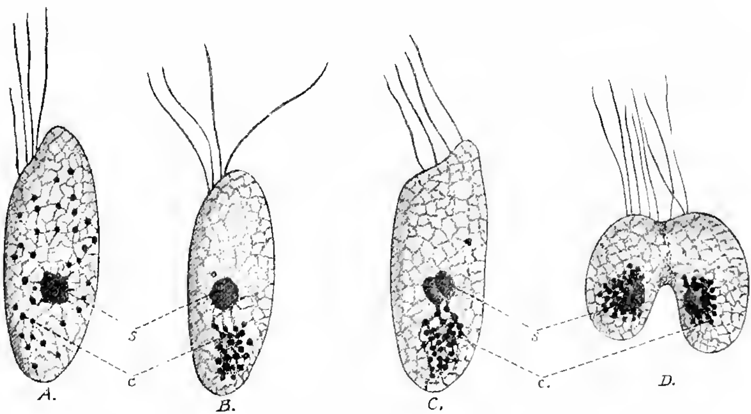

FIG. 10.—*Tetramitus chilomonas.* *A*, Ordinary form with distributed chromatin (*c*) and centrosphere (*s*). *B*, The chromatin granules are collected prior to division. *C*, The division-centre has divided. *D*, Later stage in division; each daughter nucleus is surrounded by a group of chromatin granules. (Prof. G. N. Calkins' work, "The Protozoa," p. 270.)

chromatin such as that which exists in Tetramitus is not enclosed in a membrane.

The centrosphere subsequently divides into two equal parts, which then move away from one another, and as they separate each part draws with it half of the whole quantity of chromatin (Fig. 10, c.). While these changes are in progress the body of the cell has become constricted longitudinally, so that ultimately the Tetramitus separates into two beings which rapidly assume the form and functions of the parent cell. This proceeding runs its course in a few hours, so that many generations of these organisms are produced in two or three days; but a vigorous process of this description is necessarily followed by the exhaustion of its living matter, the organism then becomes torpid, loses its flagella, and assumes a passive form. If, while in this state two of these beings meet, they join together and produce a mass round which a protective membrane forms. The living matter contained in this cyst goes through a series of changes, which terminate in its producing a number of spores, each of which in a favourable environment, may give rise to a new Tetramitus. These processes foreshadow the development of a true nucleus, and with it sexual generation.

A considerable number of other unicellular organisms, like Tetramitus, contain numerous chromatin granules scattered through the protoplasmic meshwork of the cell during its resting stage.[1] These masses of chromatin aggregate, if placed in a favourable environment, and at the time of the proliferation of the organism become concentrated towards the centre of the cell, where they collect to form a nucleus which undergoes various processes of division. "After division of the cell body the nucleus again fragments into minute scattered granules."

These facts, as Prof. Wilson observes, indicate that the nucleus and cytoplasm have arisen through the differentiation of a common protoplasmic mass. The nucleus, as Carnoy has well said, is like a house built to contain the chromatic elements, and its achromatic

[1] See Prof. Wilson on "The Cell," p. 40.

linin elements were originally a part of the general cell elements.

In a unicellular organism known as *Calcituba Polymorpha* we find from an early stage of its existence that the chromatin granules form a minute mass near the centre of the cell, and are in direct contact with its cytoplasm; in fact in this, as in every other instance throughout the whole of the animal and vegetable kingdoms, chromatin is invariably when active found in contact with a living basic substance. When a Calcituba has reached its full growth vacuoles appear in the central mass of chromatin it contains, as these spaces increase in size the chromatin is compressed into a meshwork with a more solid central portion, and a thin outer layer which forms a membrane separating the chromatin from the surrounding cytoplasm. From the central mass of condensed chromatin, bud-like processes are given off, the containing nuclear membrane disappears, and each bud, composed of a baso-chromatin material passes into the surrounding cytoplasm from which it gains an investment, and comes then to form a being from which another Calcituba may be produced.

In *Euglena viridis* the young cell contains a nucleus in which a centrosphere exists, and as the time for its reproduction approaches centrosomes appear in the granular achromatic body. The chromatin granules aggregate and form rod-like masses connected by fibres of living matter. The centrosphere elongates and forms a dumbbell-shaped body, the two ends of which remain connected by a fibrillar strand of living matter which subsequently divides. After separation the daughter division-centres with their surrounding chromatin form the starting-point of another group of Euglena.[1] In this process, as in Tetramitus, the aggregated chromatin masses divide into two apparently equal portions, which are attracted by, or at any rate follow the movements of the living protoplasmic division centres. No sooner is the life of the organism abolished than division-centres cease to form in its remains, and we may stop the production of these bodies if we suspend the action of the living matter of the cell by means of an anæsthetic.

Chromatophores are organs formed of aggregations of granular living matter, whose function it is to produce various kinds of pigmented chemical materials. The basic substance of these bodies is colourless, and has been traced back to the granular protoplasm of embryonic cells. These bodies divide and thus reproduce their like, each one of them forming its own special kind of colouring matter; under the stimulus of light they move from one to another part of the cell[2]—whence their name.

In many unicellular animals reddish-brown aggregations of pigment exist which are known as "eye-spots"; in front of such a chromatophore a lens-like body may sometimes be defined; organs of this description appear to be more sensitive to the stimulus of light than the surrounding protoplasm.

We can form some idea of the forces which have led to the development or growth of organs in beings such as those we have been considering, by referring to the

[1] "The Protozoa," by Gary N. Calkins, p. 271, also Dallinger and Drysdale. Month. Mic. Jour., 10, 11, 12, 13 for 1873; see Prof. E. B. Wilson on "The Cell in Development and Inheritance," p. 91.

[2] Alfred Binet, "The Psychic Life of Micro-organisms," p. 35.

production of colour-bearing structures in the Cyanophyceæ, one of the simpler class of plants, and in Heteromita, one of the Monadida.

In *Oscillaria tenuis,* which, except in its mode of sporulating resembles some of the coloured bacteria, a definite colour-bearing organ exists. These algæ are unicellular beings often connected end to end so as to form a filament, they do not contain a nucleus, and proliferate asexually. (Fig. 11.) The protoplasmic meshwork of these beings, especially when young, contain numerous reddish-green bodies produced, we have reason to believe, by the agency of the living matter of the cell. They are sensitive to the action of certain rays of the solar spectrum, and under the influence of energy derived from this source become attracted to the inner exposed surface of the cell-wall, where they collect and form a well-defined structure. (Fig. 11, C H.) An organ of this description having been produced in the manner described for many successive generations, and being of great advantage to those genera which have most completely developed it, has become an hereditary character of this group of plants.

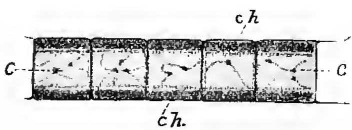

FIG. 11.—Section of a filament of Oscillaria tenuis. *ch*, hollow cylindrical chromatophore; *c*, body of the cell

Growth.—Our contention has in the preceding pages been, that the development of intracellular organs was due to reactions excited in the living matter of the cell by various modes of energy. The organisms to which we have referred, have been subjected through long ages to changes in their environment by forces engendered through slowly acting geological, meteorological, and other influences. It has been in response to these changes that the living matter has become modified, and structures produced which have brought the elements forming these organisms into harmony with surrounding forces.

It seems to us that the conditions above referred to apply also to the ordering of the limits of growth of living structures. We have described the building up of living molecules from non-living matter, and the excretion of its worn-out products; and have also said that the form and functions of the living matter is preserved by heredity in moulding successive generations after a common type, so long as they exist in a like environment. It is, however, a matter of every day experience that there is a limit to the power which living matter has of continuing to carry on these processes. Prof. Maupas, experimenting on members of a family of Infusoria, known as the Paramœcia, found that "each individual was the starting-point in a sequence of generations, there being, on an average, two generations in three days. The rate of division was recorded, and the records furnished the basis of a curve of vitality. The experiment established two points, the first being the presence of fluctuations of vitality of fairly regular character, the curve alternately rises and falls in about a month. The second is that the curve, as a whole, steadily falls, each successive rise in vitality is a little less than its predecessor, each depression a little lower, until—about the 170th generation—the race dies out."[1] Mr Woodworth draws

[1] W. B. Hardy on "The Physical Basis of Life." *Science Progress*, October 1905, p. 189.

special attention to the fact that in periods of depressed vital action the transmission of characters is imperfect. The moulding power of heredity fails, and many monsters are born.[1]

If, however, the period of decay has arrived in a Paramœcium, Prof. Calkins found that by placing the worn-out being in a vegetable infusion or in a variety of other media, the rate of growth and reproduction was re-excited, and, in place of the animal's death occurring as it would under ordinary conditions after producing 170 generations, it could be made to produce 860 generations, and was still an active organism. From these facts we learn to what a remarkable extent the physiological activity and growth of living organisms may be increased by changes in their environment.

Prof. E. H. Starling has shown that during the early stages of pregnancy, if the embryo together with the structures enclosing it are removed, the mammary glands of the animal which were rapidly enlarging cease to grow. If fœtuses which have been removed from an animal are subjected to certain processes, a chemical substance may be obtained from them which, if injected into the circulation of an unimpregnated animal will cause its mammary glands to enlarge, and if the injection of this substance is repeated at regular intervals, the glands grow to the full size they would attain had the animal been pregnant. Having reached this size the glands produce a flow of milk.[2]

[1] Journ. of Exp. Zool., ii. 1905.

[2] "The Croonian Lectures on Chemical Correlation of the Functions of the Body," by Prof. E. H. Starling, 1905. See Brit. Med. Journ.

From a series of such experiments Prof. Starling has arrived at the conclusion that a chemical substance is formed in the growing fœtus, and this substance is absorbed into the maternal circulation, that it passes to the mammary glands, and acts as an assimilative stimulus to the living protoplasm of the cells of these glands, so that their assimilation or building up processes are excited to increased action and consequent rapid growth. After the birth of the fœtus and therefore the cessation of the production of this chemical stimulant, the cells of the gland which had been built up to a high state of activity break down, and their dissimilation is accompanied by a flow of milk from the gland.[1]

Again the growth of the bones and various other tissues of the body are influenced by chemical substances produced by the action of the living matter of the cells of the thyroid gland. As a rule, the individuals described as Cretins suffer from goitre or an enlargement of the thyroid gland. The bones of young cretines cease to grow; their bodies and skulls are deformed; but the fat of their subcutaneous tissues increases, so that the child often has a bloated appearance. In these cases it is evident that certain chemical products of the cells of the thyroid gland are not properly elaborated, and the consequence is defective action of the living matter of the bone and other cells of the body, and hence their imperfect function. This idea is confirmed by the fact that if young cretins are fed with

[1] Prof. B. Moore and Dr H. E. Roaf have demonstrated the increased cell division and growth under the action of a slight alkalinity, and its inhibition on the increase of alkalinity. Proc. Roy. Soc., vol. lxxvi. and vol. lxxvii. B.

an extract made from the thyroid glands of healthy animals, the growth of their bones, etc., is carried on normally. It is therefore evident that chemical compounds produced by definite forms of living matter, exercise an important influence on their growth by directly stimulating the assimilative power of this substance.

CHAPTER IV

In response to the action of external stimuli, the outer layer of the living matter of unicellular animals produce contractile, prehensile and defensive structures.

In this chapter we propose to refer to the nature of certain structures produced from the living matter which forms the outer layer of the bodies of the Protozoa or unicellular animals. Some of these beings consist of protoplasm which has hardly become differentiated into distinct structures; others, as for instance some of the Infusoria, possess highly differentiated protoplasmic structures.

The Protozoa consist of a single cell, the protoplasmic substance of which, as a rule, forms an outer or *Ectoplasmic* layer, and an inner or *Endoplasmic* portion in which the nucleus is situated, and which constitutes the greater part of the animal's body. (Fig. 12.)[1] In the simpler forms of Protozoa no marked difference exists between these two portions of protoplasm; but in the higher classes of these unicellular animals, the ectoplasm is distinct, and in all Protozoa it is from the outer layer of the cytoplasm which is directly exposed to the action of incident forces of various kinds, that structures are produced necessary for the locomotion, the obtaining of food, defence, and the protection of the soft endoplasm and nucleus of the animal's body.[2]

[1] "The Protozoa," by Gary N. Calkins (Fig. 10), p. 36.

[2] In the higher orders of Protozoa the outer or ectoplasmic may be divided into three layers. "These layers are in all cases organically

The Protozoa or unicellular animals contain a group of beings known as the Amœba, which consist of a minute nucleated mass of naked protoplasm. The body of an amœba contracts when exposed to the action of various harmful stimuli; a reaction of this description is evidently useful in that it protects the greater part of the surface of the body from the harmful stimuli.[1] On the other hand the protoplasmic body of the animal under the action of favourable stimuli becomes extended outwards in the form of elongated processes, known as pseudopodia; a greater extent of the surface of body is thus brought into contact with the favourable environment or source of stimulation. The locomotion of the amœba is to a large extent effected by the protrusion and contraction of their pseudopodia.

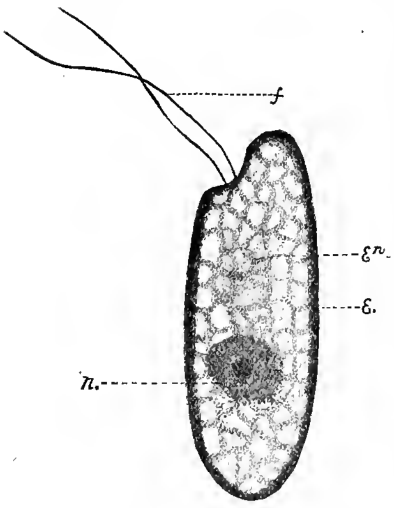

FIG. 12.—Chilomonas paramæcium. *e*, ectoplasm; *en*, endoplasm; *n*, nucleus; *f*, flagella.

The pseudopodia of some of the Rhizopoda assume the form of fine elongated fibrils, which branch

continuous, and are rightly regarded as being built up of living substance." See S. J. Hickson, on "The Infusoria," part i., p. 365; Lankester's "Treatise on Zoology."

[1] Carl Snyder in his work on "New Conceptions in Science," p. 240, states—that Campanularia if brought into contact with some solid substance retracts its extended arms and contracts into a small living

and unite so as to form an open meshwork or web of sensitive living matter.[1] Should a minute body such as a diatom while floating in the water come into contact with this slender meshwork it becomes entangled in it, and the stimulus thus applied to the living matter causes it to be retracted, and with it the morsel of food, which, after passing into the animal's body is assimilated, its elements being employed for metabolic and other purposes. Action of this description is a foreshadowing of the reflex nervous action which plays so important a part in the life cycle of the higher forms of animals.

An axial fibre may be demonstrated to exist in the elongated pseudopodia of some of the Rhizopods. Pseudopodia of this description are in fact nearly allied to flagella; some of them have a regular slow waving motion. Rudimentary flagella of this kind may be traced to intracellular bodies possessing the characters of a centrosome. (Fig. 14.)

Living organic matter possessing properties such as those to which we have referred, has in the course of time produced structures calculated to bring the internal and external forces which play on this matter into harmony; it is in this way we explain the development of pseudopodia into flagella or prehensile and protective structures.

In connection with this subject we must keep in

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mass of protoplasm. But if this mass is restored to its natural environment (water), it assumes a form which is "a direct reaction to external forces and conditions, so that the point where regrowth shall begin may be fixed at the will of the experimenter. Here the sole condition of reversibility in the evolution or devolution of this organism appears to be that of contact."

[1] See (Fig. 1), p. 49, part i., Lankester's "Treatise on Zoology." Article on the Foraminifera, by J. J. Lister, F.R.S.

mind the fact referred to by Prof. B. Moore, that changes in the physical properties of any substance implies a change of molecular equilibria, and that slight causes suffice to bring about these changes in living organic matter, in consequence of the unstable state of its molecular equilibria, which renders it specially sensitive to the action of its environment. It is easy to profoundly change the molecular and atomic equilibria of matter of this kind when it is acted on by appropriate agents; and this is a point to which we would draw special attention; it is not so much the intensity, as the form of energy which effects changes in the molecular structure and arrangement of living organic or of other kinds of matter. As Dr Gustave Le Bon observes—a well-known acoustic analogy allows this difference between the intensity, and the quality of the effort to be clearly shown from the point of view of the effect produced. The most violent thunder-clap, or the most deafening explosion may be powerless to cause the vibration of a tuning-fork, while a sound, very slight but of suitable period, will suffice to set it in motion;—showing that insignificant causes can produce great transformations in matter.[1]

An example of the results following the action of a specific form of energy on the structure of matter is afforded, by the invisible ultra-violet radiations which dissociate the atoms of a steel block, on which all the forces of mechanics would have no effect. This action depends on the fact that these rays form a stimulant to which steel is sensitive. The component parts of the

[1] "The Evolution of Matter," by Dr Gustave Le Bon. Translated from the third edition, with Introduction and Notes, by F. Legge, p. 173.

retina, on the other hand, are not sensitive to the stimulus of the ultra-violet rays, and this is why light of this kind, capable of dissociating steel, has no action on the eye which does not even perceive its presence.[1]

We may now pass on to consider the structure and development of some modification of the living matter of unicellular organisms.

Microsomes (see p. 47).—At the base of some forms of cilia a minute highly refracting body can be seen; from the deep surface of this body a process of protoplasm may be traced into the substance of the cell. (Fig. 15.) In some of the protozoa these fibrils are contractile, and are known as myoneme fibrillæ. (Fig. 13.) Microsomes are we believe produced through the agency of the living matter of the ectoplasm, and in some of the protozoa the fibrils which pass from the microsomes perform functions similar in their action to the contractile substance of muscular fibres in the higher animals. For instance, in one of the Sporozoa known as *Gregarina munieri* the forward movement of the body is effected by the contraction of the myoneme fibrils which surround the *living matter* of the cell. (Fig. 13.)

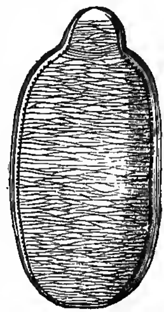

FIG. 13.—*Gregarina munieri* (A. Schn.), (par. *Timarcha tenebricosa*), showing the network of myocyte fibrillæ. (From Lankester.)

In some of the Protozoa the myoneme fibrils form bands of contractile tissue which encircle the opening leading to the central cavity of the animal's body. Bands of this description relax when the protoplasm forming the body of the animal becomes exhausted, and thus allows food to pass into its central cavity; the

[1] *Idem*, p. 177.

living matter thus regains its energy, the myonemes contract, and for the time being a further supply of food is excluded. In one of the Infusoria (*Vorticella*) we find a complicated system of spiral and other myonemes, which by their contraction and relaxation regulate the somewhat complicated movements performed by this animal.

With regard to the microsomes from which myonemes are produced, there is reason to suppose that their action depends on a form of energy analogous to that which influences the activities inherent in centrosomes. That cilia, and other protoplasmic filaments are connected with centrosomes has been recognised since the year 1896, when M. Lewis Henneguy demonstrated the connection between these forms of living matter. (Fig. 14.)

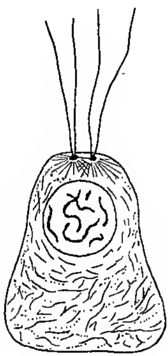

FIG. 14.

In the male cells of certain plants, Mr W. I. R. Shaw has shown that myoneme fibrils are produced which extend into the body of the cell, and that other fibrils or cilia pass outwards from centrosomes. And further, he holds as other observers do, that centrosomes arise *de novo* from living protoplasm.[1]

Cilia and Flagella. We have already referred to the cilia of bacteria (p. 29), and to the fact that the axial fibres of pseudopodia are allied to flagella both in their structure and functions (p. 71).[2]

[1] The Fertilisation of Onoclea. Ann. Bot. xii. 47. Wilson, p. 175.

[2] Prof. Calkins states that "some forms of pseudopodia change

The cilia in some of the Protozoa pass outwards from well defined microsomes, situated in the external layer of the ectoplasm.

Some of the Infusoria possess three distinct kinds of cilia alike in structure but differing in function. One set of these cilia are employed as motile organs, another set as sensory prehensile structures; the functions performed by the third set of cilia is still an open question.[1]

There can be no doubt that among their other functions cilia constitute sensory organs; that is, under

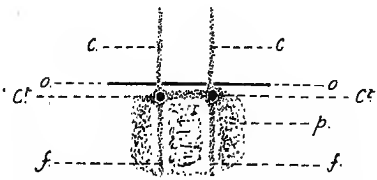

FIG. 15.—*c c*, cilia; *ct ct*, microsomes; *f f*, fibrils of protoplasm; *p*, cytoplasm of the cell.

the action of appropriate stimuli, their living protoplasm becomes the agent in conducting energy it receives from various sources to the body of the cell; a part of the potential energy of the living matter of the cell is thus released, and becomes manifest in the movements of the cilia, and in other kinds of work.

But as Prof. A. J. Ewart states: A direct physical explanation can hardly apply to all the movements of organisms which possess cilia and flagella (and we

into flagella, and flagella into pseudopodia." A fact which was demonstrated some years ago by Dujardin. *The Protozoa*, by Prof. Gary Calkins, p. 44.

[1] Fig. 11, p. 369, part i., Lankester's "Treatise on Zoology,"—The Infusoria. By S. J. Hickson, F.R.S.

may add pseudopodia, p. 71). "It is undoubtedly often the case that physical forces such as surface tension, osmosis, imbibition, etc., when intense, may overpower the organism, but there can equally be no doubt that the latter has acquired the power of directing and controlling these natural forces for its own benefit, so that a simple direct physical explanation can hardly be postulated for phenomena which may be due to a multiplicity of interacting factors." [1]

If two fine glass tubes with open mouths at one end are introduced into a drop of water on a glass slide, the one tube containing a weak alkali and the other an acid solution, an unequal movement in the mean velocity of particles in the water between the tubes occurs. If the drop of water contains a number of bacteria they follow the laws influencing other particles, and settle in numbers where their motion is most retarded; namely, in the region of maximum acidity. But as Dr J. O. Wakelin Barrett reminds us in his recent researches into the subject (Chemiotaxis), we are at present hardly competent to solve the nature of all the forces at work in producing these movements in living bacteria, and it is therefore not desirable to attempt to arrive at any positive opinions on this subject.

The truth of Ewart's statement is confirmed by most persons who have been in the habit of watching the movements of unicellular organisms by the aid of a good microscope. M. Alfred Binet in his work on the *Psychic Life of Micro-Organisms* (p. 108) insists on the fact that many of these unicellular beings manifest a power of selection, exercised either in the search of

[1] "On the Physics and Physiology of Protoplasmic Streaming in Plants," by A. J. Ewart, Lecturer on Botany in the Birmingham Technical Institute, p. 112.

food, or the manœuvres attending conjugation. This act of selection he holds is a capital phenomenon; we may take it as the characteristic feature of functions pertaining to the nervous system. Romanes observes that the power of choice may be regarded as the criterion of psychical faculties.

It is beyond the scope of this work to attempt to define the properties of consciousness, or the development of the intellectual processes from the simpler to the higher classes of animals. It will rather be our object to show, that through the action of the living matter constituting some of the simplest organisms, these beings possess the power of favourably reacting to the various forces acting upon their bodies, and that in an ascending scale of animals this matter has become differentiated into "consciousness-matter," capable of elaborating and associating psychical processes adequate for the preservation of the individual and of the species. It, however, appears reasonable in a work devoted to the subject of *intelligent* speech to refer to the opinions expressed in recent works on Psychology, concerning the connection which it is possible to conceive may exist between living matter and the phenomena of consciousness.

Professor Villa, when dealing with the theory of psycho-physical parallelism, states that modern scientific ideas can accept no theory which is not founded upon continuity of phenomena, whether physical or psychical. The idea therefore that consciousness may have arisen *ex nihilo*, or out of something entirely different from itself, must be at once rejected. If, on the other hand, we do not meet with mental life outside animal organism, it is reasonable to suppose that, like life itself, it is the result of a peculiar organisation and combination of elements which already pre-exist along with the primitive elements which constitute life. On the other hand, these primitive mental elements are not themselves consciousness, as we understand it, any more than inorganic elements in themselves are life. The psychical life of universal matter is not therefore a real and actual life, but merely a "latent life," which manifests itself under certain conditions. These conditions do not appear to tally with those of life itself, for plants which are living organisms are endowed with no real psychical life. It may easily be imagined to what an infinitesimal degree the psychic life must be reduced in those beings in which hardly any differentiation of organs and functions exists, though we already find in them, in an extremely simple form, the three fundamental elements of psychical life; to wit—sensation, feeling, and will. The evolution of consciousness proceeds *pari passu* with the biological organism. In both cases a homogeneous and incoherent whole becomes gradually complex and differentiated.[1]

Professor A. Bain is one of the ablest exponents of the doctrine of parallelism, which holds that physical and psychical life form two parallel currents, or in his own words, "the only tenable supposition is that mental and physical proceed together as undivided twins."[2]

From this, we hope pardonable digression we must

[1] "Contemporary Psychology," by Guido Villa, lecturer on Philosophy in the University of Rome. Translated into English by Harold Manacorda.

[2] "Mind and Body" (ninth edition), by Alexander Bain, LL.D., p. 130. International Scientific Series. See also in the same series, A. Binet on "Mind and the Brain," pp. 214, 243, 246.

return to the subject we were considering regarding the arrangement of the cilia on the surface of the bodies of Protozoa, constituting as they do one of the means of classification of these animals. When the cilia exist in definite rows or circles, they are not unfrequently united by a very delicate membrane or webbing (membranula).[1] *Cilia* may thus become bound together into a bundle forming structures known as *Cirri*. Structures of this kind which project from the surface of an animal's body constitute one of the simplest forms of tactile sense organs. The living matter of cirri pass from their attached surface into the external layer of the animal's body.[2]

In some of the Infusoria (*Hypotricha Peritromus*) rows of cirri are united by membranulæ into a membrane; in some of the Sporozoa a membrane of this kind has an extremely rapid undulatory movement when exposed to the action of a favourable environment.[3]

The structures we have above referred to consist of living matter derived from the outer sensitive layer of the bodies of unicellular animals, matter which is directly subjected to the action of forces derived from their environment. Surface tension,[4] undulations of

[1] "The Psychic Life of Micro-Organisms," by Alfred Binet, p. 10.

[2] Prof. A. J. Ewart on "Protoplasmic Streaming," p. 112.

[3] "Fig. 70, p. 410 and pp. 362, 369, Lankester's "Treatise on Zoology," part i., "The Protozoa." Also *Bt. Med. Jour.*, p. 443, Feb. 25th, 1905.

[4] The equilibria determined by the attraction and repulsion of molecules are discernible only dimly in the case of solid bodies, but we can render them visible by isolating their particles, by dissolving a solid in some euitable liquid. The molecules are then nearly as free as if the body were transformed into gas, and it is easy to observe the effects of their mutual attraction and repulsion. It is to action of this kind that the form taken by a drop of liquid assumes when it clings

various kinds, and other forms of energy have through innumerable generations played upon this layer of living matter, and we presume have thus come to modify its molecular structure, so as to bring it into forms to harmonise with these forces; as Professor Calkins remarks, "the Protozoa thus offer in the most striking manner an example of how species may have originated through structural adaptations of the parts (ectoplasm) that are in direct contact with the environment."[1]

Trichocysts consist of spindle-shaped rods located in the external layer of the ectoplasm of some Protozoa. In a Paramœcium they form an almost uniform layer below the outer surface of the cell body, and undergo a rapid change if the animal is exposed to an irritating fluid. Under these conditions the trichocysts are suddenly projected in thread-like filaments from the surface of the animal's body .These structureless filaments have been described as weapons of defence, etc., but little is known regarding their functions, and still less of the mechanism by which they act.[2]

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to the extremity of a glass rod. They are the origin of the *surface tension* of liquids, a tension in virtue of which a surface behaves as if it were composed of a stretched membrane. "The Evolution of Matter," by Dr G. Le Bon, p. 242.

[1] "The Protozoa," by Gary N. Calkins, pp. 183, 4.

[2] "Comparative Anatomy of Animals," by G. C. Bourne, vol. i. p. 192. Also Calkins on the "Protozoa," p. 50, and "The Psychic Life of Micro-Organisms," by A. Binet, pp. 48, 53.

CHAPTER V

The proliferation of fertilised cells is described in reference to the reproduction of germinal and somatic or body cells—the process by means of which acquired may become hereditary characters is noticed.

Before proceeding to describe certain modifications in the structural arrangements of the simplest forms of multicellular animals, it is desirable to refer to the movements which take place in the living matter of the nuclei of fertilised cells while undergoing proliferation. From our point of view this subject is of importance, because, in the first place, by the aid of a good microscope we can, from properly stained specimens, form an idea of the movements going on in the substance of the nuclei of proliferating somatic and germinal cells; and in this way, to some extent, realise the far more active molecular changes which are constantly at work in these structures in obedience to the forces which are perpetually acting upon them.

The series of complicated changes we have to describe in the nuclear substance, which lead to its separation into two or more parts are alike in all members of the vegetable and animal kingdoms, including man. The physiological properties of the cell contents must differ in every species, but the processes followed in the reproduction of fully formed nucleated cells are identical; and so far as we know have always been so, in spite of the adaptative changes in the structures, and the arrangement of the materials constituting the bodies or somatic elements of plants and animals.[1]

In the present state of our knowledge it seems futile to speculate as to the nature or mode of action of the forces which produce the changes we refer to in the living matter of proliferating cells; reliable work is being done to elucidate this subject, and we may with confidence look forward to the time when much that is now incomprehensible regarding the processes will be

[1] It has been assumed that a fertilised cell, such, for instance, as that of a human being, which has a diameter of about the $\frac{1}{20}$ mm., is too minute in size to contain a sufficient amount of matter to produce a man with all his structural and mental qualities. This idea, however, is not entertained by those best qualified to form an opinion on the subject. Prof. J. G. M'Kendrick states that taking the average cubical diameter of a human ovum at $\frac{1}{20}$ mm. and an atom at $\frac{1}{10000000}$ of a millimetre, and assuming that about fifty exist in each organic molecule (proteid, etc.), the cube would contain at least 25,000,000,000,000 organic molecules. Again, the head of the spermatozoid, which is all that is needed for the fecundation of an ovum, has a diameter of about $\frac{1}{200}$ mm. Imagine it to be a cube; it would then contain 25,000,000,000 organic molecules. When the two are fused together, as in fecundation, the ovum starts on its life with over 25,000,000,000,000 organic molecules. If we assume that one half consists of water, then we may say that the fecundated ovum may contain as many as about 12,000,000,000,000 organic molecules. Clerk Maxwell's argument that there were too few organic molecules in an ovum to account for the transmission of hereditary peculiarities does not apparently hold good. Instead of the number of organic molecules in the germinal vesicle of an ovum numbering something like a million, the fecundated ovum probably contains millions of millions. Thus the imagination can conceive of complicated arrangements of these molecules suitable for the development of all the parts of a highly complicated organism, and a sufficient number, in my opinion, to satisfy all the demands of a theory of heredity. Such a thing as a structureless germ cannot exist. Each germ must contain peculiarities of structure sufficient to account for the evolution of the new being, and the germ must therefore be considered as a material system. See *Nature*, Sept. 26, 1901, p. 547.

explained in a satisfactory manner (see note, p. 82). This remark applies with even greater force to the question of the transmission from one generation of beings to another of constant and acquired characters.[1] We do not for an instant overlook the interest and importance of this subject in its relation to the origin of species; but it seems to us that we have much to learn regarding the nature of the living matter concerned in the division and the reproduction of cells, before we can hope with success to tackle the question of heredity. We have, however, thought well to refer to one theory on this subject, because it seems to bring our ideas concerning the adaptability of living matter to its environment into a concrete form, and to explain how it is possible that variations in structures may arise and be transmitted from one generation of beings to another[1] (p. 95).

It is almost impossible to describe the changes in the nucleus of a fertilised cell during its proliferation, without making use of terms which are unfamiliar to the majority of persons; it may therefore be well for those who cannot easily follow us, to pass on at once to p. 95, which may be done without break of continuity in the argument.

We have already described the changes which take place in the bodies of non-nucleated organisms during their proliferation (p. 35). Prof. Klein, writing on this subject, remarks that we must conclude that at present no

[1] *See* Mr Bateson and Mr Punnett's report to the Committee of the Royal Society on Evolution, and Mr W. B. Hardy's remarks on the Mendelian Laws. P. 200, *Science Progress*, for October 1906. Mr G. A. Reid in his work on "The Principles of Heredity" enters fully into the history and the prevailing opinions of biologists on this subject. An able résumé of this subject by G. A. Payley, "Biology and Politics," in No. 1 of the *New Quarterly* may with advantage be studied.

data exist which justify our ascribing to bacteria a nucleus, that is, of a definitely shaped and definitely placed, well-defined central substance which, in the cells of higher plants and of animals, plays the part of a division centre. If further proof were needed, it is found in studying bacteria during division. Here no appearance can be observed which would denote division of the alleged nucleus.[1] Not only are the bacteria without a nucleus, but so far as we know they do not possess fully formed chromatin. Nevertheless, this class of beings constitute the most prolific organisms in existence. They have become split up into many genera and species, the constant characters of which have been passed on from one generation through long ages of time. We infer therefore, that the transmission of the fixed and acquired characters of these asexual beings, have been transmitted from generation to generation by the living protoplasmic elements which constitute their bodies.

In the simplest class of beings, such as the bacteria and lower forms of algæ, the somatic and germinal elements are intermingled up to a certain stage in their life cycle.[2] But in all other classes in which the cells contain a nucleus, the elements which take the leading part in the process of reproduction are aggregated in the nucleus. When once nuclei have become

[1] The Horace Dobell Lecture, delivered by Prof. Klein on the 22nd November, 1904.

[2] In the most complex form of Protozoa, the Infusoria, we find a distinct differentiation of the germinal and somatic elements of the cell which form separate nuclei. After the conjugation of two of these beings their nuclei undergo a series of complex changes, which result in the germinal producing a somatic nucleus. Prof. S. J. Hickson on the Infusoria, pp. 389-95; Lankester's "Treatise on Zoology."

established in cells their proliferation invariably takes place from pre-existing nuclear matter.

As we have already shown in the case of Tetramitus, although it has only a rudimentary nucleus, during the proliferation of the cell the chromatine granules appear to be attracted round the centrosome, and closely follow the movements of this body in the division of the organism. After many generations of Tetramiti have thus come into existence, the elements concerned in this process become exhausted. Under these conditions two unfruitful beings fuse and form a single virile organism; the act of conjugation in these, and numerous other Protozoa, would appear to consist in forming a single vigorous out of two worn-out individuals, a process of rejuvenescence. The union of these two beings, which are precisely alike in character, gives rise to exactly the same form of animal as that from which the uniting beings had proceeded.

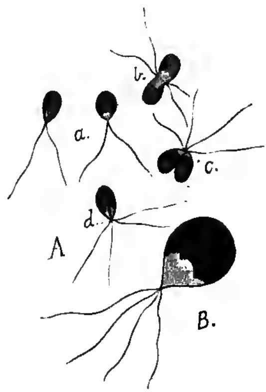

FIG. 16. — *B*, Fully developed spore of *Ulothrix*. *a*, small spore with two cilia; *b*, small spores uniting to form a fertile being.

We find a similar state of affairs in some of the lower forms of algæ, as for instance in the well-known case of Ulothrix, which bears two kinds of spores, the one being small and possessing only two cilia, the other larger and having four cilia (Fig. 16).

Under favourable conditions, the larger four ciliated spores develop into a new plant; but the two ciliated smaller spores are alone unable to produce a new Ulothrix. But if two of these small spores meet, provided they have grown in separate Ulothrix cells, they conjugate, and a four-ciliated spore results, from which a new plant may be produced.

It may be, as Prof. Vines argues, that the conjugating spores of Ulothrix differ from one another physiologically, although they are alike in external form; but it seems probable that these small spores, like the weakened Tetramitus, are unable individually to supply what is necessary to form a new plant; and arising out of this state of things the reproductive elements have assumed rudimentary sexual characters. After passing through successive phases of development, processes of this description have culminated in differentiated male and female organisms.

In the monad known as Heteromita, of two conjugating beings, one, which is formed by transverse division, is motile, and becomes attached to a stationary form resulting from a longitudinal division and anchored by one of its flagella. Here for the first time, in Protozoa, a distinction can be made between the more quiescent and the more motile conjugant.[1] This distinction is still more conspicuous in *Volvox,* which, however, comes near to a multicellular being, in that it exists only as an aggregate of individuals or units united into a mass or colony.

A Volvox consists of a colony of some 1200 members. Each being is formed of a minute mass of protoplasm which gives off processes connecting it with its neighbours, and from its free surface two cilia project outwards (Fig. 17).

[1] Prof. Gary N. Calkins, on the Protozoa, p. 221.

The individuals forming a Volvox are thus united and constitute a hollow sphere, the whole being enclosed by an investing membrane. The outer layer of cells contains the somatic or working portion of the colony, the whole of their cilia are in constant rhythmical action. The living matter of this layer of cells not only constitutes the motile part of the colony, but it also prepares raw nutrient material for the use of the germ cells.

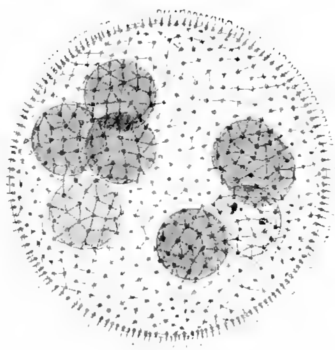

FIG. 17.—*Volvox*, showing the small ciliated somatic cells and eight large germ cells. (Drawn from life by J. H. Emerton. See E. B. Wilson, "The Cell in Development and Inheritance," p. 123.)

Within this outer layer of somatic cells the space is filled with a jelly-like substance in which some eight or ten large cells are embedded. From their earliest appearance these cells, which separate from the protoplasm of the somatic cells, increase rapidly in size, and stain deeply with basic (nuclear) dyes. By a process of asexual division, the contents of these cells produce small colonies which escape outwards from the parent colony. After rapid reproduction of this kind the parental germinal matter becomes exhausted, and at this stage of its existence only stains faintly with nuclear dyes. Under these conditions the germinal substance of the cells separates into what we term male and female elements, forming two distinct kinds of organisms. Each of the cells containing the female germinal substance assumes a flask shape, and passes from the outer to the central part of the colony, still however, maintaining a protoplasmic communication with the outer layer of somatic cells. The cell containing the male germinal matter divides into numerous flagellated spindle-shaped beings, these gather round one of the large female cells into which a male penetrates and fertilises it. The processes which follow in the fertilised female cell are precisely similar in a Volvox to those which occur in the fertilised cell of the higher orders of plants and animals.

In the lowest class of multicellular animals the somatic and germinal matter is also mingled in certain cells. For instance, in the simplest kind of sponges (*Olynthus*) we find wandering cells derived from the living sensitive matter of the cells which form the outer layer of the animal's body. These cells work for the whole colony, performing elementary functions of digestion, distribution, and probably excretion. Some of these cells give rise to spermatozoa or male cells, others to ova or female cells, the latter, until they are fully matured, are nourished from matter prepared by surrounding cells. A male cell enters and fertilises an ovum or female cell, the two nuclei break up to form the maternal and paternal chromosomes, which can be recognised side by side and distinct from one another.[1] We thus find that somatic and germinal elements are present in the living substance of certain of the nucleated cells of the simplest classes of multicellular beings. We assume their separation to be effected by forces similar to those which cause their separation

[1] Prof. Minchin's article on the Sponges, p. 61, part ii; Lankester's "Treatise on Zoology."

in the bodies of bacteria. But the germinal matter of nucleated cells, unlike that of the bacteria, undergoes further differentiation, and assumes sexual characters, which help in the production of hereditary variations of species.

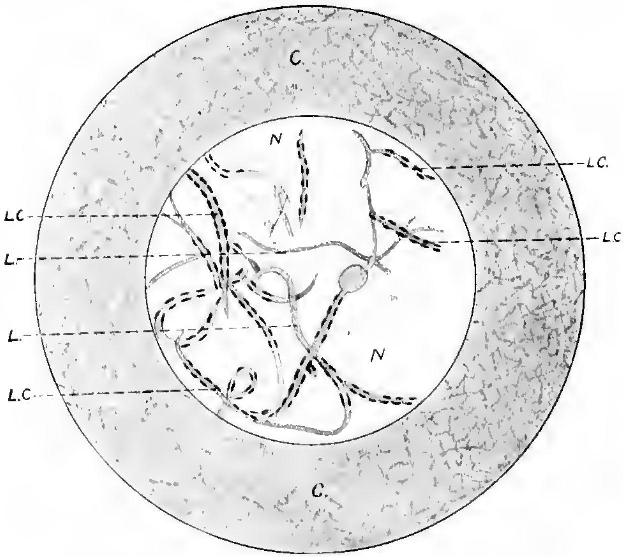

FIG. 18.—*C*, cytoplasm of cell; *N*, nucleus; *L*, linin (thread); *L.C*, chromatin granules on linin. (See Fig. 14, p. 28, "A Treatise on Zoology," edited by E. Ray Lankester. Paper by Dr J. B. Farmer, "On Structure of the Cell.")

We may now proceed to examine in detail the changes which take place in the nuclear substance of a fertilised cell.

When the time arrives for the proliferation of a fertilised cell, the chromatin granules, which had previously been scattered through the nuclear substance, aggregate along the threads of living basic substance which forms the linin (p. 58) of the nucleus (Fig. 18).

Shortly after these changes have taken place the linin substance becomes as it were unravelled and drawn out into a thread, with the chromatin matter adhering to it (Fig. 18). This thread becomes coiled up near one of the poles of the nucleus, where a centrosome surrounded by granular matter may as a rule be detected. The centrosome divides into two parts which separate and take up positions at opposite poles of the nucleus (Fig. 19). The linin thread now becomes shorter and thicker, and finally divides into a number of rod-like bodies, or chromosomes. At the same time fibrils spread from both of the centrosomes so as to form cones with their bases in the equatorial plane of the nucleus, and their apices at the centrosomes. The chromosomes now take a position along the base of the cone (Fig. 19). This completes the first stage in nuclear division. Up to the termination of this stage, the changes which take place in somatic and germinal cells in the process of division are identical in character. These processes are known as the first stage of *Mitosis* or indirect nuclear division.

In the second stage of the nuclear division of *somatic* cells the chromosomes assume a V-shape with their apices turned centrally on the equatorial plane of the nucleus. Each limb of the V-shaped chromosome is connected with fibrils passing from the centrosomes, or, as it is usually called, the spindle. The chromosomes, or rather the living linin thread on which they rest, split apart longitudinally (Fig. 19), carrying with it its attached chromatin. Each half of the limbs of the original V-shaped rods, is drawn by means of the contraction of the fibrils of the centrosome towards either pole of the cell, the membrane enclosing the nuclear substance disappears, and the chromosomes come into immediate connection with the two centrosomes.

In the third stage of mitosis in somatic cells the chromatin forming the chromosomes loses its active properties and stains only faintly. It then either disappears or the linin network reappears with chromatin

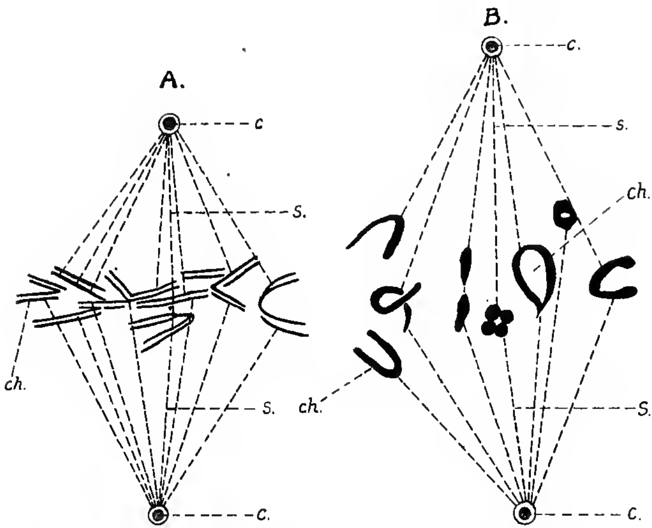

FIG. 19.—Diagram showing division of nucleus of *A*, somatic, and *B*, germinal cell. *c*, centrosomes; *s*, spindle fibres; *ch*, chromosomes. (After Profs. J. B. Farmer, J. E. S. Moore, and C. F. Walker's paper, read before the Royal Society, Dec. 10th, 1903.)

granules, a membrane forms round these elements, and two young nuclei are produced. During the time these processes have been going on the cytoplasm of the cell has become constricted through its central plane; it ultimately completely divides into two parts, each of which contains a nucleus formed in the manner above described. So far as our observations have enabled us to form an opinion, it is to the effect that the division of the cytoplasm of nucleated cells is carried on by processes similar to those we have described as taking place in non-nucleated organisms, such as the bacteria and lower Algæ (p. 35). By a repetition of these processes we can understand how the somatic cells, which form the various tissues and organs of our bodies grow, and tissues are repaired after being injured by disease or by accident.

The production of *germinal* or reproductive tissue differs from that which we have described. This difference rests on the diversity of functions which germinal and somatic cells perform. It is evident that if the male and female germ cells each contained the number of chromosomes proper to the species to which they belong, when the male cell enters and fertilises the female cell, the resulting ovum would contain double the number of chromosomes proper to the species; in this way, in the course of a few generations, the nuclei would be over-crowded and rendered unworkable from the number of chromosomes they contained. But during the second stage of the reproductive process of germinal cells provision is made for meeting this difficulty. The chromosomes of the germinal cells appear, not as delicate rods arranged on the spindle as V-shaped bodies which split lengthwise as in somatic cells, but as loops, rings, and aggregations of four beads, etc., which are arranged longitudinally upon the spindles and divide transversely. Furthermore, it is seen that (in these germinal nuclei) the chromosomes are present in only *half the number* proper to the species. This is a most remarkable fact, and is constant throughout the whole ranges of animals and plants.[1] The subsequent courses of events in these germinal cells are similar to the ordinary somatic processes, except that the reduced number of chromosomes continually reappear. In the case of the fertilisation of the female by the male cell, each possessing half the number of chromosomes proper to the species, the whole number is restored. This number continues at each division until the time comes for the development of germinal cells, when the processes above described recur.

Professors Farmer and Moore are of opinion, that the reduction in the number of chromosomes in germinal cells is achieved, by the association or non-separation of somatic pairs of chromosomes, such as that which takes place at the second stage of the mitotic process in somatic cells.[2] They are of opinion that, "the heterotype mitosis [3] essentially consists in the separation and distribution between the daughter nuclei of entire somatic chromosomes, the separate identity of which is marked by their temporary union previously to the onset of the *diaster*,[4] and thus the exact numerical reduction is accounted for." [5]

[1] We are indebted to the researches of Profs. J. B. Farmer and J. E. S. Moore, in conjunction with Mr C. E. Walker, for the above facts (see their papers read before the Royal Society, Dec. 10th, 1903), and the *Quarterly Journal of Microscopical Science*, Feb. 1905. Mr R. P. Gregory has demonstrated the fact that changes in the mitotic processes of germinal cells, such as we have referred to, exist in all the lower orders of plants he has examined. See "Annals of Botany," vol. xviii., No. lxxi., July 1904, and the Cambridge Philosophical Society, vol. xiii , Part. iii.

[2] Paper read before the Royal Society, Dec. 10th, 1903.

[3] Heterotype mitosis, that mode of cell division in which the daughter chromosomes remain united by their ends to form wings.

[4] *Diaster*, the double group of chromosomes during the later period of mitosis.

[5] *Quarterly Journal of Microscopical Science*, Feb. 1905, p. 505.

Prof. E. B. Wilson, in his work on the Cell, gives an able résumé of the opinions held regarding the nature and functions of chromosomes, pp. 294-301. The opinions we have arrived at, after many years' study, differ from those held by the authorities quoted by Wilson and by English biologists, but we nevertheless hold to our opinion that chromatin, like chlorophyll, is a product of chemical action effected through the agency of living matter, especially of that description which is known as *linin*. Chromatin becomes aggregated into chromosomes during certain stages of the cell's existence, and acts as a specific transformer of energy, derived largely from centrosomes. Under energy proceeding from these bodies and other sources the basis substance or linin of the nucleus is equally distributed among the daughter nuclei; after which a portion of the chromatin with its linin living matter remains to form the foundation of a new nucleus, but much of the chromatin disappears in the cytoplasm of the daughter cell. According to our ideas, chromatin is the agent, but the living matter of the cell (linin and cytoplasm) are the active elements concerned in the reproduction of cells.

From the preceding evidence we seem to be justified in arriving at the conclusion, that in addition to its fundamental properties, including its sensitivity and its adaptability to external forces, living matter separates into somatic and germinal elements when exposed for a lengthened period to the influence of energy derived from certain forms of physico-chemical action.

The somatic elements develope into structures which form the body of an animal; this matter is capable of undergoing modifications through the action of forces derived from its environment, a fact we have already referred to in the two previous chapters, and shall return to in the following chapter, in which we show that it is from the living matter of cells forming the external layer of the bodies of some of the simplest classes of animals, that muscular and nervous structures have been developed.

The special function of germinal matter is to reproduce beings similar in character to those from which it is derived. In the case of fertilised cells however, the germ consists of a mixture of reproductive elements derived from the male and female germinal cells. The germinal matter of the ovum, therefore, from which a new being springs, is of a mixed character, and within restricted limits, leads to variations in the characters of a being derived from its elements. We conceive that germinal matter may receive, and by repetition in the course of time come to retain impressions made upon it through the action of the surrounding protoplasm. Action of this kind is comparable with impressions made through energy derived from the sense organs on the living matter of certain nerve-cells, impressions which are certainly retained, but this is a subject to which we shall return in another chapter, and need not therefore discuss it in this place.

It remains for us to consider if it is possible to frame an hypothesis which may assist us to realise the nature of the action, by which modifications in the structural arrangements of the somatic elements of living beings may become impressed, and be transmitted through the germinal elements to succeeding generations of cells.

The well-known monad *Heteromita* consists of a pear-shaped mass of protoplasm enclosing a nucleus and provided with two flagella. One of these flagella passes forward from the pointed end of the body, the other projects from its lower surface. In common with other unicellular organisms, Heteromita sometimes reproduces by simple cell-division, either in length or across the body, accompanied by division of the nucleus. When the fission is transverse, the body of the animal divides into dissimilar halves, one with an anterior flagellum and one without. The ventral flagellum simply splits into two, one of which remains attached to each daughter-cell, but no possible division of the anterior flagellum could provide both new cells with such a structure. What actually happens is that one of the daughter-cells keeps the old anterior flagellum, while the other develops an entirely new one from what was the posterior extremity of the parent.[1]

H. Spencer states that it is an unquestionable deduction from the persistence of force, that in every individual organism each new incident force must work its equivalent of change, and that where it is a constant or recurrent force, the limit of the change it works must be an adaptation of structure such as opposes to the new outer force an equal inner force. The only thing open to question is, whether such readjustment is inheritable; and further consideration will show that to say it is not inheritable is indirectly to say that force does not persist. If all parts of an organism have their functions co-ordinated into a moving equilibrium, so that every part perpetually influences all other parts, and cannot be changed without initiating changes in all other parts; and if the limit of change is the establishment of a complete harmony among the movements, molecular and other of all parts, then among other parts that

[1] Prof. A. Dendy, "On the Nature of Heredity." From the "Report of the South African Association for the Advancement of Science," vol. i., April 1903, p. 12.

are modified, molecularly or otherwise, must be those which cast off the germ of new organisms. The molecules of their produced germs must tend to conform to the motions of their components, and to the molecular forces of the organism as a whole, and if this aggregate of molecular forces is modified in its distribution by a local change of structure, the molecules of the germs must be gradually changed in the motions and arrangements of their components, until they are readjusted to the aggregate of molecular forces. For to hold that a moving equilibrium of an organism may be altered without altering the movements going on in a particular part of it, is to hold that these movements will not be affected by altered distribution of forces, and to hold this is to deny the persistence of force.

Prof. A. Dendy observes,—that we have in the reproduction of Heteromita a simple case of heredity, and as I believe, one of inheritance of acquired characters. There can be no doubt that the evolution of the flagella in Heteromita was due in the first instance to the direct action of the environment. We know how readily an Amœba's temporary pseudopodia are emitted when the protoplasm is appropriately stimulated, and the transition from pseudopodia to flagella is a perfectly gradual one (p. 71). At first temporary, these organs gradually become permanent structures by frequent use. Their development must have disturbed the pre-existing balance of forces between the cell-body and its nucleus, but as it probably took place very gradually extending over many generations, this disturbance was not sufficient to produce disruption, and the forces in the nucleus became slowly rearranged in equilibrium with the changing structure of the cell-body. Thus in turn the nucleus acquired a new potentiality, a tendency to compel the cell-body to produce a flagellum in order to equilibrate its own stored-up force. In other words, the development of a flagellum by the cell-body acts as a stimulus upon the nucleus, and this stimulus is stored up in the nucleus and given out again subsequently to the cell-body, inducing the latter to develop a flagellum when necessary to restore the equilibrium between cell and nucleus. Thus in time the production of the flagellum comes to partake of the nature of an after-effect, which may take place independently of the environment.[1]

Prof. Dendy further states that, in the young Heteromita, the new flagellum appears before its possessor commences to lead an independent life; and it appears in such a definite fixed position, and with such rapidity and precision, that we cannot believe it is produced *de novo* by the action of the environment in the development of each individual.

The living germinal matter of the nucleus is however the bearer of the characters possessed by the parent organism to its descendants, so that when new molecular arrangements have become fixed properties of the nuclear substance, this kind of matter, at the time of the development of the organism, reacts on its

[1] "If the intensity factors of any particular form of energy in a system are not equal, the system will be in a state of unstable equilibrium. Such a condition will not be permanent, and energy will flow, so to speak, from one part to another until the different intensity factors become equal. The cause of chemical action is the universal tendency of chemical energy at different intensities to attain the same degree of intensity." And so with heat, electricity, mechanical and other modes of energy. "Text-Book of Chemical Statics and Dynamics," by Dr J. W. Mellor, pp. 26, 27.

cytoplasm and gives rise to structures corresponding to those which had produced the impression on the nuclear germinal matter.

With regard to plants, Prof. G. Henslow has arrived at conclusions which approach those we have above referred to, for he remarks that we have now abundance of proof, both by induction and experiment, that the form and structure of the organs of plants are due to the immediate response of the living protoplasm to the influence of the environment, and that it, or rather the nucleus, builds up just those cells and tissues which are in adaptation to the conditions of life. Then after a few years they become hereditary, and so fix the varietal or specific characters by which botanists recognise and distinguish plants in nature.[1]

Mr Luther Burbank is well known to be one of the most ingenious and successful of all recent experimenters in plant breeding, his experience now extending over some thirty years, during which time he would seem to have produced almost distinct species of certain berries, prunes, plums, and so on. Mr Burbank is a thorough believer in the inheritance of acquired characters. He remarks that "there is no fixity in species other than that due to long repeated ontogenetic reiteration of this or that characteristic."[2]

Without discussing the causes which give rise to epileptiform affections, there can be little doubt that attacks of this description arise, from irregular action in the living matter constituting the reflecto-motor nerve-

[1] *Journ. Hort. Soc.*, vol. xxix., Dec. 1904; "Heredity of Acquired Characters in Plants," by Rev. Prof. G. Henslow.

[2] "Evolution and Animal Life," by D. S. Jordan and V. L. Kellogg, pp. 101, 114.

cells of various parts of the central nervous system. The fact that interests us in connection with epilepsy is, that Dr Brown-Sequard by injuring definite parts of the nervous system in the lower animals, has caused them to become subject to epileptic attacks, and that the young born from these animals also suffered from epilepsy. This statement has been confirmed by experiments carried out by Romanes, Professors Obersteiner, Luciani, and others. A change in the shape of the ear has been demonstrated to occur in animals born of parents, in which such a change was the effect of the division of certain nerves supplying the ear. Other deformities arising from similar lesions of the nervous system have been described, and, like those we have referred to, were passed on to a younger generation, and furnish a fairly strong argument in favour of Lamarck's ideas concerning the transmission of acquired character from one to a succeeding generation of animals.

It is well known that Darwin repudiated Lamarck's views regarding progressive adaptation, but it seems questionable if he understood Lamarck's ideas on this subject. Darwin refers for instance to a statement he attributes to Lamarck, to the effect that animals will that the egg shall be a peculiar form, so as to become attached to particular objects, a statement which is not to be found in any of Lamarck's writings. So far as Lamarck's theory regarding the inheritance of acquired characters extends, Darwin himself employs the same illustrations as those cited by Lamarck, and in his work, "Animals and Plants under Domestication," remarks, "These general considerations alone render it probable that variability of every kind is directly or indirectly caused by changed conditions of life. Or, to put the case under another point of view, if it were possible to expose all the individuals of a species during many generations to absolutely uniform conditions of life, there would be no variability."[1]

[1] "Evolution and Adaptation," by T. H. Morgan, pp. 231, 307.

At the meeting of the British Association in Dublin (1908), Col. H. E. Rawson read a paper on the colour changes in flowers produced by controlling isolation in the cultivation and raising of various kinds of flowers. Flowers are found to be affected in a definite manner by the sun's rays. The principle which has been followed in a series of successful experiments is to shade off with a perfectly opaque screen all direct rays of the sun for certain intervals of daylight. Nasturtiums (Tropæolums) were selected for experiment, and in the course of four months the flowers were changed from orange to mauve. No other special treatment had been given, and the only fertilisers used were soot water and liquid manure. The remarkable thing about these experiments is that the changed flowers show no tendency to revert to the old colours, and may even be reproduced true to the mauve colour from seed.

CHAPTER VI

Having gained an idea of the nature of the fundamental properties possessed by living matter, we are prepared to consider some of its potential powers culminating in the production of nervous matter—It is through the action of this form of living matter that human beings are enabled to express their thoughts in intelligent speech—The foundation on which these ideas rest is based on comparative biology, and we therefore commence this part of our subject by referring to the development of the sense organs and the nervous system of the lowest classes of invertebrate animals.

In this chapter we propose to consider the nature and the functions performed by certain structures produced by the living matter of the external layer of the cells of some of the simplest forms of *multicellular* animals, our attention being confined however, to the development of the sense-organs, nerve-cells, and contractile muscular fibres, and to the evolution of these structures in typical examples of invertebrate animals.

The simplest class of multicellular animals is represented by the Sponges, which are developed from ciliated larvæ. After swimming about for some time in the water, the larva passes through certain changes, terminating in the production of a young growing sponge. Throughout its life a sponge remains attached to some fixed substance, often to a rock at the bottom of the sea, consequently the animal requires neither locomotor nor sense organs to enable it to procure its food, or to effect its reproduction. In fact, the nutrient and other matter required by a sponge for its maintenance are brought to it dissolved in the water which percolates through the animal's body.

In the following description we limit our observations to one of the simplest known types of sponges, the *Olynthus*, from which however all sponges may be regarded as ideally derived. The body of this being, as distinguished from its calcareous skeleton, is formed of an outer or dermal layer of epithelial cells, and an inner or gastral layer; between these layers there are a number of cells derived from the dermal layer which constitute a large part of the body of the animal. The bulk of these body cells are known as porocytes, that is, a single cell through the living substance of which a canal or passage runs. The external opening of this canal is on the surface of the animal's body, and its inner opening in its central gastral cavity. The wall of the canal therefore, is formed of living protoplasmic matter. The body of the sponge being to a large extent formed of porocytes, constitutes a system of perforated cells through which water constantly passes, containing nutrient, calcareous, and other materials necessary for the growth, maintenance, and reproduction of the animal.[1]

The canal system of sponges seems to afford an example of the action which a sensitive, contractile, living substance like protoplasm may take in regulating the work carried on by an organism. The canals, as we have stated, pass directly through the substance of the porocytes, when this matter has received a sufficient supply of nutriment to enable it to effect its metabolic

[1] Professor E. A. Minchin on the Sponges. Lankester's "Treatise on Zoology," Part ii., p. 26.

process, and the stimulus supplied to its sensitive surface by a stream of water is sufficient to cause this matter to contract and close the canals. This state of affairs does not last long; it seems to us this fact may be explained by supposing, that the potential energy of the living matter of the cells becomes used up, its protoplasm is thus exhausted, and for a moment fails to work; the canal system therefore relaxes, its passages are opened, and a fresh stream of water and nutrient matter passes through them.

Beyond the direct control exercised by the living matter of the porocytes on the passage of water through their canals, we find an additional mechanism developed in many sponges, whereby the ingress of water into their canals is restricted under certain conditions of their living matter. This action is effected by the contraction of a number of filiform cells which surround the external openings of the system of canals, these fibrils contract, and close the openings during the resting state of the sponge.

The point, however, to which we would draw special attention is, that the porocytes, the contractile fibrils, the cells which build up the calcareous skeleton, and certain wandering and reproductive cells of sponges, all originate from the living matter of the external layer of cells. As Prof. E. A. Minchin states, "in the most primitive sponges, as has been seen in olynthus, the dermal epithelium performs a variety of functions while remaining a uniform layer of cells. Apart from the fact that in the lowest forms the skeletogenous layer is recruited from it, and that its cells may even secrete spicules while retaining their epithelial position, the dermal epithelium commonly combines contractile (neuromuscular) and glandular functions."[1]

The pore cells, in like manner, are directly derived from the living matter of the dermal epithelium, which in the embryo at first constitutes the whole of the dermal layer. From this layer of cells the porocytes, scleroblasts, and the amœbocytes migrate inwards.[2] The scleroblasts secrete within their living substance calcareous matter, and build it up into the skeleton of the sponge. At first these cells resemble the epithelial cells in being very granular in character, but as the spiculæ of calcareous matter grow, the granules gradually disappear, and at the same time the nucleus of the cell decreases in size.

The living matter of the dermal layer of sponges, as above stated, produces the amœbocytes or wandering cells, which exercise functions not only as carriers of nutrient matter from one to another part of the animal's body, but also give rise to the reproductive cells.

From what has been stated regarding the power possessed by the living matter of Sponges, we shall be prepared to entertain the idea that this substance under different conditions may give rise to nerve and muscle cells; and as we show in the next section, this is actually the case in the Hydromedusæ, the class of animals which follow the Sponges.

Professor Minchin states that nerve and muscle cells do not exist in sponges. He observes that there is a great lack of co-ordination in the movements in the

[1] Professor E. A. Minchin on the Sponges. Lankester's "Treatise on Zoology," Part ii., p. 44.

[2] Idem, p. 22.

cells forming the bodies of these animals. Thus the flagella of cells lining the central cavity of sponges do not act in unison like the cilia of the higher orders of animals, but each works independently of the other. Their sensitivity again to external impressions is often marked, but in such cases each cell possesses this quality equally. No class of cells are marked out as sense cells by the possession of special physiological or structural characters.[1]

Among the class of animals known as the Cœlentera we select the well-known Hydromedusæ as an example of one of the simplest existing groups of beings which possess a definite nervous and muscular system, together with several varieties of sense-organs or receptors of energy. It is only with a typical form of this class of individuals that we propose to deal, in so far as the development and functions of their sensory, nervous, and muscular system are concerned.

The Hydromedusæ present two main forms of individuals the non-sexual or hydroid, and the sexual or medusoid. In this case the life-history exhibits an alternation of generation, in which the hydroid produces the medusoid by lateral budding, and the fertilised eggs of the medusoid develop into a hydroid.[2]

Hydroids exist either as solitary beings or they are grouped into colonies. Many of them pass their life fixed to some solid substance, their bodies however, and tentacles or grappling-lines, are in constant motion

[1] Minchin on Sponges; Lankester's "Treatise on Zoology," p. 87, part ii.

[2] Professor G. H. Fowler on the Hydromedusæ; Lankester's "Treatise on Zoology," part ii. p. 1; also, "The Cœlenterata; Comparative Anatomy of Animals," by G. C. Bourne; and Marshall and Hurst's "Junior Course of Practical Zoology," sixth edition.

seizing food from the surrounding water and passing it into their digestive cavity.

The external surface of a hydroid's body is formed of one or more layers of cells known as the *ectoderm.* The inner layer which lines the central cavity is termed the *endoderm.* Between these layers is a non-cellular layer known as the *mesoglœa,* which foreshadows the *mesoderm* of higher animals.

The ectoderm includes several varieties of cell forms. Some of these cells possess a stiff sensory protoplasmic filament, which stands erect on the outer surface of the cell forming a palpocil. The living matter of these filaments, like that of cilia, is continuous with the protoplasm of the body of the cell. Cells of this description are known as tactile sense-cells. From the deep or attached end of some of these cells the protoplasm extends to form a contractile fibre, which lies parallel to the long axis of the animal's body. These fibres are sometimes striated, and are attached to the mesoglœa; they are, in fact, muscular fibres, and in contracting effect the movements of the animal's body (Fig. 20). The muscular fibres therefore of Hydroids consist of a differentiated form of the living sensitive matter produced from the external or epithelial layer of the animal's body, *the sense-organ and muscle forming one cell.* From the deep or attached surface of some of the tactile sense-cells of Hydroids a process of living matter may be traced into what appears to be an expansion of

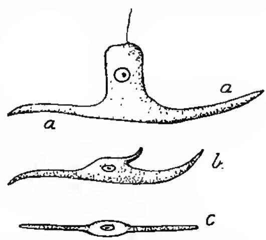

FIG. 20.—Tactile sense-cell of Hydroid, its protoplasm being prolonged into contractile muscle-cell. (After Lendenfeld.)

the filament, and forms a nerve-cell (Fig. 21 B and C). As these structures, so far as our observations go, can be more clearly defined in Medusoids than in Hydroids, we may defer our description of them to the next section.

In addition to the cells we have referred to, the

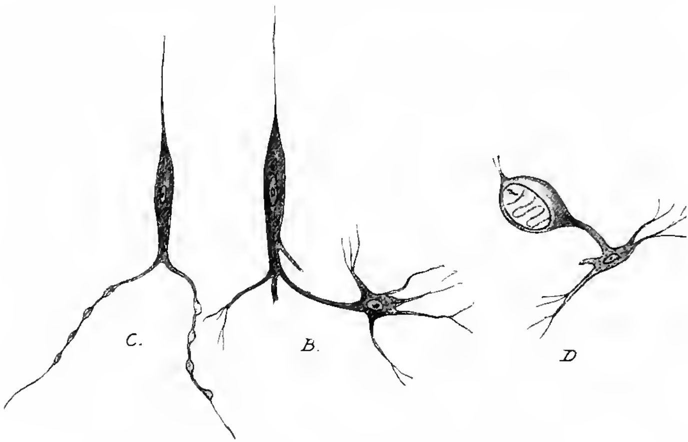

FIG. 21.—*B*, Sense-cell connected with ganglionic nerve-cell. *C*, Protoplasmic fibre of a tactile sense-cell forming nodular enlargements (nerve-cells?). *D*, Cnidoblast connected with ganglionic nerve-cell by a protoplasmic fibre (Medusoid).

ectoderm of Hydroids is covered by protoplasmic "lumps," in which a number of highly refringent capsules are imbedded.[1] These capsules (*cnidoblasts*) contain one or more organs known as *nematocysts*, each of which is prolonged outwards into a stiff hair-like projection or *cnidocil*. The nematocysts contain a barbed filament which, on the application of a stimulus to

[1] "Comparative Anatomy of Animals," by Gilbert C. Bourne, vol. i. p. 226.

its cnidocil, is discharged from the surface of the animal's body with force. The protoplasm of the cnidoblast may be traced from its deep surface into connection with a subjacent nerve-cell (Fig. 21 D).

The Medusoids are generally bell-shaped, the clapper of the bell being formed by a projection (the *manubrium*), at the end of which is the mouth (Fig. 22). A typical form of one of the small jelly-fishes may be said to consist of a tubular body or manubrium, its free end being open and thus forming the animal's mouth. From the mouth a passage leads to the gastric cavity, from which canals pass outwards and terminate in a passage or canal which extends round the margin or edge of the bell. These canals are lined with glandular or secreting cells. In many of these medusoids a shelf or velum projects inwards from the margin of the bell, and from the junction of the velum and rim of the bell tentacles hang downwards (Fig. 22).

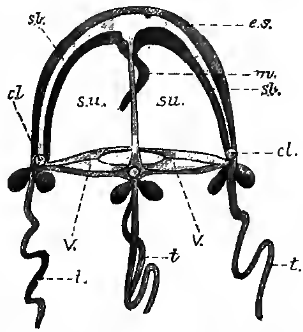

FIG. 22.—Diagram of a Medusoid (*Sarsia*). *m*, manubrium; *es*, external surface of bell; *sb*, subumbral surface; *v v*, velum; *su*, subumbral cavity; *cl*, circular canal; *t t t*, tentacles. (After Lankester's "Treatise on Zoology," part ii. p. 17, The Hydromedusæ.)

The ectoderm or outer layer of cells forming the surface of the bell consists of a layer of flattened cells. Epithelio-muscular cells exist on this surface of the bell, but are inconspicuous, appearing only in scattered groups connected with the middle layer of the bell (Fig. 20). In the manubrium the circular arrangement of muscular fibres is well developed; longitudinal fibres can also be demonstrated, and may be traced extending outwards over the inner surface of the bell to its margin. Round the margin of the bell a band of muscular fibres can be seen and followed into the velum, which is essentially a muscular structure.[1] It is to be clearly understood that the muscular fibres in Medusoids are still combined cells and fibres.

Between the ectoderm of the under surface of the bell and its muscular layer, we find a complex arrangement of nerve fibres and ganglionic nerve-cells (Fig. 23). Von Lendenfeld and Schulze state, and we concur in their opinion, that it is possible to show that, from the attached surface of the cells forming the ectoderm of the under surface of the bell of Medusoids, come protoplasmic processes of considerable thickness terminating in fibrils continuous with the living matter of ganglionic nerve-cells (Fig. 21 B).[2] In this way the living matter of the sense-cell and subjacent nerve-cell are directly connected with one another. The beautiful drawings of O. and R. Hertwig, illustrating the nervous system of Medusoids, demonstrate a condition of the protoplasmic

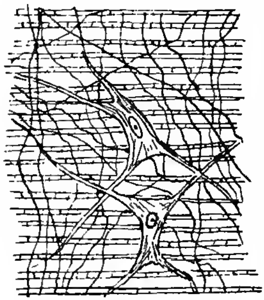

FIG. 23.

[1] G. H. Fowler on the Hydromedusæ, "Treatise on Zoology," p. 8; See also "Elements of Comparative Anatomy," by C. Gegenbaur, edited by Professor Ray Lankester, p. 108, English translation by F. Jeffrey Bell.

[2] Von Lendenfeld and Schulze, "Über Cœlenteraten der Südsee, I. Zeit. wiss. Zool.," xxxvii., 1882.

fibrils proceeding from one of the sense-cells, which appears to indicate their development into nerve-cells[1] (Fig. 21 C, B).

G. J. Romanes compares the network of nerve-fibres extending over the inner, sub-ectodermic surface of the Medusoids' bell, with a "disc of muslin, the fibres and meshes of which are finer than the closest cobweb. These fibres have their origin in the ganglionic nervous system of a medusoid."[2]

In some of the Medusoids a double circle of nerve-cells and fibres extends round the tissues forming the edge of the bell. The upper nerve-ring was originally constituted, according to Romanes, from processes of protoplasm proceeding from that of the cells forming the ectoderm, and afterwards these prolongations disappeared, leaving only their remnant to develop into ordinary ganglionic cells. The lower nerve-ring contains many more ganglion cells and fibres than the upper ring; the two rings however, are connected by many intercommunicating fibres, and together give off the close plexus of fibres which extends as a continuous network over the inner surface of the bell and manubrium, in close connection with their system of longitudinal and circular muscular fibres (Fig. 23).

From the above statement we seem able to appreciate the fact, that the nervous system of Hydromedusæ has been produced from the living matter of the ectoderm by the action of specific modes of energy stimulating this specialised matter. We have referred to the

[1] "Das Nervensystem und die Sinnesorgan der Medusen," Oscar Hertwig und Richard Hertwig. Leipzig, 1878.

[2] G. J. Romanes on "Jellyfish, Starfish, and Sea Urchins," pp. 17, 20.

development of pseudopodia into flagella under the action of energy derived from the environment; we conceive that under the action of similar forces the living matter of the ectoderm of some primitive form of the Hydromedusæ, produced pseudopodia-like processes which grew into the subjacent structures.

In multicellular animals definite external modes of energy no longer act on the whole of the living matter of the body, but on a vast number of cells, in some of which this matter has become specialised and responds to definite forms of energy. Specific external forces acting on this matter, releases part of the potential energy, which, passing along certain lines of the living matter, has led to the formation of nerve fibres. Aggregations of this matter constitute ganglionic nerve-cells, and from these structures a nervous system has developed, by means of which external stimuli become co-ordinated and concentrated on muscular fibres, which in contracting effect the movements of the animal's body. The living matter of a nervous system of this kind, as we shall subsequently explain, in the course of many generations of beings has come to retain impressions made upon it by external stimuli, and also to regulate the discharge of its nervous energy.

Nemec states that in plants, longitudinal strands of fibrils can be seen in the cells at the apices of roots, and that these fibrils are always connected with the nuclei of young cells. These fibres seem to pass from cell to cell along the longitudinal rows of cells in the plerome, but when present in the periblem they are usually more radially arranged. He states that these fibrils may be made to appear by the action of various chemical agents and by stimulation. They seem to represent the channels along which stimuli are more readily transmitted than through the general mass of protoplasm. If so, their increased development after stimulation

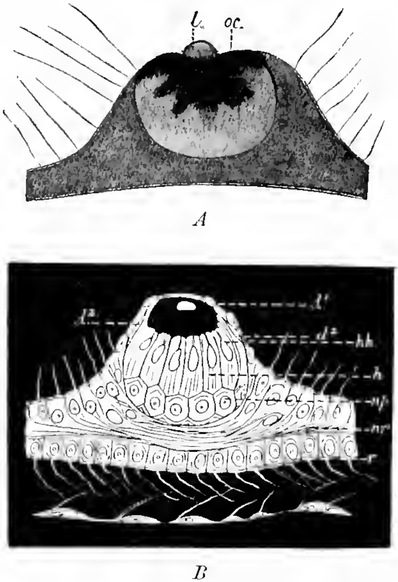

FIG. 24.—*A*, Ocellus. *oc*, pigmented ectodermal cells *l*, lens. *B*, Statocyst (Otocyst). d^1, superficial layer of ectoderm; d^2, deeper layer; *h*, specialised cells of ectoderm; *hh*, supporting filaments; *np*, nervous structures; *npr*, upper nerve ring; *r*, endoderm ring of circular canal. The calcareous body and cavity of sense-organ seen above. (Hertwig.)

would partly explain the slow but ultimate response o far-removed parts to stimuli, which produce no effect upon them if of short duration.[1]

[1] "On the Physics and Physiology of Protoplasmic Streaming in Plants," by Prof. J. Ewart, p. 102.

In intimate relation with the nervous system of Medusoids we find a number of sense-organs.

Tactile organs are extensively dispersed over the surface of the margin of the bell and its tentacles. These organs consist of a supporting cell and palpocil, similar to that which exists in Hydroids (p. 107). They are located among, and are evidently modified epithelial structures. Their living matter is directly connected with that of subjacent ganglionic nerve-cells.

Ocelli, or eye-spots, are to be found in large numbers in some Medusoids on the margin of the bell. In their simplest form they consist of sense-cells and pigment cells, the former being in close relation to the cells of the nervous system. The surface of some of the ocelli projects above the general surface of the ectoderm, and a lens-like body is developed (Fig. 24 A).

Statocysts (Fig. 24 B) or *Otocysts*, as they have been called in consequence of their supposed auditory functions. Like other receptors of energy appear to form the outposts of the nervous system. Each of these organs consists of a minute mass of organic and calcareous matter, supported in a cavity containing sensory fibrils which communicate the vibratory impressions they receive to subjacent nervous structures (Fig. 24 B).

We attribute the development of the sense-organs possessed by Hydroids and Medusoids, to the action of the environment, upon a long line of ancestral forms of beings, which gradually became modified in structure and functions in order to arrive at a condition in harmony with their surroundings.

CHAPTER VII

The action of the nervous and muscular systems of a jellyfish in response to stimuli is referred to—Also the development of this system in the starfish, flat worms, sea-mouse, crayfish, and certain insects is described.

In the concluding paragraphs of the preceding chapter we referred to the fact, that the peculiar organisation and combination of elements which go to form the sense organs of Medusoids, had not arisen out of something different, but form a continuous although modified form of matter, derived from pre-existing simpler species. This remark applies equally to the nervous and muscular systems of these animals, which were developed from the same external layer of sensitive matter as that which produced the sense-organs. The structures developed from this common basic substance remain intimately associated with one another. The sense-organs constitute the receivers of the energy they receive from the external world, and its transformers into a form which passes, by means of protoplasmic processes of living matter or nerve fibres, to subjacent ganglionic nerve-cells, and there releases potential energy or nerve force, which is conducted by nerve fibres to the contractile matter of the muscular system.

With a system of sense organs, nervous system, and muscular fibres such as those we can demonstrate to exist in Medusoids, we understand how it comes to pass that if we prick or pinch, that is stimulate, a point (*a*, Fig. 25) at the inner surface of the margin of the bell of a Medusoid, its manubrium first contracts; at the same time the bell bends inwards, as far as it is able at the point stimulated; the manubrium then moves, and with unerring aim brings its open extremity down to this point. If another spot is irritated, the manubrium leaves the first and moves to the second spot; and when left to itself, visits first one and then another irritated point, dwelling on those most severely irritated, its stinging fibres being freely extruded, as if in self-defence (Fig. 25).

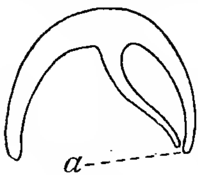

FIG. 25.

The manubrium moves exactly to that part of the margin of the bell which is irritated, that is, the impression made on the tactile organs at this spot passes, by means of nerve fibres to the adjacent ganglionic ring of nerve-cells, from which a discharge of energy takes place and becomes manifest in the movements of the body and manubrium, by the contraction of those muscular fibres which are included in the meridian irritated.

Romanes showed, by excising the entire margin of the bell of a living medusoid, including therefore its tactile sense-organs and ganglionic nervous system, that it was through means of the above-mentioned train of action the movements of the manubrium were effected. After the animal had been thus mutilated, irritation applied to the remaining part of the bell caused no movements of the manubrium.

In place of excising the margin of the bell, Romanes made an incision through it, parallel to its margin and above the situation of its ganglionic nervous system. If then, a spot between the incision and the margin of the bell is irritated, the direct nerve path to the muscle fibres of the manubrium is cut off; the stimulus or energy has therefore to travel round either end of the incision, and in this way becomes diffused in its passage to the manubrium. Under these conditions the movements of the manubrium are uncertain, it no longer bends down to the seat of irritation, but dodges about from one to another part of the margin of the bell; it has lost its power of localising the spot irritated. The manubrium is in fact acted on by a diffused nervous force, which impels it to wander first here and then to another spot, in place of taking any decisive action in the matter.

From these experiments we learn that definite, simple, co-ordinate action of different parts of the body takes place through a nervous system. The ordinary movements of a medusoid which influence its locomotion, depend on the regularly recurring contraction and relaxation of the muscular fibres of the bell and velum. This action in its turn depends on a constant flow of energy from its surroundings to the sense-organs, and from thence to the nervous and muscular systems, which are charged with potential force, derived from the metabolic processes carried on by their living protoplasm. A discharge of energy having been released from a series of ganglionic nerve cells, their living matter for the instant is exhausted, and until it receives a fresh supply of energy derived from its metabolic processes it cannot act on the muscular fibres. During the instant therefore that the supply of potential energy is being renewed, the kinetic energy received from the sense organs is suspended, and the tension of the muscles of the bell and velum is relaxed; but when the potential energy of the cell is restored, the external stimuli produce another discharge of nervous energy, followed by contraction of the muscular fibres. So long, therefore, as the fundamental properties carried on by the living matter of the system referred to and a supply of potential energy are thus secured, regularly recurring contractions and relaxations of the muscular fibres of the bell and velum take place at regular intervals, whereby the locomotion of the animal is effected.[1]

Movements such as we have above referred to occur in the cilia of unicellular organisms, and are foreshadowed in the action of the protoplasm in the closing and opening of the canal system of Sponges. A beautiful example of this mode of action is afforded us by a colony consisting, it may be, of some 1200 unicellular organisms, constituting a Volvox (Fig. 17). Each one of these organisms bears two cilia. The whole of the units forming the colony are connected by means of protoplasmic fibrils, and so form a continuous network. The 2400 cilia of Volvox act in unison, relaxing and contracting, and so producing a waving motion which propels the colony through the water. This action is caused by stimuli from without, which the living matter of each organism receives, and which releases a portion of its potential energy, followed by a momentary pause. And so on, in this way, the rhythmical movements of the cilia and the locomotion of the Volvox are effected.

With reference to the action of the swimming bell and velum of the Medusa, Prof. C. Sherrington remarks

[1] Halliburton's "Handbook of Physiology," p. 101 (seventh edition).

that in this animal, so far as these parts are concerned, we have a simple distribution of muscular fibres which practically only execute one movement. "Each and every receptor (sense)-organ, which under stimulation produces locomotion, is therefore connected by nerve fibres with that single muscle of locomotion, and when impelled by each or any of them, the muscle effects practically the same action as it does when impelled by any other of the sister receptor-organs. The movement of locomotion which is provoked through each receptor is practically the same as that provoked through any of the rest. The mechanical organ in this case can perform but one movement, and its performance of that movement is, so to say, the one purpose demanded from it by each of the receptor channels playing upon it." ("The Integrative Action of the Nervous System": Sherrington, p. 64.)

The class of animals known as the *Scyphomedusæ* differ from the Hydromedusæ in the mode of the segmentation of their ova, and in the structural arrangement of their gastric system and bell. This latter structure, in addition to the sense organs common to the Hydromedusæ, presents at least eight depressions on its margin, each depression being guarded by overhanging lappets. These depressions contain one or more otocysts and ocelli, from which sensitive fibres project outwards, and by their deep surface they are connected by protoplasmic fibres with ganglionic nerve cells.

In considering the effects produced by the action of the environment through the sense-organs, on the development of the living matter of the central nervous system of the Invertebrata, we can only refer to those classes and orders of animals which seem to illustrate this subject. We pass on therefore, to the Echinodermata, which includes in one of its orders the well-known starfish.

The nervous system of the Echinodermata is directly continuous, as in the Medusoids, with the living matter of the ectoderm, and although it has passed from the immediate surface of the body into the deeper structures, it retains distinct indications of its epithelial origin.[1] In the same way we clearly trace the origin of the sense-organs of this class of animals to a differentiation of the sensitive living matter of the ectoderm or outer layer of epithelial cells. These organs are connected with the underlying nervous system by protoplasmic fibrils.

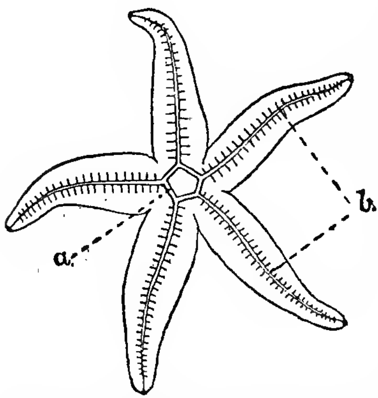

Fig. 26.—Diagram of the nervous system of a starfish. *a*, central nerve-ring surrounding the mouth; *b*, peripheral nerves of the arms. (J. Loeb, p. 61.)

The nervous system possessed by the snake-armed starfish affords a good example of the general type of structures possessed by this class of animals. In this echinoderm the nervous system is formed of a super-

[1] "Catalogue of Physiological Series," vol. ii. p. 2, Museum of the Roy. Coll. Surg. of England. See also A. Milnes Marshall on the Nervous System of Antedon Rosaceus, *Journ. Microp. Science*, July 1884.

ficial pentagonal ring which surrounds the animal's mouth (Fig. 26), and from which five radial nerves extend outwards throughout the length of the animal's arms. These nerve cords give off side branches to numerous muscular tubes which end in plates or suckers known as the ambulacral feet. It is by means of these feet that the starfish attaches itself to solid substances and effects certain movements of its body. If one of these animals is turned on its back the tube-feet of all the arms are at once stretched out, and move hither and thither as if feeling for something, and soon the tips of one or more arms turn over and touch the underlying surface with their tube-feet, which attach themselves to the solid matter on which the animal rests, and it is then able to drag itself over and regain its natural position.[1]

If the radial nerve cords of the five arms are cut through at their junction with the central ring, the power of co-ordinate action between the various arms is destroyed. But the mutilated limbs of such an animal, when stimulated, display independent power of movement. The circumoral ring therefore, is something more than the nerve path along which stimuli pass from one to other segments of the body; it would seem to fulfil one of the most important functions of a central nervous system, in that it forms a centre for the co-ordinating action of the rest of the body. We can account for the independent action of the arms when separated from their nerve ring, by the fact that the radial nerves contain ganglionic nerve cells.

Mr R. H. Burne states that the superficial oral system of nerves in *Ophiocoma echinata* is "to a large

[1] Prof. J. Loeb, p. 62, "Comparative Physiology of the Brain."

extent sensory in function; it innervates the entire body surface, the ambulacra, the mouth, and alimentary canal."[1] The ring, as well as its nerve cord, contains ganglionic nerve-cells, supported by a meshwork of attenuated epithelial cells and fibres.

In addition to the superficial nervous system we have referred to, a deep oral system exists, the two

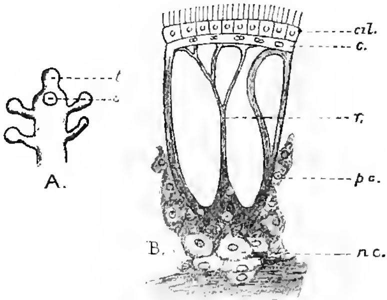

FIG. 27.—*A*, Diagram of terminal tentacle of *Diotenia setosum*. *t*, terminal tentacle; *e*, eye-spot. *B*, Diagram of a transverse section of a single cup of the eye-spot. *cil*, represents a layer of ciliated epithelial cells which cover (*c*) the transparent nucleated corneal structure. Below the cornea is a refractive body (*r*) containing nucleated protoplasmic strands. Outside the base of the cup are a layer of pigmented cells (*pc*) which dip down into a layer of subjacent ganglionic nerve-cells. (See Lankester's "Treatise on Zoology," part. iii. p. 285.)

systems being connected by means of protoplasmic fibrils. The deep oral is the motor centre for the muscles of the animal's arms; it probably gives off fibres that accompany the peripheral and ambulacral nerves of the superficial system.

The tactile sense-organs of the echinodermata vary considerably in structure, each being adapted to the

[1] "Descriptive Catalogue of the Physiological Series of the Royal College of Surgeons," vol. ii. p. 3.

habits of the various orders in which they have become developed.

Visual organs exist in the Asteroids. Probably all echinodermata are sensitive to light, owing to the action of their pigment-bearing amœbocytes. The eye-spots in Asteroids lie at the base of each of the terminal tentacles (Fig. 27 A); they consist of a cushion which possesses red pigment, and contains a number of conical cups representing an eye (Fig. 27 B).

Although the nervous system of this class of animals is more highly differentiated than in Medusoids, their sense-organs are, on the whole poorly developed, but their general sensibility (touch, etc.) is probably more discriminative than in Medusæ.[1]

Having described the Echinodermata with their imperfectly developed sense-organs and nervous system, we may now pass on to the Platyhelminthes with its three classes, represented by the Flat-worms (Turbellaria) the Flukes (Trematoda), and Tape-worms (Cestoda). Most of these animals move in a definite direction, and possess an anterior end or head, and a posterior end or tail. Their bodies contain a third layer, the mesoderm, interposed between the ectoderm and endoderm.

[1] In some of these animals there are peculiar organs which are supposed to constitute an auditory apparatus, but it is more probable they are connected with its position or orientation. These organs are only found on the oral side, and when the animal is in its natural position they hang down like the clapper of a bell; but when the animal is tilted over, each of these sphæridia press against the nerve cushion surrounding the stalk, and thus stimulate groups of muscles, and by their action the animal regains its normal position. See Mr F. A. Bather on Echinodermata; Lankester's "Treatise on Zoology," part iii. p. 101. Also see Prof. Sedgwick's "Students' Text-book of Zoology," vol. i. p. 156.

Professor W. B. Benham states, that while the three classes of Platyhelminthes exhibit many different forms, habits, and life cycles, yet they have so many features in common that we are justified in supposing they are derived from one ancestral stock.[1] He states that an ideal ancestor of this phylum would probably have had a small, oval, flattened body with a defined front region or prostomium, which contained the animal's brain (Fig. 28). The surface of the body was probably clothed by cilia, so that the animal could move through the water, aided by a system of muscles which had formed below the epidermis, with which it had, however, lost its connections, and become arranged in the form of circular and longitudinal bands. The nervous, like the muscular system, had also separated from the external layers of epithelial cells, and assumed a distinct and definite form, many of its ganglionic nerve-cells having become aggregated near the anterior end of the animal's body, that is, in that end of the body which is directed forwards during the movements of the worm. This aggregation of nerve-cells and fibres is placed near the dorsal surface of the body anterior to the mouth; it

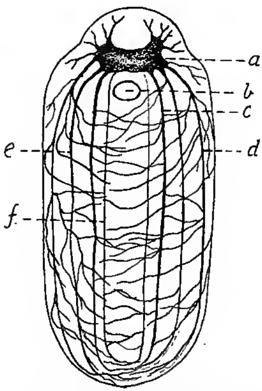

FIG. 28.—*a*, cerebral ganglia; *b*, mouth; *c*, ventral nerve tract; *d* and *e d f*, respectively marginal, dorsal, and medio-dorsal nerve tracts.

[1] Professor W. B. Benham, article in part iii. of Lankester's "Treatise on Zoology," on the Platyhelmia, p. 2.

forms a bilobed cerebral ganglion from which a meshwork of nerves spread over the whole of the body. Certain of these nerves were well developed, as shown in Fig. 28, and among their fibres ganglionic cells existed, but they did not give rise to other ganglia than the brain.

Several orders of existing Turbellaria retain the ancestral type of nervous system which, although it has sunk below the epidermis, consists of a close network, in which cells and fibres take a share and extend over the whole surface of the body. Ventrally

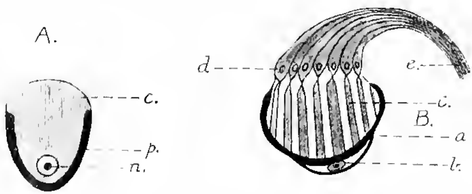

FIG. 29.—*A*, Unicellular eye of *Geoplana*. *c*, refrigent portion of the cell; *n*, nucleus; *p*, peripheral pigment. *B*, Section of eye of *Leptoplana*. *a*, pigment cup; *b*, nucleus of pigment cell; *c*, rods, the modified ends of nerve-cells; *d*, nerve-cells, which are prolonged into nerve fibres; *e*, optic nerve.

it radiates from the brain. In other orders of the Turbellaria the bilobed brain, and the nerve cords proceeding from it, show a more complete differentiation of the nervous system.

With reference to the sense-organs of the multitude of animals included among the class of Turbellaria, Professor A. Dendy has described in one, the Geoplana, a unicellular eye (see Fig. 29 A).

Passing from the lower to the higher class of worms, or the Annelida, we find they assume what is known as the metamerically segmented form. By this term we understand an animal whose body is made up of a number of successive segments or metameres, in each of which the essential structural characters are repeated. Thus, in each segment, we get a pair of nervous ganglia, excretory organs, etc.

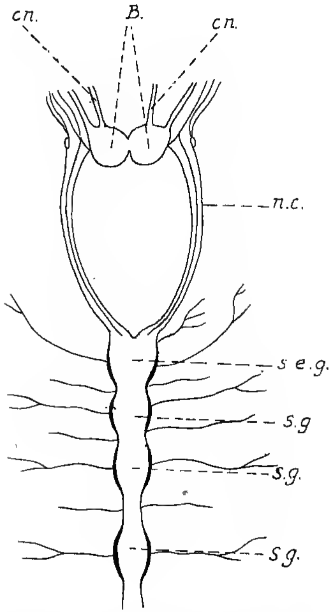

FIG. 30.—Diagram of nervous system of Annelida. *B*, brain; *cn*, cephalic nerves to supply sense organs of anterior end of the worm; *nc*, nerve cord passing from the brain to *seg*, the sub-œsophageal ganglion; *sg*, segmental ganglia giving off nerves to the corresponding segments of the body.

The nervous system of the Annelida consists of a bilaterally arranged cerebrum, its two halves being united by connecting or commisural nerve fibres. The brain is situated in the pre-oral or anterior end of the body; from it two nervous cords pass backwards to the sub-oral, or, more correctly, sub-œsophageal ganglion. From this latter nervous centre, segmentally arranged pairs of ventral ganglia run along the mid-line of the body, they are united by longitudinal and transverse fibres (Fig. 30). There is much diversity in the degree of concentration of these nervous segmental ganglia; but the "size and complexity of the cerebral ganglia depends entirely upon the degree of development of the cephalic sense organs."[1] Each pair of the ventral chain of ganglia constitutes a reflex system for the innervation of its own segment of the body.

The anterior end of many of the higher classes of worms form leading segments, and are thus exposed to the influences of external conditions more directly than the rest of the body. Their distant receptors or sense organs therefore, undergo considerable development, and as we have stated, there is a corresponding increase in the complexity of the structural arrangement of their cerebral ganglia.


FIG. 31.

The Annelida include four classes; of these we can only refer to one, known as the Chætopoda, or Bristle-worms.[2] The well known Sea-mouse (Aphrodite aculeata) is included among the Chætopoda; it is of an oval form, about 6 or 8 inches long and 2 or 3 broad, and is beautifully coloured. The head is furnished with a tentacle and two filamentous palps (Fig. 31). The Sea-mouse is generally to be found concealed under stones; it dwells amongst the mud at the bottom of

[1] Cat., Roy. Coll. Surgeons, "Physiological Series," vol. ii. p. 5.

[2] The chætæ are ʃ-shaped chitinous rods embedded in epidermic sacs, and movable by special muscles. They are the chief organs of locomotion of the earthworm, and from them this class of animals have received the name of Chætopoda.—"Comp. Anatomy of Animals," by G. C. Bourne, vol. ii. p. 19.

Two specimens of the nervous system of Chætopoda are to be seen among the Physiological Series in the Museum of the Roy. Coll. Surgeons, No. D 6—one of the Lug-worm (Arenicola marina), the other of the Sea-mouse (Aphrodite aculeata).

the sea. Storms frequently throw them on the beach in great numbers.[1]

The cerebral ganglion of this animal consists of a central mass of ganglion-cells with their ramifications and supporting structures. This mass of nervous matter can be separated into two main centres—the fore and mid brain; between them is a third lobe from

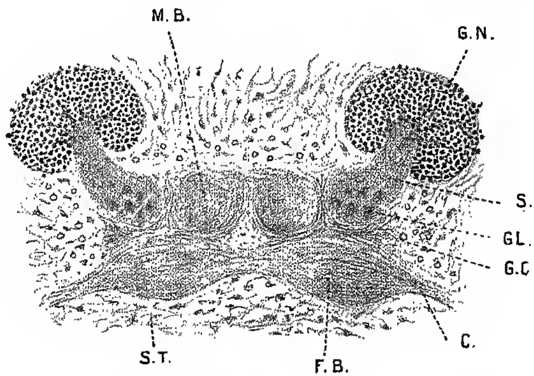

FIG. 32.—Transverse section through the brain of *Aphrodite aculeata*. × 50. *C*, root of œsophageal connective; *FB*, fore-brain; *GC*, ganglion cells; *GL*, glomeruli; *GN*, ganglionic nuclei; *MB*, mid-brain; *S*, stalk of fungiform body; *ST*, supporting tissue. (Copied from Fig. 6, Cat. Roy. Coll. Surgeons, Physiological Series, p. 10.)

which two fibrillated processes project upwards towards the dorsal integument, and terminate in masses of closely packed nucleated matter, which appear to us to constitute aggregations of what M. Binet terms "consciousness matter," or a specialised form of living protoplasm, through means of which the animal's intellectual processes come into play (see Fig. 32). As these aggregations of protoplasm are more highly developed in the brain of the crayfish and of some insects, we

[1] "Chambers's Encyclopædia," Revised Edition.

refer the reader to p. 133 for further details on the subject.

The cerebral ganglion of *Aphrodite aculeata* is enclosed in a capsule or layer of fibrous tissue containing ganglionic cells. The ganglia of the ventral chain are united, each of them gives off nerves to the muscles of the parapodia, and of the trunk of their respective segments of the body.

In the Lug-worm, as might be expected from its sluggish habits the nervous system is poorly developed, the cerebral ganglion being a small lobulated body ; on the other hand, in the active Polychæte known as *Marphysa sanguinea*, the central ganglia are well formed.[1] This latter animal's eyes and tactile sense organs, have undergone an amount of development such as to enable it to accomplish its active movements, and we find a corresponding increase in the complexity of structure of the brains. The animal's palps receive their supply of nervous energy from the living matter of ganglionic cells located in the fore-brain ; the mid-brain supplies the nerves of the eyes and tentacles, and from the hind-brain nerves are given off to the nuchal region.[2] We are therefore justified in drawing the conclusion, that in these orders of animals the structural complexity of the brain depends upon the degree of development of the cephalic sense-organs.

Although the nervous system of the lower orders of worms is not far removed in structure from that of the Echinoidea, it is evident that in the higher order a

[1] The Polychætæ are an order of the class Chætopoda ; usually they have a distinct head formed by the modification of the anterior segments of the animal. The head bears tentacles on its dorsal side and a pair of palps, and frequently eyes, cirrhi, and parapodia.

[2] Fig. 4, Cat. of Physiol. Series, vol. ii. p. 8, Roy. Col. Surgeons.

considerable advance has been made in the complexity of their cephalic ganglia. This advance in the structural arrangement of the brain in these animals, is referable to the increased use they necessarily make of their cephalic sense-organs in their struggle for existence.

The *Arthropoda* include among its members the spiders, scorpions, insects, water-fleas, wood-lice, lobsters, and the cray-fish. With reference to the four classes into which this phylum is divided, we must confine our attention to the nervous system of one class—the Crustacea, comprising such animals as the water-fleas and cray-fishes. As an example of the former group we may select the *Apus cancriformis*, and of the latter the *Astacus fluviatilis*, which latter being has been so admirably described by Prof. Huxley in his work on "The Crayfish, an Introduction to the Study of Zoology."

Although in the lower forms of the Arthropods the central nervous system does not differ essentially from that of the higher orders of worms, in the higher forms of this class of animals, especially in insects, we find that the brain has a very complex structure, accompanied by elaborate sense-organs.

The cerebral ganglion of the sub-class of Crustacea to which Apus cancriformis belongs, consists of a small quadrilateral body, situated in the fore part of the animal's body. From ganglionic cells located in this nervous centre, nerves pass anteriorly to the paired eyes. From the posterior corners of the cerebrum communicating fibres pass on either side of the œsophagus to form the subœsopheal ganglia (Fig. 30). The first pair of antennæ are supplied by nerves that seem to rise from the circumœsophageal connectives; their true centres of origin however, are situated in the lateral parts of the cerebral ganglion. On a level with the mouth each circumœsophageal connective enlarges to form an œsophageal ganglion which gives off two nerves, one to the second antenna, the other to the viscera. The two ganglia are united by a double commissure. Mr R. H. Burne remarks that the condition of the antennary nerves in Apus suggests, that the direct origin of these nerves in the higher Crustacea from the cerebral ganglion, is the result of an anterior concentration of centres originally separate and post-oral in position.[1]

The ganglia of the ventral chain are paired, and connected by transverse and longitudinal fibres. They supply motor, and receive sensory nerves from the segments of the body to which they belong.[2] The nervous system of these small Crustacea therefore appears to form a link between the higher Annelids (p. 126) and the larger Crustacea, represented by such animals as the crayfish.

The tactile and visual organs of the small Apus cancriformis conform in their general outline so closely to those met with in the crayfish, that we may best refer to them in connection with this larger Crustacean.

The ordinary crayfish (Astacus fluviatilis) is common to many of our streams and rivulets; it is rarely more than three or four inches long, and usually of a dull greenish or brownish colour. The animal, during the summer months, may be seen walking along the bottom

[1] Cat. Nervous System, Roy. Coll. of Surgeons Museum, p. 19. "Compt. Anatomy of Animals," by G. C. Bourne, p. 104, vol. ii.

[2] Pelseneer, *Quart. Journ. Mic. Sci.*, 1885, p. 433.

of shallow water by means of four pairs of jointed legs; but if alarmed, the crayfish swims backwards with rapid jerks, propelled by the strokes of a broad, fan-shaped flapper, which terminates the hinder part of its body. A sort of shield covers the front part of the body, and ends in a sharp spine. On either side of this there is an eye, mounted on a movable stalk, which can thus, by the action of its muscles, be turned in any direction. In front of and above the animal's mouth are a pair of long feelers (antennæ), which are kept in constant motion exploring the surrounding water. Above and in front of the antennæ there are two pair of small feelers or antennules; in the basal joint of the animal's antennules an oval aperture exists, which is covered by numerous fine sensitive processes (setæ). This aperture leads to a cavity or sac containing structures adapted to regulate, through the action of the nervous system, the orientation of the animal's body. These structures have been described as auditory sense-organs.[1]

During the winter months the crayfish lies at the mouth of a burrow that he has made in the banks of a stream, with his claws and feelers protruding, thus keeping watch on passers-by in the shape of larvæ, insects, water-snails, tadpoles, or small frogs. No sooner does such prey come within the reach of the animal's claws than it is seized and devoured.[2]

We have referred to the habits of the crayfish in order to show that its existence depends on its power to appreciate the distance from its body of moving

[1] "The Natural History of some Common Animals," by O. H. Latter, p. 13.

[2] "The Crayfish," by T. H. Huxley, pp. 5, 6, 115.

objects, and then rapidly to adjust its own movements so as to seize its prey. The animal effects this object through the use of its eyes, or those receptors of energy which respond to stimuli reaching them from distant objects. Stimuli received through these organs initiate sensations in the brain having the psychical quality termed *projicience.* The projicience refers the object which has caused the sensation to its proper direction and distance in the environment, and thus enables the crayfish accurately to adjust its movements so as to seize its prey. We shall return to this subject in another chapter of this work, and would only here observe that we concur in Dr W. H. Gaskell's opinion that "the brain is always the part of the nervous system which is constructed upon, and evolved upon, the distant receptor organs."

By comparing Fig. 33, which represents a section of a crayfish's brain, with Fig. 32, the section of a sea-mouse's brain, we shall comprehend better than words can express, the increased complexity of the structural arrangement of the former as compared with the latter brain. With the highly differentiated brain of the crayfish, we find an equally complex arrangement of the structures forming the animal's eyes and other sense-organs (Fig. 34).

The fungiform bodies we have referred to found in connection with the brain of the sea-mouse (Fig. 32) are more fully developed in the crayfish, and enter into close relation with the cerebral ganglionic centres of vision and touch (Fig. 33). But it is in Insects, such as the bee, that these portions of the central nervous system reach their highest state of development, and seem to bear a distinct relation to the intellectual capacity of the animals in which they exist. For instance, in the bee they form a pair of cap-like discs covering the upper part of the rest of the brain.[1] Protoplasmic fibrils pass from the fungiform bodies

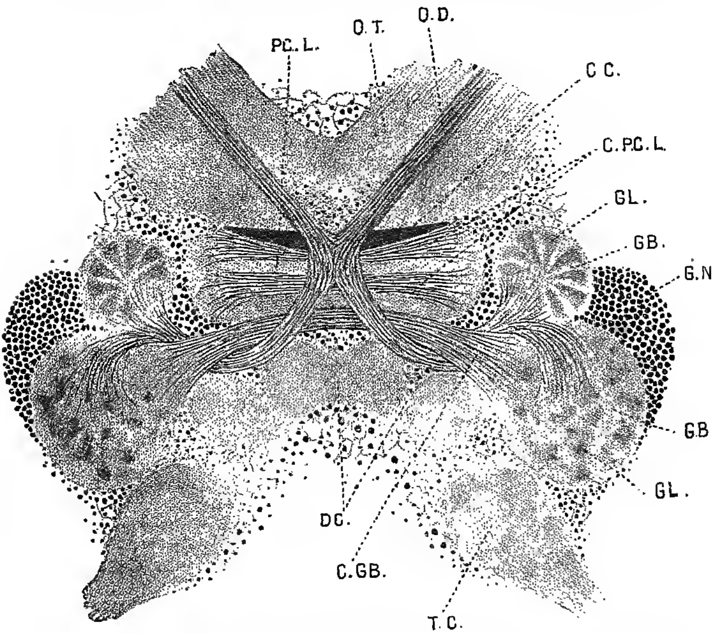

FIG. 33.—Horizontal section through the brain of *Astacus fluviatilis*. × 40. *CC*, corpus centrale; *CGB*, commissure of globuli; *CPCL*, commissures of protocerebral lobes; *DC*, deutocerebrum; *GB*, globulus; *GL*, glomeruli; *GN*, ganglionic nuclei; *OD*, oecussating bundle of optic tract; *OT*, optic tract; *PCL*, protocerebral lobe; *TC*, tritocerebrum. (Cat. Physl. Series, Museum Roy. Coll. Surgeons, vol. ii. p. 22.)

not only to the antennary and optic lobes, but to all the other parts of the brain, and these nervous structures "increase roughly in proportion to the intelligence

[1] Newton, *Quart. Journ. Mic. Sci.*, vol. xix., 1879, p. 340; also Cat. Roy. Coll. Surgeons, Nervous System, pp. 34-36.

of the Insect. Among social forms they may even vary in development between persons of the society, being for instance, proportionately larger in the Worker bee than in the Drone or the Queen bee."[1] The fungiform bodies may be said to bear a relation to the rest of the insect's brain, analogous to that of the cortex of their cerebral hemispheres to the intellectual capacity of the higher animals.[2] Movements resulting from work performed by the living matter of these psychical centres or consciousness substance, tend to balance the action of external forces acting on the organism, and in the course of a long series of generations have lead to its structural modification.[3]

The compound eyes of a crayfish consist of a large number of elongated structures, each of which is formed of a complex arrangement of parts, adapted to receive, and bring to a focus on their deeper or nervous layer, rays of light which impinge on the outer or free surfaces of these visual rods (Fig. 34). The whole of the outer ends of the rods converge from the transparent cornea towards a mass of ganglionic cells and fibres situated in the eye-stalk; from these nerve-cells numerous fibres pass into relation with the optic lobes of the brain. In these animals the structural arrangement of nerve-cells and fibres of the optic lobes is

[1] Cat. Roy. Coll. Surgeons, Nervous System, p. 35.

[2] Professor A. Bain states that "if a honey-bee were to alight on one flower, try its quality, go to a second, and then return to the first as the better of the two, such an act of deliberate preference would imply intelligence along with volition." The fact that one impression can remain in the mind when the original is gone so as to be compared with a second impression, implies the very essence of intelligence, however limited the degree ("The Senses and Intellect," p. 5, by A. Bain).

[3] Villa, p. 275.

vastly complicated, illustrating clearly the relation existing between the structural elaboration of the animal's visual apparatus, and the nervous matter which receives impressions through means of this apparatus.

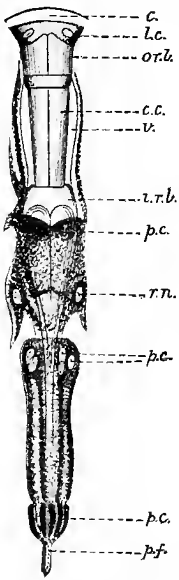

FIG. 34. — Transverse section through one of the visual rods of *Palæmon squilla*. *c*, cornea; *lc*, lentigen cell; *cc*, crystalline cones; *v*, vitrellæ; *irb*, inner refractive body; *orb*, outer refractive body; *rn*, retinular nuclei; *pc*, pigment cells; *pf*, nerve fibres passing to form the eye-stalk. (Copied from a drawing in Gilbert C. Bourne's work on the "Comparative Anatomy of Animals," vol. ii. p. 138.)

The visual organs of the animals hitherto referred to consist essentially of a refractive medium, by which rays of light are focussed on specialised nerve and pigment cells. The living matter of the nerve-cells responds to the stimulus of light, transforming it into nervous impulses which act on the subjacent system of ganglionic nerve-cells. "It is supposed that the change effected by the agency of the light which falls on the retina is in fact a chemical alteration in the protoplasm, and that this change stimulates the optic nerve-endings."[1] The colouring matter contained in the pigment cells is in the form of granules. On being stimulated by light the granules of pigment in the cells (which are part of the retinal structure) pass down into the processes of these cells; at the same time a movement in the retinal cones takes place. It has also been found that under the influence of light,

[1] "Halliburton's Handbook of Physiology," seventh edition, pp. 802-3.

certain kinds of pigment are not sensitive to light, while other colours, especially visual purple, have a selective action on the colours of the spectrum. Beyond this there is good reason to hold, that under the influence of light the colouring matter of the visual organs effects chemical changes in the substance of the nerve-cells, accompanied by an electrical discharge. Action of this kind seems to bear on that to which we have referred in the case of chromatophores, chlorophyl-bodies, and chromosomes.

The so-called auditory apparatus of the crayfish is located in the basal joints of the antennules, its external opening being closed by setæ. Beneath this is a small sac with chitinous walls. The inferior and posterior wall of the sac is raised so as to form a ridge, from each side of which setæ project into the cavity of the sac, which is filled with particles of sand and other foreign matter known as otoliths. The posterior end of the sac is pointed, and receives the auditory nerve (a branch of the antennary), which divides and spreads along the ridge and walls of the sac. Fibres of these nerves pass into the hollow setæ, and may be traced to their apices, where they end in peculiar elongated rod-like bodies.[1] Professor Kreidl instituted a series of experiments by which finely powdered particles of iron were substituted for the otoliths of some of these animals. He found that under these conditions the animals adjusted the position of their bodies in obedience to the influence which a magnet exercised on the particles of iron.[2] It has, however, been shown

[1] "The Crayfish," by T. H. Huxley, p. 117.

[2] "The Natural History of some Common Animals," by O. H. Latter, pp. 60, 65.

that the "auditory" setæ of some Crustaceans are thrown into vibration by certain noises and musical notes.

Professor Huxley states that there is reason to believe that odorous bodies affect crayfish, and may be connected with some peculiar structures located on the under side of the outer branch of the antennule. The animal also probably possesses something analogous to taste, and a likely seat for an organ having this function is the upper lip.

We have already referred to the antennæ possessed by the crayfish as being constantly employed as feelers, and it is probable that the setæ, which are so generally scattered over the body and appendages of the animal, are delicate tactile organs supplied with fine nerve fibres which may be traced to the base of these hair-like protoplasmic processes.

It is therefore certain that the sense organs of the crayfish are of no mean order, and that their eyes and other sense organs contain specalised forms of living matter, to receive and transmit luminous and other vibrations to the brain. These organs, as we have explained, are of particular importance, as they enable the nervous machinery to be affected by bodies indefinitely remote from it, and to change the place of the organism in relation to such bodies.[1]

By examining sections of the brain of a crayfish, such as that represented in Fig. 32, it becomes evident that the increased complexity of the animal's sense-organs are faithfully represented in the structural development of its nervous system; the optic and antennary lobes of the brain are conspicuous, and the fungiform matter is

[1] *Idem*, p. 116.

present in considerable quantity and is diffused over the various sections of the brain. From the structure therefore, of the central nervous system of a crayfish, we seem drawn to the conclusion that there is a distinct connection between the animal's intellectual and his visual and tactile faculties.

We find that there is a marked tendency in the nervous system of the crayfish for its various parts to become concentrated into a brain and nervous cord. Beyond this structural arrangement of its nerve-cells and fibres, it approximates to the central nervous system of Vertebrata, in that the protoplasmic processes or fibres given off from its nerve cells do not, as a rule, form a continuous structure, as is the case in the Hydromedusa; a space or synapse exists between the fibres of adjacent cells (Fig. 39). We shall explain the bearing of this arrangement of the nervous structures in a subsequent chapter.

The segmental character of the nervous system in the crayfish is functional as well as structural, for each ventral ganglion forms an independent reflex centre for activities of its innervation area. Co-ordination of action is mainly the result of the transmission of stimuli from one ventral ganglion to another.

With regard to voluntary movements of the limbs, if the subœsophageal ganglion of a living animal be removed, it can no longer control the movements of its limbs in a co-ordinate manner so as to move from one spot to another. The central nervous system in these animals therefore, exerts a higher controlling influence over locomotion than is the case in the lower classes of beings to which we have referred, and suggests the idea that the brain of these Crustaceans has not only the power of controlling the movement of the limbs, but also of instigating activities in the rest of the nervous system.

We have thus far traced the progressive development of a nervous system such as that which exists in medusoids, consisting of a simple network of ganglionic cells and their nerve fibres, up to the concentration of these structures into a system which in the star-fish forms a co-ordinating centre for the rest of the body. In worms a further concentration and differentiation of nervous structures takes place in the anterior part of the animal's body—that is to say, in that part which is most freely exposed to the action of the environment. In the higher order of worms, cephalic sense organs are developed, and with them we find that an increase takes place in the complexity of the cephalic nervous centres which are in communication with the sense-organs. In this class of beings the brain exerts a certain amount not only of initiative, but also of inhibitory power over the movements of the animal's body. Finally, in the higher orders of the Crustacea, a complex brain exists, which appears capable of initiative and also of carrying out complex co-ordinate and distinctly purposive actions.

It seems to us therefore, that in the preceding pages we have given sufficient evidence to substantiate the fact, that the development of so important an organ as the brain of the Invertebrata, depends on the response of healthy living nervous matter to stimuli which it receives through the sense-organs of their bodies. These stimuli produce structural modifications in those parts of the brain which are in direct relation with the animal's eyes, and other sense organs; and we have endeavoured to show there is good reason to hold that the sense-organs have been developed, by the action of external stimuli on the sensitive living matter which constitutes the outer layer of the bodies of these animals.

Adaptative modifications of this kind constitute the foundation on which structural alterations in nervous matter are effected and become hereditary; and under the action of natural selection the useful characters possessed by such matter are developed in varieties and species of animals.

It is beyond our purpose to attempt a description of the progressive development of the nervous system of Vertebrates. It is, in fact unnecessary, for Prof. J. B. Johnston's recently published work,[1] together with the fine collection of specimens in the Museum of the Royal College of Surgeons, with its admirable catalogue, afford the means by which those interested in this branch of science may acquire a knowledge of all that is at present known on the subject.

[1] "The Nervous System of Vertebrates," by Prof. J. B. Johnston. London: John Murray, 1907.

CHAPTER VIII

An outline of the vocal apparatus is given, and the structure of those parts of the nervous system which control its action—This leads us to consider the nature of reflex actions and the structure of nerve-cells and certain parts of the central nervous system which are more directly concerned in the production of intelligent speech.

In the following chapter we refer to the structure and arrangement of those parts of the central nervous system which directly control the action of the vocal apparatus. To persons unacquainted with the anatomy and physiology of this system, we fear the details and the technical terms we are constrained to employ will be a source of embarrassment. But we nevertheless urge such persons to study this chapter, for the structure and arrangement of the nervous matter it refers to are not difficult to master; and it is almost impossible to realise the action of the sense-organs on the nervous substance of the brain, and of the brain on the vocal apparatus, unless we comprehend the nature of the structures concerned in producing vocal sounds, and the means by which we come to employ these sounds to express our thoughts in intelligent language.

In the lowest classes of organisms which possess nerve-cells and striped muscular fibres, the living matter of these structures is connected with corresponding receptors or sense-organs. Thus in Medusoids, mechanical stimuli acting on the tactile sense-organs of the animal's body liberates a portion of their potential energy, which is conducted by means of protoplasmic fibrils to subjacent nerve-cells, and becomes manifest in the contraction of the muscular fibres contained in the bell and velum of the animal. These muscular fibres however, are by no means all continuous with one another; gaps exist between them, and across these gaps nerve fibrils may be traced which constitute a connecting link between one and another of the muscular fibres. The co-ordinate action of this system is effected by the energy it receives through the nervous fibrils, which, by their nerve cells are in communication with corresponding receptors of energy. The nervous apparatus therefore of Medusoids brings its muscular fibres into co-ordinate action, serving the same purpose as the protoplasmic processes which connect together the living matter of the cells of a Volvox, whereby the orderly, rhythmical motion of its cilia is effected (p. 37).

It is almost needless to repeat, that action such as this depends on the effective working of the metabolic and other fundamental processes, necessary for the supply of potential energy to the living matter of the structures taking part in movements, such as those to which we have referred.

It may appear at first sight that there can be but slight connection between the response made by the muscular system of a Medusoid to tactile and other impressions, and the production of vocal sounds by human beings. Nevertheless, as we hope to explain, the mechanism which effects the muscular contractions and movements of these animals, is similar to that which effects movements of our vocal apparatus, and leads to the production of articulate sounds. In order to explain the grounds on which this statement rests, it is necessary briefly to refer to the nature of the apparatus by means of which man produces vocal sounds, and also to the structure and functions of those parts of the living matter of the central nervous system which controls the action of this apparatus.

The apparatus by means of which vocal sounds are produced in man and some other animals consists of a tube, leading from the lungs into a chamber known as the larynx, which opens at the back of the mouth. The framework of the larynx is formed of cartilages movable on each other by the action of groups of muscles attached to them. Across the middle of the larynx is a transverse partition formed by the folds of its lining membrane, which stretch from side to side, but do not quite meet in the middle line, so that between their free edges a narrow chink exists. The edges of this chink are known as the vocal cords; their degree of tension is regulated by the action of the muscles of the larynx. A blast of air passing up from the lungs through the windpipe into the larynx throws the more or less tense vocal cords into a state of regular vibration, which necessarily produces condensation and rarefaction of the air passing through the chink above described, and causes a sonorous wave.

The current of air necessary to set the vocal cords vibrating, is produced by the contraction of certain of the chest and abdominal muscles, so that the chest walls and the lungs contained therein constitute a sort of bellows without a valve, in which the chest and lungs represent the body of the bellows, while the passage leading to the larynx forms the pipe; and the effect of the respiratory movements is just the same as that of the approximation and separation of the handles of the bellows, which drive out and draw in the air through the pipe.[1] According to the state of tension or of relaxation of the vocal cords, so will the rate of their vibration and the pitch of the sound be raised or lowered. The spaces above the vocal cords, especially the mouth, form a series of resonators which can alter their shape so as to resound at will either to the fundamental tone of the vocal cords or any of its overtones. Through the agency of the mouth we can mix together the fundamental tone and overtone of the voice in different proportions, and the different vowel sounds are due to different admixtures of this kind. It is, in fact, by movements of the muscles of the lips, tongue, and larynx that the sounds produced by the vibrations of the vocal cords are moulded into articulate speech, and these movements result from the action of the nervous system on the complex arrangement of muscles which form the respiratory and vocal apparatus.

The structure of nerve-cells in mammalia, including human beings, varies at different periods of life. In the

[1] "Elementary Lessons in Physiology," by T. H. Huxley, p. 90:—

As far back as the year 1780, Kempelen produced a speaking-machine, and Willis, in 1828, by means of a vibrating reed and tubes of various lengths, imitated the sounds of some of the vowels. Wheatstone demonstrated the resonating functions of the mouth, and ultimately, in 1877, Edison produced the phonograph. Professor M'Kendrick, in a lecture delivered at the Royal Institution on the 6th March 1903, on the "Experimental Studies of Phonetics," gave a most interesting account of these instruments, and of the graphic representation of the human voice.

early embryo the nerve-cells consist of small nucleated masses of protoplasm which in the course of a short time give off a number of branches.

The central nervous system, which comprises the brain and spinal-cord, is formed of a vast aggregation of nerve-cells and their fibres embedded in a soft fibro-cellular material (neuroglia), which also contains vascular and lymphatic structures.

The nerve-cells of the central nervous system of an adult human being are of considerable dimensions, and consist of a mass of cytoplasm which has a finely granular fibrillar structure, and these fibrils can be traced into the central part of the branches which proceed outwards from the cell (Fig. 35). We allude therefore, to these branches as being processes of the cytoplasmic body of the cell to which they belong; they form the paths along which energy is conducted into, and passes from the living matter of the nerve-cells. The cytoplasm of the nerve-cell contains a nucleus, nucleolus, and granular material, which latter substance appears to consist principally of nucleo-proteid compounds employed probably as a store of nutrient matter, which becomes available when the living matter of the cell is excited into a condition of hyper-action.

As may be seen by reference to Fig. 35, each of the nerve-cells of the central nervous system possesses two sets of protoplasmic processes or nervous fibrils; the greater number of these branch soon after leaving the body of the cell, divide and subdivide until each branch terminates in an arborescence of fine fibrils. These comparatively short branches are known as *dendrons*. The terminal fibrils of the dendrons from one nerve-cell intermingle with dendrons derived from other nerve-cells, but in the central nervous system the two sets of fibres do not unite with one another

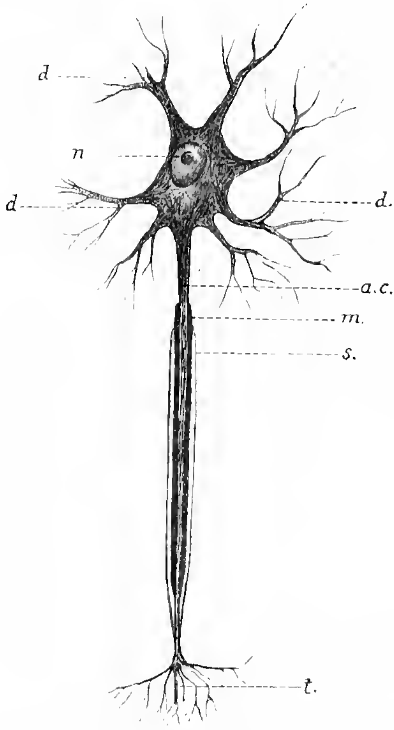

FIG. 35.—Diagram of a ganglionic nerve-cell (neuron). *d d d*, dendrons; *n*, nucleus and nucleolus; *ac*, axis-cylinder; *m*, medullary sheath; *s*, neurilemma; *t*, terminal branches.

(Fig. 39). Nervous energy therefore passing along one set of dendrons to another set, has to overcome the resistance offered to it by the matter which intervenes between the two sets of dendrons. In this respect, as we have explained, the *central nervous system* of the mammalia differs from that of Medusoids, and some of the other lower classes of animals in which the nervous system forms a continuous meshwork of cells and fibres.[1]

In addition to their dendrons, the living matter of each nerve-cell of the central nervous system gives off one or more bundles of protoplasmic fibrils, which together constitute what are known as the *axis-cylinder or neurite* (Fig. 35). These fibrils send off side branches, and after becoming enclosed in various coverings unite to form a nerve fibre. Many nerve-fibrils of this description become bound together and constitute a nerve. The axis-cylinder may run a long course, but ultimately terminates in an arborescence of fibrils which end in muscular fibres, or it may be in glandular structures.

We may follow the axis-cylinder of one of the motor nerve-cells of the brain into the spinal-cord, and find that it there breaks up into terminal fibrils which come into relation with similar fibrils of another motor nerve-cell, and from this latter cell an axis-cylinder may pass to a muscle; when excited, the energy passing along nerve fibrils from the living mattter of the nerve-cell, causes the muscle fibres with which they are connected to contract (Fig. 39, p. 160).

The term *Neuron* is applied to the complete nerve unit, that is the body of the cell including its nucleus,

[1] In human beings however, the muscular fibres of the vascular and alimentary structures are innervated by means of a continuous nervous system, the protoplasmic fibrils of one nerve-cell being continuous with those of a neighbouring cell ("The Nervous System of Vertebrates," by J. B. Johnston, p. 85; and Professor Sherrington, *op. cit.* p. 58).

as well as the dendrons and axis-cylinder which proceed from, and form a part of the nerve-cell (Fig. 35).

Embryology. We only propose referring to this subject in so far as it points to the fact that the development, and organisation of the nervous system of Vertebrates proceeds on similar lines to that which prevails in Invertebrates.

We may allude to the development of the nervous system, and the special sense-organs of a bird as being a familiar representative of Vertebrates. If we open an egg which is being hatched, we find at an early stage of this process, in the yolk, a small mass of material which includes the embryonic structures or first rudiments of a future bird. The embryo consists of cells arranged in an orderly manner, upon its dorsal surface a longitudinal streak appears known as the neural plate. This streak has elevated edges, which grow and lap over so as to unite by their free edges, and thus enclose a canal, the upper extremity of which is dilated; this canal will eventually form the cavity of the spinal cord and brain.

The neural plate therefore is formed from the living matter of the external or ectodermal layer of the embryo, that is to say, from the layer of cells which corresponds to that from which the nervous system and the sense organs of the Hydromedusæ and other invertebrates are produced.

If we examine the structure of the material which forms the walls of the neural canal, we find that they consist of supporting cells, among which are a number of rapidly proliferating cells. These germinal cells are especially numerous in the structures which border the canal; and the young cells which they produce pass into the canal, and from their living matter pseudo-podal-like processes grow outwards and develop into the characteristic neurites and dendrons of nerve-cells. In the early stages of their existence however, the neurites (axis-cylinders, Fig. 35) do not possess a myelin sheath, and until they have acquired this covering the neurons to which they belong are incapable of fully performing their functions. It has been shown that in the developing human brain certain fibre tracts produce their myelin sheaths earlier, others later, and that the order of myelinisation is measurably regular and constant; we may thus study the order in time when various nervous pathways in an infant begin to function or come into active operation. The first fibres to become myelinated are those which carry impulses from the limbs, and this accords with the evident importance in the early life of the infant of the tactile impressions received through the limbs.[1] The olfactory fibres are fully developed even in embryonic life, and are followed by those of the visual, and auditory sense organs.

While the growth of the spinal-cord and brain are progressing, the special sense-organs are making their appearance, the olfactory and auditory organs are formed directly from the living matter of the ectoderm. The olfactory organs appear as a pair of thickened patches in the ectoderm at the cephalic border of the neural plate; the patch becomes depressed, and forms the deep olfactory pit. The auditory organs arise in the dorso-lateral surface of the head, opposite to the region of the future medulla oblongata.[2] These latter

[1] "The Nervous System of Vertebrates," by Professor J. B. Johnston, p. 347.

[2] *Idem*, pp. 36, 46.

sense-organs originate in ectodermal patches, which form pits that eventually separate from the ectoderm as closed sacs. In some of the lower vertebrates, cells undoubtedly wander from the walls of the pit and form nervous ganglia, no part of which is produced from the neural crest.[1] Professor J. B. Johnston states that in some fishes the cells forming these ectodermal thickenings (placodes) multiply by mitosis, and form a mass which spreads beneath the ectoderm and produce nervous ganglia connected by fibres with tactile sense organs. These tactile organs resemble those of certain invertebrates in that they consist of differentiated epidermal cells, provided with sensitive processes which project outwards from their external surface. But in the vertebrates these cells eventually sink beneath the surface of the body, and come to line ectodermal pits.

The optic vesicles of vertebrates first appear as outgrowths of the neural plate on either side of its expanded portion, or that part from which the brain is formed. These areas grow outwards, and finally become constricted next to the brain, so that they remain connected to that organ by a narrow stalk (optic). The optic vesicle, or outer expanded portion of the stalk undergoes changes whereby its cells come to produce the rods, cones, and other structures forming the retina. The essential part of the retina therefore consists of modified nerve-cells, differentiated so as to perform a special function; or rather, as we maintain, have become structurally modified in the course of a vast number of generations by the action of vibrations of light. The ectodermal layers external to the outer surface of the optic vesicle produce the transparent

[1] *Idem*, pp. 58, 62.

lens and cornea, through which rays of light are brought to a focus on the retina.

The brain and spinal-cord consist of two kinds of structures, known as the white and grey matter of these organs. The white matter is formed in human adults of medullated nerve fibres, which differ from those of ordinary nerve fibres in that they do not possess an external sheath (Fig. 35). The grey matter of the brain and cord is formed of layers of neurons imbedded in a mass of neuroglia, into which blood-vessels and lymphatics penetrate.

The Spinal Cord is continued upwards into the brain, and extends downwards throughout the greater length of the spine. Deep fissures exist in the front and behind the cord, reaching nearly to its centre, where a bridge of nerve fibres connects the two halves of the cord together. This bridge of nervous matter is traversed by a canal, which opens above into a cavity in the brain. The grey matter of the cord is situated internally, and is so arranged that on a transverse section each half forms a crescent. The outer part of the cord is formed of medullated nerve fibres.

The nerve-cells forming the grey matter of the cord produce axis-cylinder fibrils, which enter into the formation of what are known as the anterior and posterior nerve roots of the spinal cord. In man, each half of the cord gives off thirty-one pairs of spinal nerves; those proceeding from its anterior part are distributed to the muscles of the body and limbs, and are known as motor nerves. The nerves passing into the posterior part of the cord are sensory in function, along which impressions made on the various sense-organs of the skin etc., are conducted to sensory nerve-cells of the cord. These latter are known as *afferent* nerves, as they conduct impulses from the surface to nervous centres. On the other hand, the motor are *efferent* nerves, as they conduct impulses from the nerve-cells of the central nervous system outwards to the muscles and other parts of the body (Fig. 39).

The Medulla Oblongata and Mid-Brain.—The spinal cord is continued upwards into that part of the brain which is known as the medulla oblongata, and onwards to the mid-brain.[1] There is a considerable rearrangement of the fibres of the cord in the medulla, but a vast number of them pass upwards and terminate in relation with nerve-cells situated in the cerebrum, or else in the cerebellum. In their passage downwards from the brain, and upwards to it, the nerve fibres cross from one side to the other in the medulla oblongata, so that the left half of the brain governs the right half of the body, and *vice versâ,* both as regards motion and sensation.

We can appreciate the great importance of the nervous elements contained in the comparatively small area of the brain, comprised in the medulla oblongata and the mid-brain (Fig. 36), when we state that they contain the nuclei or centres from which the nerves originate, which govern the action of the muscles of the vocal apparatus, respiration, the heart, and other important organs of the body. Fibres passing from the ganglionic nerve-cells of the nuclei come into intimate relation with one another, and with nerve fibres passing

[1] In the following pages, when making use of the term *brain*, we mean the whole of the nervous structures contained within the skull. The brain is subdivided into the medulla oblongata and pons, which, in an average adult male having a stature of 69 inches, weighs about one ounce; the cerebellum weighs about five ounces, and the rest of the brain, known as the cerebrum, weighs about 42 ounces.

upwards from the spinal cord and downwards from all parts of the cerebrum and cerebellum.

The longitudinal nerve fibres of the medulla oblongata form two bundles of diverging fibres which pass upwards and forwards (cruri cerebri), and enter two masses of nervous matter called the *optic thalami;* many fibres may be followed into two other masses of nervous matter, the *corpora striata,* and onwards to the nerve-cells forming the cortical or outer layer of the cerebral hemispheres. These four aggregations of nerve-cells and fibres (optic thalami and corpora striata) form part of the cerebrum, and are frequently referred to as the *basal ganglia.*[1] Fig. 36 indicates the course of the nerve fibres we have referred to, passing from the spinal-cord up to the medulla oblongata and on into the basal ganglia, to terminate in the nerve-cells of the cerebral cortex. But this diagram does not show the relation that exists between the branches given off by these fibres to the aggregations of nerve-cells which exist in the medulla, cruri cerebri, and basal ganglia. These nervous centres are thus all intimately related to one another and with the nerve-cells of the cortex of the cerebrum. In addition to the communication thus established between the cortical nerve-cells and the aggregations of nerve-cells above referred to, these latter centres are brought into relation with one another by numerous association or intercommunicating fibres (red lines, Fig. 36).

The Cerebral Hemispheres in human beings form by far the largest part of the cerebrum. They are two in number, and are closely connected by commissural nerve fibres. Each hemisphere has an outer layer of grey

[1] "Hand-Book of Physiology," by Prof. Halliburton, p. 653.

nervous matter, containing a vast number of nerve-cells, arranged in layers closely related to one another by the intermingling of their dendrons and medullated nerve fibres (p. 147), the whole being protected by the fibro-cellular tissue (neuroglia) in which they are imbedded.

The hemispheres contain large central cavities (lateral ventricles). Their outer grey layer passes from the surface down into numerous fissures; these fissures map out the external surface of the cerebrum into a number of *convolutions.* Each hemisphere is further divided anatomically into what are known as lobes. The anterior lobes are called the *Frontal,* the middle lobes the *Parietal,* and the posterior the *Occipital* lobes; the inferior are known as the *Temporal* (Figs. 36, 37). It is unnecessary for us to refer to the other lobes of the brain.

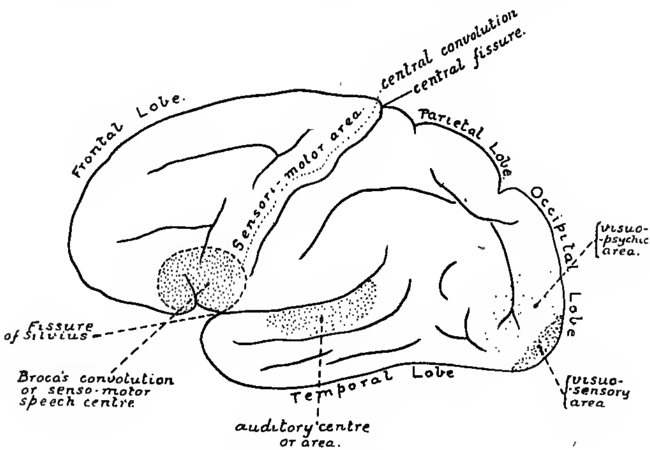

FIG. 37.—Diagram of left cerebral hemisphere (outer surface) of human brain. (From Halliburton's "Handbook of Physiology," p. 688.)

We may now proceed to consider, how the various nervous structures we have referred to in the preceding pages are brought into play so as to express our thoughts in silent and in spoken language.

As we have stated, the various sense-organs or receptors consist of differentiated forms of matter, each of which has become adapted to receive and transmute, a definite mode of energy into a form capable of passing along nerve fibres to the living matter of certain cells of the central nervous system. The receptors are extensively distributed, not only on the surface of the body, but also throughout its internal structures. These latter receptors however, are to a large extent stimulated by energy supplied by the organism. For instance, the muscular receptors receive energy derived from their muscles in contracting, the contraction of the muscle having been excited by the stimuli it receives through external receptors.[1]

On the other hand, the specialised sensitive matter which constitutes the essential part of each description of sense-organs, particularly those of vision, hearing, and smell, in addition to their power of responding to energy derived from near objects, are also stimulated by impressions they receive from distant objects. We allude to them therefore as "distant receptors," or sense-organs capable of initiating sensations having psychical qualities, termed *projicience* (p. 133).

Professor Sherrington remarks that the distant receptors generate reactions which show "adaptation," *e.g.*, in the direction of movements, etc., to environ-

[1] "The Integrative Action of the Nervous System," by Charles S. Sherrington, Holt Professor of Physiology, University of Liverpool, pp. 130, 324.

mental objects at a distance, the source of those changes impinging on, and acting as stimuli at the organism's surface. We know that in ourselves sensations initiated through these receptors are forthwith projected into the world outside the "Material Me." The projicience refers them, without elaboration by any reasoned mental process, to directions and distances in the environment fairly accurately corresponding with the "real" directions and distances of their actual sources. Thus, the patch of light constituting a retinal image, excites a reflex movement which turns the eyeball towards the source of the image, and adjusts ocular accommodation to the distance of that source from the animal itself.[1]

We may realise the importance and complexity of the connections that exist between some of the distant receptors and the brain, when we find that the optic nerve which conducts the impressions received by the retina to the brain is said to contain about 1,000,000 nerve fibres, whereas the whole of the afferent spinal roots of one side of the body put together contain only 634,000 nerve fibres. This statement bears out the conclusions we arrived at when referring to the evolution of the nervous system of some of the lower invertebrata. We found that the cerebrum of these animals increases in complexity of structure in proportion to the perfection reached in the development of their distant receptors. Professor Sherrington lays stress on this point, and endorses Dr W. H. Gaskell's opinion that, "the brain is always the part of the nervous system which is constructed upon and evolved upon the distant receptor

[1] Sherrington, p. 324.

organs."[1] The reactions and sensations effected by these organs are consequently of paramount importance in the functioning of the nervous system and of the individual, a subject to which we shall return when describing the effects produced on the mental development of young persons who have become blind and deaf in early childhood.

The nuclei of the nerve-cells contained in the brain and spinal-cord are enclosed in cytoplasm extending outwards from the body of the cell as fibrils, which form the essential part of the dendrons and axis-cylinder of the cell (Fig. 35).[2] The protoplasmic elements forming an axis-cylinder terminate in an arborescence of living matter which comes into contact with the contractile elements of a number of muscle fibres (Fig. 38).

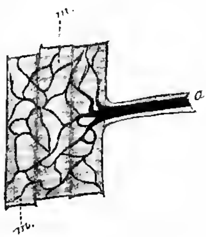

FIG. 38.—*a*, Axis-cylinder of nerve; *m m*, muscular fibres.

A muscle supplied in this way by living matter proceeding from a motor nerve-cell is known as being an *effector organ*. For example, the nervous elements of the retina are the receptor of vibrations of ether which we call light; these retinal elements respond to this stimulus, and transmute the energy they receive into a form which is conducted by the nerve fibrils proceeding from the receptor, to the dendrons of an aggregation of nerve-cells situated in a definite centre or area of the brain. Some of the potential energy contained in

[1] Trans. Eighth Intern. Med. Congress, 1884.

[2] The term "neuron" includes the nerve-cell together with its dendrons and axis-cylinder, or cylinders.

these cells (which energy is derived from the metabolic processes carried on by their protoplasm) is thus released and conducted by the axis-cylinder of the cells to an effector organ or muscle, which is thus brought into play. Action of this description is known as a *reflex* action[1] (Fig. 39).

A reflex *action* therefore embraces an effector organ, a gland, or muscle, and a conducting path, leading to a receptor organ, whence the reaction starts. The three constitute a reflex arc.

These reflex processes have been compared to that of telegraphic communication; the written message received at an out-station is transmuted by the receptor into a form in which it passes by means of a conducting wire, (nerve fibre), to the central office (neuron), where out of numerous stations one is selected at which the message arrives, and by an agent or effector is delivered at its destination. It is evident that if breaks or intermediate stations have to be passed during the transmission of the message, that it will take a longer time to reach its destination than if there were no such interruption to its passage along the line of communication. This is precisely what happens in the passage of a stimulus from a receptor to an effector organ. And the loss of time which is known to occur in the passage of energy along a reflex arc is, in great part, attributable to the delay to which it is subjected in overcoming the resistance offered to its passage by the surface of separation that exists between the dendrons of one and those of another neuron (Figs. 39, 40). The loss of time thus occasioned in the transmission of energy

[1] The structures concerned in this process are described as a reflex arc.

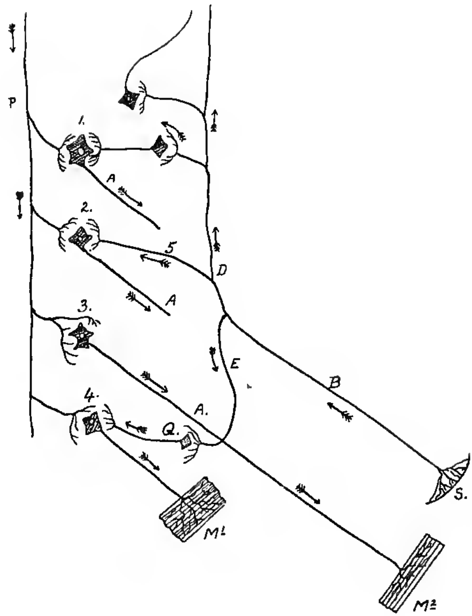

FIG. 39.—"Represents in a schematic way the manner in which the fibres of *two* roots of spinal nerves are connected to the grey matter in the spinal cord" (Halliburton's "Handbook of Physiology," p. 613). 1, 2, 3, 4 represent four nerve-cells situated in the anterior part of the grey matter of the cord. Each of these cells produces an axis-cylinder fibre *A A A*, the lowest of them terminating in a muscle M^1 M^2. Each of these four cells is further surrounded by a terminal arborisation of nervous fibrils derived from branches of an axis-cylinder fibre *P*, proceeding downwards from a nerve-cell of the brain into the grey matter of the spinal cord. *S* represents one of the receptors or sense organs of the skin; from its fibrillar arborisation sensory stimuli are conducted by a nerve fibre *B*, which enters the posterior part of the grey matter of the spinal cord; an arrow points to the direction of this impulse. After entering the cord this sensory nerve fibre divides into two branches, one passes downwards *E*, and comes into relation with the dendrons of a nerve-cell *Q*, which in its turn comes into relation with the motor nerve-cell, 4, and so to the effector organ or muscle M^1 M^2. The other branch of the sensory fibre *B* passes upwards along the posterior column of the spinal cord giving off branches such as that at 5, terminating directly in arborisation with a motor-cell, but the main portion of this sensitive fibre after more than one synapse can be traced upwards into the brain, where it terminates in connections with one or more sensitive nerve-cells of that organ.

through a reflex arc has been accurately determined, and is found to differ according to the state of the nutrition, and the action of various chemical substances on the living matter which constitutes the path along which the stimulus is conducted.

Professor Sherrington also gives evidence to show, that the resistance offered to the passage of energy across the surface of separation between dendrons, varies with the kind of energy received by this surface from receptors. In the central nervous system these spaces communicate with one another. It therefore follows that energy from various receptors passing towards the central system becomes mingled in the spaces separating dendrons, and would thus tend to create confusion when acting on the living matter of the central nerve-cells. This state of affairs however, is averted through greater facilities being offered by the matter constituting the separation spaces to the passage of one over that of another kind of energy, in its progress to the dendrons of the central nerve-cell (see p. 160). One of the functions, therefore, performed by the matter intervening between the dendrons of one and another neuron is, to regulate the passage of the stimuli which are constantly flowing into these spaces from the various receptors of the body. Another of the functions performed by the separation spaces between dendrons is to stop a back flow of energy from the central nervous system to external receptors. In Medusoids the reversability of energy from the effector organs to the receptor was alluded to. This action is prevented by the system of synapse which exist in the central nervous system of all the higher classes of animals.

The various other characteristic differences between the passage of energy along a reflex arc, and that of a continuous nervous system are summarised by Dr F. W Mott, in his review of Professor Sherrington's work, published in the *Brit. Med. Journ.* for March 7th, 1907. Our limited space and the scope of our subject however, preclude us from entering on the consideration of this very interesting and important subject.

With reference to the part taken by the living matter of the central nerve-cells in a reflex arc, we have shown that the protoplasm of these cells consists of a highly specialised form of matter. The structural arrangement and motion of the elements forming the essential part of these cells, in all the higher animals has been subjected through a countless succession of beings to the continued action of an environment liable to considerable variations, which has in the course of time moulded this matter into hereditary forms possessing definite functions. It is probable that different parts of the living matter of these cells, have become endowed with properties which enable them separately to respond to the modes of energy which reach them from receptor organs, in the manner we have above referred to. Energy thus acting on the separate portions of the matter forming a nerve-cell releases a part of its potential energy, which is discharged along an axis-cylinder to an appropriate effector organ, causing, in the case of a muscle, its contraction, or suppressing or inhibiting its contraction according to the form of energy which reaches it from the nerve-cell. Professor Sherrington inclined to attribute action of this kind to the conducting properties of the central axis-cylinder of the outgoing path from the nerve-cell, which he considers can only transmit different modes of energy in succession, "one at a time." He gives a diagram in his work indicating the action of energy received from two receptors on corresponding nerve-cells of the spinal-cord, and thence transmitted to the flexor and extensor muscles of the knee-joints[1] (Fig. 40).

In certain flexor-reflexes the inhibition (relaxation) of one set of muscles goes on side by side with the excita-

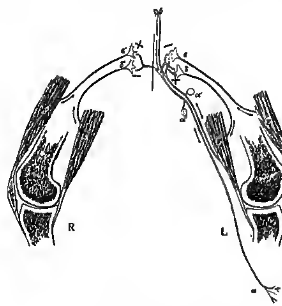

FIG. 40.—Diagram indicating connections and actions of two afferent spinal root-cells, a^1 and a, in regard to their reflex influence on the extensor and flexor muscles of the two knees. a, root-cell afferent from skin below knee; a^1, root-cell afferent from flexor muscle of knee, *i.e.* hamstring nerve; $e\ e^1$, afferent neurons to the extensor muscles of knees; $\delta\ \delta^1$, afferent neurons to the flexor muscles; $E\ E$, extensor muscles; $F\ F$, flexor muscles. The sign + indicates that at the synapse which it marks the afferent fibre a (and a^1) excites the motor neuron to discharging activity, whereas the sign − indicates that at the synapse which it marks the afferent fibre a (and a^1) inhibit the discharging activity of the motor neurons. The effect of strychnine is to convert the − into + signs.

tion (contraction) of the opposite set of muscles, as, for instance, in the case of the muscles which straighten or bend the leg on the thigh, or which cause the movements of the cartilages of the larynx in their action on the vocal cords (p. 144). The contraction or relaxation of opposing sets of muscles of this description are part and

[1] "The Integrative Action of the Nervous System," by Professor C. S. Sherrington, p. 108.

parcel of one and the same reflex action, and although opposite in direction they are co-ordinate reciprocal factors in one united response. The excitation of one set of muscles, in fact, causes the relaxation of the opposing set; the nerve fibres from the receptive field of the reflex from each, divide in the spinal cord or the medulla oblongata into end branches, one set of which, when the nerve fibre is active produces excitation, while another set, when the nerve fibre is active, produces relaxation. The single afferent nerve fibre would, therefore, in regard to one set of its terminal branches be specifically excitant; and in regard to another set of its central endings be specifically inhibitory[1] (Fig. 40).

Action of this kind is illustrated in the processes by means of which a frog seizes and swallows a fly. An analysis of this particular action shows that it is composed of several reflexes, which are discharged successively. In the first place, the movements made by the fly act as a stimulus to the nervous matter of

[1] Dr Bastian observes:—Every time a movement is executed we receive a group of sensorial impressions occasioned by and peculiar to the particular movement. This group of kinæsthetic impressions is made up, in part, of impressions emanating from the muscles in action, of others emanating from the joints moved, and others coming from tendons and skin. These groups of sensations are registered as groups in definite portions of the cerebral cortex, and are capable of being revived in memory like other sensorial impressions. Impressions coming from different muscles give "information as to their several degrees of tension or contraction." We thus appreciate the position and movement of our limbs, and derive information and guidance during the performance of movements. In this way we "are enabled volitionally to re-initiate similar movements by the ideal recall of impressions excited by past movements."—"The Brain as an Organ of Mind," by Dr H. C. Bastian (the International Science Series); and article, "Kinæsthesis," by the same author, in "Quaine's Dictionary of Medicine" (edition 1894).

the animal's visual receptors, which passes to nerve cells located in the animal's optic thalami and cortical nervous centres.[1] Nervous energy is discharged from these cells which becomes manifest in the protrusion of the frog's tongue and seizure of the fly. As soon as the fly is lodged in the frog's mouth its presence stimulates certain tactile receptors, from which energy is conducted to nerve-cells located in the medulla oblongata, and sets free a portion of their potential energy, which leads to the contraction of muscular fibres surrounding the back of the mouth and upper part of the tube leading from it to the frog's stomach. In this way the fly is carried along a part of this tube, and in its passage it excites successive receptors which bring segments of the spinal cord into action, causing as it were waves of contraction of the gullet, along which the fly is carried into the frog's stomach.[2]

The central nervous system therefore, is not simply a meeting-place of afferent paths which there conjoin with efferent paths of energy, but is a great centre of reinforcement of the energy which it receives and co-ordinates; the nervous energy it discharges is marked by absence of confusion in its action, and is adapted to the needs of the organism. The energy entering the nervous system is probably less in amount than that which leaves it, its increase in the central nervous system being due to the metabolic processes perpetually carried on by the living matter of vigorous nerve-cells. In this way the

[1] *Idem*, p. 305.

[2] "The Comparative Physiology of the Brain and Psychology," by Jacques Loeb, Professor of Physiology in the University of Chicago, pp. 142, 144.

nervous matter of this system becomes primed with potential force, ever ready to be discharged by the action of the kinetic energy flowing in from the various receptors of the animal's body.

As a rule, reflex actions take place in our bodies without our knowing anything about them, but it often happens that they excite what we call a feeling or sensation (p. 11). By an effort of the will we can control many reflex actions, such as the tendency to sneeze. On the other hand, by the help of our brains we acquire an infinity of artificial reflex actions, such for instance as riding a bicycle, which at first require all our attention, but which by practice we perform without the exercise of volition.[1] Movements such as those executed by the lower limbs in bicycling being, to a large extent, carried out by action of the nerve cells and fibres of the spinal cord, the afferent impulses to the cord from the lower limbs directing the efferent impulses on the muscles concerned in their movements. But, as we stated, actions which at first require all our attention and volition, by repetition, become in a manner part of our organisation. As Huxley states, it takes a soldier a long time to learn his drill—for instance, to put himself into the attitude of "attention" at the instant the word of command is heard. But, after a time, the sound of the word gives rise to the act, whether the soldier be thinking of it or not.

[1] Professor Huxley observed:—"We class sensations along with emotions, and volitions and intellectual processes under the common head of states of consciousness or psychical activities. But what consciousness is, or how a state of sensation or of consciousness comes as a result of irritating nervous tissue, is just as unaccountable as any other ultimate fact in nature."—"Elementary Lessons in Physiology," pp. 188, 270.

There is a story which is credible enough, though it may not be true, of a practical joker who, seeing a discharged veteran carrying home his dinner, suddenly called out "attention," whereupon the man instantly brought his hands down, and lost his mutton and potatoes in the gutter. The drill had been thorough, and its effect had become embodied in the man's nervous structure, which possesses a power of organising conscious actions into more or less unconscious or reflex operations.

From the description given in the preceding pages we can understand how, through the action of energy received from one or more of the sense organs passing to definite areas of the cortex of the brain, the muscles of the vocal apparatus are brought into action. Lord Rayleigh states: "It seems no longer possible to hold that the vibratory character of sound terminates at the outer end of the nerves along which the communication with the brain is established. On the contrary, the processes in the nerves must themselves be vibratory—not, of course, in the gross mechanical sense, but with preservation of the period, and retaining the characteristic phase" (*The New Quarterly* for November 1907, p. 13).

Unless we have compressed our subject beyond the limits of intelligibility, it should be evident that a multitude of unicellular beings, supplied with a store of potential energy derived from chemical processes, carried on by the aid of the living matter of which they are formed, possess contractile elements which respond to the action of their environment. The action of various modes of energy on the living matter of these beings is the direct cause of the movements made by their cilia and contractile fibres. In individual organisms these movements are of an extremely simple character, but when beings of this kind become united, as in the case of a volvox, into colonies, the action of their environment leads to the rhythmical movement of a vast number of their motile structures.

The animals included in the lowest class of multicellular beings (Sponges), remain throughout their lives fixed to some solid substance, their supply of food being conveyed to them in the water which flows through their system of canals, the calibre of which is regulated by means of the contraction and relaxation of the sensitive living matter which forms the walls of these canals.

In the next higher class of animals, the Hydroids, we find their bodies and tentacles consist of highly contractile living matter, so that when irritated the animal becomes folded up into a small mass. But Hydroids are not altogether stationary beings, and their tentacles are employed to seize food and to convey it to the opening in their bodies which leads to their digestive organs. In these animals the deep surface of the living matter of some of their external layer of cells is prolonged into muscular fibres, which are attached to the middle layer of the animal's body. Between the ectodermic cells we find a number of cells which produce free protoplasmic processes from their external surface, and from their deep surface the living matter of the cell is prolonged into a fibril which is directly connected with the living matter of a subjacent nerve-cell (Fig. 21). The nerve-cell gives off numerous fibrils which come into contact with the contractile elements of many muscular fibres. A stimulus applied to the external free process of one of these epithelio-neural cells is communicated to the body of its cell, and passes to the corresponding nerve-cell. A portion of the potential energy of this cell is thus liberated, and, by means of its fibrils, is conducted to a number of muscular fibres, which are thus caused to contract in a co-ordinate manner and to effect a definite movement of the animal's body. Besides these tactile sense organs, the ectoderm of a Hydroid's body and tentacles contains a number of cnidoblasts with their coiled-up, barbed fibres. These cells possess an upstanding free process which projects from the external surface of the animal's body, while their deep surface is connected with a nerve-cell. When in working order if the external process is unduly stimulated, the energy thus received passes to the living matter of the nerve-cell, causing a discharge of its nervous force, which in its turn is communicated to the cnidoblast, and effects the forcible ejection of its barbed fibre. The effect of a stimulus applied to the specialised tactile sense organ or receptor is thus transformed, in one case into a mode of energy which directly produces contraction of certain muscular fibres and causes a definite movement of the animal's body, and in the other case to a discharge of its weapons of defence.

In the succeeding classes of animals represented by the Jelly-fish, Star-fish, and Worms, we find that their nervous systems, although they become more complicated, are more or less perfectly arranged so as directly to conduct energy applied to their receptors to an aggregation of nerve-cells, and by these cells to the effector organs. Most of the animals included in these three classes of beings, as compared with the higher orders of animals, lead a passive existence, their habits, as a rule, not requiring them to make much use of distant sense-organs.

As we pass on from animals such as those to which we have referred, to beings like the crayfish whose existence depends on the quickness of its movements, and power to judge the distance between its body and distant (often moving) objects, we find that the animal possesses highly developed distant receptors and a corresponding increase in the proportions and complexity of its brain. Beyond this, effectual barriers exist to the direct passage of energy passing from their receptors to their central nerve-cells, and between the passage of nervous energy from the latter to the effector organs. We have endeavoured to describe some of the most important functions performed by this synaptic system, which apparently takes a prominent part in regulating, and in co-ordinating the action of energy on the muscles and other organs of the body.

No hard and fast line however, can be drawn between animals possessing a continuous and those having a synaptic nervous system.[1] For instance, among the Gastropoda, which include snails, limpets, sea-slugs, and hosts of other forms, we meet with many instances of animals having well-developed optical organs and central nervous systems, with a rudimentary synaptic arrangement of their dendrons. But in other orders of Mollusca we find a continuous nervous system with an aggregation of ganglionic nerve-cells which represent their cerebral lobes.

[1] As we before stated (note, p. 148), the muscular fibres which regulate the calibre of the blood-vessels and of the intestines, are in man and the higher orders of animals under the control of a continuous nervous system.

Working on the above premises, we come to realise the idea that the living matter of the nervous system of the existing predominant orders of animals, has been moulded into harmony with its environment, principally by the action exercised on it through energy received from its distant receptors. Beings thus equipped with an efficient central nervous system, which has become hereditary, under the laws of natural selection have come to hold their own in the struggle for existence, whereas their less perfect brethren have succumbed to its action. We seem justified in going a step further, and assuming that those animals which for the time being have become adapted to changes of their environment, might give rise to varieties capable of adjustment to further alterations in their surroundings, changes always increasing in complexity, in consequence of the action on living creatures of the many inimical conditions to which they are constantly exposed, and which probably culminate in the persons of civilised human beings.

CHAPTER IX

The knowledge already acquired concerning the structure and functions performed by the living matter of certain centres or areas of the brain is applied to explain, why parrots and other birds can imitate vocal sounds which, for the most part, they employ automatically, but which may contain some amount of intelligence.

In the following pages we frequently make use of the term psychical processes, and areas of the brain ; it seems well therefore, to state the meaning we attach to these terms.

We have referred (p. 11) to the fact that all we know about matter, relates to the series of phenomena in which energy is transferred from one portion of matter to another, till in some part of the series our bodies are affected, and we become conscious of a sensation. By the mental processes which are founded on such sensations we gain ideas concerning objects which are not part of ourselves, but in every case the fact that we learn is the mutual action between bodies. It is through the living " consciousness-matter " directly surrounding the senso-motor cortical nervous centres (p. 209), that energy received from external objects through the sense organs, is transmuted into ideas concerning the form and other qualities possessed by external objects.

It is in the outer or cortical psychical areas of the cerebrum, that ideas become associated with one another and with the intellectual processes, in which form they come to play on the muscles controlling the vocal apparatus or other parts of the body (p. 144). It is in the psychical areas of the brain that the *will*, which cannot be separated from the intelligence, comes into action. If the matter constituting these areas of the cerebrum is destroyed or its functions are suspended by an anæsthetic, the will and consciousness are obliterated for the time being. Intellectual processes are manifest only in connection with healthy working "consciousness matter."

Psychologists hold "that all acts of *willing* may be divided into two classes," the first comprising simple or impulsive acts, the second composed of complex acts, which imply freedom and choice, acts of "free will."[1]

All those acts which have for their object the preservation of the individual species, or which favour vital functions, are accompanied by feelings of pleasure. Stimulated by such feelings, acts of this description have become habitual or impulsive acts. And as the psychical life of the lower races of men and other animals are largely confined to these acts, it follows that their intellectual processes are almost exclusively confined to impulses. The linking together of these impulsive acts is what we call *Instinct*, which, as we have stated, predominates the mental life of the lower orders of animals, but which in civilised human beings, as a rule, is kept under control by a higher order of complex psychical processes.

Instincts therefore, are merely a chain of impulsive acts which have become simplified, and connected through continued impressions made on the living matter of certain areas of the brain, and in this way have become a part of the physiological organisation.

[1] "Contemporary Psychology," by Guido Villa, pp. 213, 292.

This process has required a lengthy series of generations to become perfected, each generation adding an imperceptible contribution to the hereditary aptitudes of the organism.

Impulsive acts however, are not without a degree of spontaneous consciousness, and therefore of volition; many actions which are at present impulsive were originally the outcome of choice.[1]

We have already explained the nature of the processes by which the living matter of the nervous system of animals is constantly replenished with potential energy, and also indicated the paths through which kinetic energy reaches this charged matter, and releases a portion of its latent force. We have also described the complex reflex mechanism by which voice sounds can be made on stimulation of appropriate sense organs; we proceed now to show by what means this complex reflex mechanism is put into connection with consciousness, and rendered capable of translating ideas into intelligent speech. In the first place, we explain how the word sounds which birds utter are almost meaningless, and consequently differ from those which intelligent human beings employ in articulate language.

In working out this subject it will be convenient to adhere to the plan we have hitherto followed, and in the first place to refer to the mechanism, and then to the functions of the nervous and muscular structures employed by a bird, such as a parrot, when he utters certain words which he has been taught to repeat.

The apparatus concerned in the production of vocal sounds in birds is analogous to that which we have described as existing in man (p. 144). The bird's lungs

[1] *Idem*, pp. 213, 292.

force a current of air through the bronchi against the vibrating membranes of the syrinx, whereby a sound is produced which becomes moulded by the resonators of the mouth and tongue into a word sound.

Parrots not only possess a perfectly efficient vocal apparatus, but also elaborately constructed auditory and visual sense-organs or receptors. It is beyond our purpose to describe the arrangement of the structures which enter into the construction of a bird's ears and eyes; but we may observe that they are formed from essentially similar, though differently arranged, nervous, pigmentary, and other structures as those which exist in the crayfish and other invertebrates (p. 135). The sense-organs of birds and all the higher animals are, as in the invertebrates, derived more or less directly from the specialised sensitive living matter of the external epithelial layers of the body, each kind of receptor being adapted to respond to a definite mode of energy, and to transmute it into a form capable of acting on certain ganglionic nerve-cells (p. 136). The forces controlling the arrangement and motion of the molecules of the specialised living matter of the sense-organs, has been gradually brought into harmony with its environment by means of the adaptability of this matter to the various forces which act upon it from without. As the habits of the higher classes of animals have become more complicated in consequence of the increasing complexity of their environment, the living matter of their sense organs has responded to such stimuli, and become adapted to its requirements. In this way the eyes and ears of birds have reached a high order of perfection, while their olfactory organs are not so completely developed as they are in some of the lower orders of animals.

In a previous chapter we have (p. 128) referred to the division of the brain of some of the higher invertebrates into a hind, mid, and fore-brain. In fishes which include the lowest class of vertebrates, upon similar foundation certain excrescences of nervous matter have been developed in connection with the senses of sight and smell. The secondary fore-brain consists of two parts, a posterior (the hemisphere), and an anterior olfactory lobe. The hemispheres are mesially united by a commissure, but although they have ganglion cells in their walls they show no signs of cortical structure.[1] In the next higher class of animals, the Reptilia, we find the first indication of a cerebral cortex; and in the succeeding class of animals, Birds, as we shall proceed to explain, the hemispheres of the brain are to a large extent enclosed by a thin layer of cortical nervous matter.

If we examine a parrot's brain we find that its medulla oblongata is curved and short, the optic lobes and cerebellum are, as compared with the brains of some other birds, rather small. The outer surface of the brain is divided into two hemispheres, connected by commisural fibres; the hemispheres extend backwards, so as to cover the optic thalami, and may be divided into lobes analogous to those we have described as existing in mammalia, but the occipital and temporal lobes are imperfectly developed. On the surface of the hemispheres there are a few fissures, one of them being particularly well marked, which is known as the Sylvian fissure (Fig. 41).

The great development of the cerebrum in birds over that of the Reptilia and other lower vertebrates depends

[1] "Phys. Series," vol. ii. p. 67, Cat. Museum of R.C.S.E.

almost entirely on the increased dimensions of its corpora striata, which are brought into close relation by nerve fibres with the optic thalami, so that in birds the basal ganglia come to constitute the chief part of the cerebrum; in this respect they differ therefore, from the brains of the Mammalia, for in this latter class of

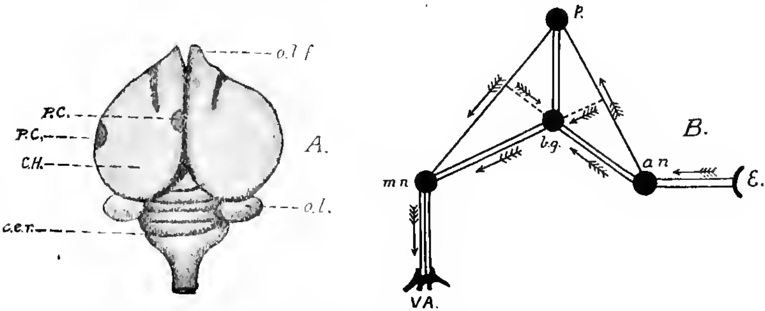

Fig. 41.—(*A*) Bird's brain. *PC*, position of excitable areas; *CH*, cerebral hemispheres; *cer*, cerebellum; *olf*, olfactory bulb; *ol*, optic lobe. (*B*) represents the path followed by energy derived from *E*, the internal ear which passes to *an*, the sensory auditory nucleus, and from thence to *bg*, the basal ganglia; from these ganglia part of the released energy passes directly to *mn*, the motor nucleus of the muscles controlling *VA*, the vocal apparatus; part of the energy from *bg* passes to *p*, the psychical cortical area, from which energy extends to *mn*, and so to *VA*. The second nervous arc starts from *an*, and giving off energy to *bg*, passes direct to *p*, and from *p* to *mn*, giving off energy in its path to *bg*.

animals the hemispheres of the brain are its predominant feature (Fig. 36, see p. 154).

We may trace fibres passing from the corpora striata of birds, not only into the optic thalami, but also upwards to the outer or cortical layer of the hemispheres, and downwards to the nuclei of the nerves arising from the medulla oblongata, and into the spinal cord. Nerve fibres may also be traced in a parrot's brain from the basal ganglia to the rudimentary temporal lobes; it is in this latter area of the cerebrum that the auditory nervous centres in Mammalia are located[1] (Fig. 37).

The cortex of the hemispheres of a bird's brain is, as compared with the higher classes of animals, rudimentary in its structure; its ganglionic nerve-cells are disposed in two layers, and from the living matter of these cells fibres pass into relation with the nuclei of the auditory nerves situated in the medulla oblongata (Fig. 36) and onwards into the spinal cord. The cells of this thin cerebral cortex are also in close relation with one another by means of association fibres.

Starting, therefore, from the nervous structures of a bird's ears, protoplasmic fibrils pass into relation with the nerve-cells forming the nuclei of the auditory nerves. From these cells fibres may be followed to those of the basal ganglia, or that part of a bird's brain which is directly concerned in the elaboration of automatic and mimetic movements. From the nerve-cells of these ganglia fibres pass downwards, to come into relation with the cells which form the nuclei of motor nerves located in the medulla oblongata and spinal cord, which govern the action of the muscles concerned in working the vocal apparatus (Fig. 41 B).

In addition to the nervous arc to which we have referred, ending in the nerve-cells of the motor nuclei of the muscles which control the vocal apparatus, another arc of nerve fibres may be traced from the auditory nucleus through the basal ganglia (with which it is associated) upwards, to enter into relation with the ganglionic nerve-cells of the bird's cerebral cortex.[2]

[1] Cat. Roy. Coll. Sgns. Museum, Nervous System, p. 126.

[2] Dr Mott, referring to the cortical layers of neurons in Mammalia, describes them as the anatomical basis of the seat of consciousness.

And fibres from the neurons of the cortex pass downwards through the basal ganglia to nerve-cells which order the action of the vocal apparatus (Fig. 41 B).

The above conclusions are based, not only on the arrangement of the nerve-cells and fibres of those parts of the cerebrum referred to and which may be demonstrated anatomically, but also from experiments made on the various structures during life with the object of demonstrating their functions.

If the outer surface of a pigeon's brain be exposed, and a weak electric current applied to a definite part or centre on its outer surface, certain muscles of the bird's eyes are thrown into action, all the other muscles of the body being at rest (Fig. 41 A). If the electric current is applied to another cortical centre, co-ordinate action of a group of muscles of the bird's neck and head take place, and so on with other areas of the surface of the brain and other groups of muscles. These motor cortical nerve centres are well defined, and when stimulated in different birds always produce similar muscular contractions.[1] From these centres, as shown in our diagram, Fig. 41 B, nerve fibres or conductors of energy may be traced to the nuclei of motor nerves situated in the medulla and spinal cord; other fibres from the cortex come into relation with the ganglionic nerve-cells of the basal ganglia.

With regard to the psychical areas of the brain, it is to be noticed that although certain parts of a bird's brain when stimulated excite definite groups of muscles, by far the larger portion of the cortex when stimulated, does not produce any effect on the muscles of the

[1] Sir Rubert Boyce on the Nervous System in Birds, "Phil. Trans." for 1899, p. 302.

head, face, or any part of the body. It is these portions of the hemispheres of the brain, we have reason to believe, that are the agents which bring the animal's intellectual activities into play. It is only possible for us to form an opinion as to the functions performed by the differentiated consciousness-matter of the cortical substance of the hemispheres, by removing this part of the brain in a living bird and watching the results which follow. Professor Schrader has made accurate observations on the behaviour of pigeons after he had excised their cerebral hemispheres, and subsequently allowed the opening he had made in the skull to heal.[1] If such a bird thus mutilated is placed a few feet above the ground in the centre of a room, he will probably stay there for some time as if asleep, but then rouses up and hops down on the floor, wandering about the room all day and sleeping throughout the night. If a chair is placed in the room the pigeon will fly up and seat itself on one of the arms of the chair. But a pigeon under these conditions must be fed by placing peas well back into his throat, when he will swallow them; the bird would otherwise die of starvation, having lost all desire to take food spontaneously.

From numerous experiments of this kind, Professor Schrader arrived at the conclusion that after the complete removal of a bird's cerebral hemispheres the animal loses his intellectual capacity or consciousness. A female bird, after excision of her cerebral hemispheres, makes no response to the coo of the male bird, or to the rattling of peas in a bag, or to the whistle which, previous to the removal of the hemispheres, made the same bird hasten to her feeding place.

[1] Pflüger's Archiv, Bd. xliv., 1889.

These mutilated birds lose their feeling and their conscious intelligence. For instance, a falcon some time after the cerebral hemispheres had been removed, was shut up in a cage with a mouse. The falcon on seeing the mouse move pounced down from his perch and caught the mouse in its claws, but made no attempt to devour it. The mouse crawled away from the bird, and when it again moved about the cage the falcon again seized the animal. This process was often repeated until one day the mouse attacked the bird, who made no effort to defend himself, and appeared indifferent to what happened. The movements of the mouse in the falcon's cage excited visual impressions which passed to the bird's optic lobes, and produced automatic reflex movements leading to the capture of the mouse. But the falcon having seized its prey, had no idea what to do with it, for the bird's intelligence had been abolished by the removal of his cerebral hemispheres.

The movements, therefore, of a falcon mutilated in this way, like those of a pigeon under similar conditions, were impulsive or automatic, but were none the less purposive. The impulses started in the bird's retina, passed to the optic lobes, and through them affected the nervous elements of the basal ganglia. The excitation of certain nerve-cells in these ganglia caused a discharge of nerve energy which was made manifest in movements terminating in the bird seizing the mouse. If the hemispheres of the animal's brain had not been removed, the excitation of the nerve-cells of the basal ganglia would, in part, have extended to the bird's visual cortical centres, and thus produced conscious visual sensations by means of the connection of these centres with those of the psychical nervous apparatus located in other parts of the cortical cells of the cerebral hemispheres.

After excision of the hemispheres of a dog's brain, Goltz found that all those reactions in which the associative memory plays a part are permanently lacking, while the simple reactions that only depend on automatic reflex action remain, as in pigeons and in other animals. The dog growled and snapped if its paws were pinched. If asleep, it could be awakened by blowing a horn in the next room. If in a dark room, it closed its eyes when a strong light was suddenly introduced. The dog could still bark and howl. But all intelligence was wanting; the dog did not seek for his food, which had to be brought close to his nose, he failed to recognise his master or other dogs, he could hear, but could not discriminate between scolding and petting. It was impossible for him to get himself out of any uncomfortable position.

In human beings we find similar effects following extensive disease of the apparatus included in the psychical areas of the brain, or in the passage of their fibres down through the basal ganglia to the medulla oblongata.[1] For instance, a French priest who for many years had led an active, useful life, from the effects of disease lost all conscious voluntary power. As a youth this in-

[1] This apparatus is an infinitely complicated machine, not only depending on the integrity of its nerve-cells, but also of the nerve fibres of association and of communication with the nuclei of motor nerves. A vast number of these fibres pass through the corpora striata, and are liable to injury from the bursting of a blood-vessel and other causes, thus blocking the passage of intellectual activities from the cerebral cortex to the motor nerve-cells situated in the medulla and spinal cord.

dividual had learnt several of La Fontaine's fables, and for years after his illness, if the first lines of one of these fables were repeated to him, he would follow on, and recite the remainder of the fable, but he was absolutely incapable of comprehending the meaning of a single word of what he repeated. This man's words were the repetition of sounds which, as a youth, had become registered on the nervous matter connected with his auditory apparatus; when stimulated by a like impression this apparatus was set in motion and word-sounds resulted. But they were meaningless, because those areas of his cerebral hemispheres, in which the ideas contained in the words he had learnt became endowed with consciousness, were out of gear, so that the vocal sounds uttered like those of a parrot with its rudimentary cerebral hemispheres were meaningless.

From the above facts we learn that some areas of the cerebral hemispheres may be obliterated in man, and in a bird entirely removed, but that if the basal ganglia, medulla, and spinal cord are preserved intact, words and movements acquired and practised in early life are repeated. We can best explain this phenomenon by applying to it the knowledge we possess regarding the adaptability of living matter to repeated stimuli. Under these conditions, changes in the molecular structure and motion of this matter continue until an equilibrium is established between its external and internal forces. Changes of this description last to a greater or less extent during the life of an organism, and, as we have shown, may be transmitted through its germinal elements. Prof. Huxley, writing on this subject, states that "it is not to be doubted that those motions which give rise to sensations leave on the brain changes in its substance, which answer to what Haller called *vestigia rerum*, and to which that great thinker, David Hartley, termed *vibratiuncules.* The sensation which has passed away leaves behind molecules of the brain competent to its reproduction, sensigenous molecules so to speak, which constitute the physical foundation of memory."[1]

After the removal of a bird's cerebral hemispheres, the animal continues to perform instinctive (see p. 180) movements, but if the connection between its basal ganglia and the origin of the motor nerves in the medulla and spinal cord are destroyed, these movements can no longer be performed. We conclude therefore, that instinctive movements in birds result from a response to external stimuli made by the living matter of definite areas of nerve-cells located in their basal ganglia, and that these movements, as a whole, are protective in character and hereditary.

There is good anatomical and experimental evidence in favour of the opinion, that certain nervous centres exist in the basal ganglia of birds (especially in the optic thalami, p. 154), which control their mimetic expression, at anyrate so far as the older or congenital expressions are concerned.[2] This opinion is strengthened by the fact we have mentioned, that the basal ganglia of birds, as compared with the lower classes of animals are greatly developed, and this accounts for the power these animals possess of imitating vocal and other

[1] Address to the British Association, delivered at Belfast, by Prof. Huxley, 1874. See also "The Unseen Universe," by B. Stewart and P. G. Tait, p. 78.

[2] Sherrington's "The Integrative Action of the Nervous System," pp. 254, 266; see also Virchow's "Archiv," xlix., p. 267, Nothnagel.

sounds. In regard to these expressions, and to the instinctive movements of birds, the action of the lower or nervous centres of the basal ganglia are almost supreme, being controlled only if at all, by nervous energy derived from the rudimentary psychical areas of their cerebrum. The reverse of this state of things is what we find in human beings, for not only are their cerebral cortical areas enormously developed as compared with the nervous matter contained in their basal ganglia, but their cerebral cortex has produced an organ of speech which, on the one hand, is intimately connected with the psychical areas of the hemispheres of the brain, and on the other with neurons located in the basal ganglia, and nuclei of nerves governing the action of the muscles of the vocal apparatus. This mechanism raises consciousness into a commanding position in man, as compared with the instinctive and mimetic processes carried on by his basal ganglia.

We therefore find *first*, that a bird's brain is distinguishable from those of the lower animals in that its optic thalami and corpora striata (basal ganglia) are highly developed.

Secondly, that these parts of the brain contain the nervous matter which controls the impulsive and mimetic movements of the animal.

Thirdly, that these nervous centres are brought into relation with sensory-motor centres located in the cortex of the cerebral hemispheres, which in their turn are closely associated with the living nervous matter of those imperfectly developed areas of the nervous matter of the cerebrum, which are concerned in the elaboration of intellectual processes.

It is well known that birds, as a rule, possess remarkable powers of imitating various sounds; the mocking bird, for instance, in its wild state is said to imitate not only the notes of various other birds, but also the cry of certain animals. The song of young birds is learnt from other birds. Nestlings which have learnt the song of a distinct species, as with the canary educated in the Tyrol, teach and transmit their newly acquired song to their offspring. The young male bird continues practising to sing for ten or eleven months before he attains anything like perfection as a songster.

If we watch a parrot while he is being taught to speak, we notice that the bird turns his head first to one and then the other side, as if striving to catch the sounds which are being repeated to him. The bird is all attention, listening not only to hear the sounds which are being spoken, but also attentively watching every movement of the face of his instructor. We often notice a bird makes ineffectual efforts to gain command of the movements necessary to produce the sounds he is being taught. After many efforts to articulate the word we may be striving to teach him, he succeeds in giving utterance to the vocal sound, often with remarkable precision and clearness. Having once learnt a word or sentence the bird remembers it, frequently for many years.

Some parrots learn to speak more easily than other birds of the same species, but they all require patient and persevering teaching, in order that the sounds we desire them to repeat should become established on their brain centres for auditory impression. Although the parrot's ears are the direct inlets through which vocal sounds pass to the nervous centres of his cerebrum, his eyes are always intently fixed on his instructor while he is learning a new phrase; his visual nervous centres thus receive impressions which, by means of their relation to his motor and other cerebral centres, assist in bringing the muscles of his vocal apparatus into play. What we wish to emphasise is the fact, that whether in the case of a parrot repeating human vocal sounds, or in the natural songs of other birds, the utterance of these sounds is preceded by a longer or shorter period of training; and, further, that the living nervous substance of the nervous centres concerned in producing vocal sounds, is acted on by impressions received from both the auditory and visual distant receptors. We can understand the nature of this action in connection with a synaptic system such as we have referred to, by means of which energy derived from various receptors operates through a common afferent path (p. 161).

In the preceding pages we have endeavoured to explain some of the properties possessed by the living matter of certain nervous centres located in the basal ganglia and hemispheres of a bird's brain. We have also described the arrangement of the protoplasmic fibres or conductors of energy which connect these centres, on the one hand with the auditory and visual receptors, and on the other with the living matter of the nuclei of the motor nerves which bring the muscles of a bird's vocal apparatus into action (see Fig. 41).

It has been shown that the nervous substance composing the various centres referred to consists of matter possessing congenital qualities which render it highly susceptible to the action of external stimuli. Impressions made on this living matter become fixed in its substance, and are reproduced by stimuli of various kind, which act upon it. In other words, the living matter of these centres, among its other functions, is imitative, in that it possesses the power of reproducing the impressions or images which have been formed in it by the action of stimuli received from the external world; and this action is automatic to a very large extent in birds, although in the Mammalia it comes more completely under the control of force received from the highly developed psychical areas of the cerebrum.

The reproduction therefore, of the notes or other sounds which have become, by constant repetition, impressed on the matter forming the nervous centres in a bird's brain, is mainly an automatic reflex process, which takes place with little, if any mental effort, but is brought into action largely by auditory or by visual excitation. Action of this kind releases a portion of the specific form of energy included in the matter of the nervous centres, and becomes manifest in the nervous force which plays upon the contractile elements of the muscles of the vocal apparatus.

We have further tried to demonstrate the relation that exists between the automatic sensory-motor nervous system of the basal ganglia of birds, and those parts of the cerebral hemispheres which, we have good reason for holding, are concerned in the elaboration of their intellectual faculties. This latter system in birds is only slightly developed, forming quite a thin plate of nervous matter, and presenting a great contrast to the densely packed mass of ganglionic cells, grouped into clusters or centres which form the basal ganglia. In consequence of the almost rudimentary character of the cortical matter of the cerebral hemispheres in birds, we can comprehend that their action on the nervous centres of the basal ganglia would be equally simple in character. The intellectual part of the mechanism being weak, only plays a small part in the processes leading to the vocal sounds produced by the bird.[1]

The point to bear in mind is, that the action of the muscles employed in producing the words uttered by a bird, are regulated to a great extent by the nervous centres located in the basal ganglia, and are therefore almost entirely automatic in their character; though, by their connection with psychical areas of the cerebral cortex their action is to a slight extent intelligent. In man the cortex of his cerebral hemispheres is enormously developed as compared with that of a bird, and with this great increase in size and complexity of structure, the force elaborated in their psychical areas has come to play the predominant part in the vocal sounds, used by civilised human beings to express their thoughts, and for other purposes. Nevertheless, in man, as in the case of the French priest we have referred to, when the influence of the psychical centres is abolished, his automatic basal centres come into operation, and the vocal sounds he then utters are parrot-like in character.

In the natural songs of birds, and in the word sounds

[1] Prof. Lloyd Morgan, in his work on "Animal Behaviour," observes that instincts are compound reflex actions or inherited motor responses, or train of responses. They often show nicely adjusted hereditary co-ordination. They are evoked by stimuli—they are often produced by an internal factor, emotional or otherwise. The relation of instincts to intelligence is essentially that of congenital to acquired behaviour. P. 168—"*Instincts may be considered as being simply the result of long-continued custom or experience.*"

they utter, there are indications of consciousness, in that these words seem to be associated with definite objects; we account for action of this description by the presence of the psychical and sensory-motor centres which exist in their cerebral hemispheres. Professor Lloyd Morgan, when referring to the words spoken by birds, states that they "indicate the possession of memory, a remarkable power of articulation, a great faculty of imitation, and some degree of intelligence in association of linked words with certain objects or actions." [1]

For instance, a parrot belonging to one of our friends remains mute so long as he is in a room alone with a stranger, but no sooner does his mistress enter the apartment than he commences to flap his wings and show other emotional movements, at the same time exclaiming "Grannie," the name he has been taught to associate with her presence. After his mistress has settled down to write or read, the bird commences to repeat a number of phrases she has taught him, until he attracts her attention. His mistress has taught him these word-sounds, and they have become impressed on the nerve centres of the bird's brain, to be called into action by other impulses, in this case derived through his visual receptors by the sight of his old friend and teacher.

The correct association of words and phrases with appropriate objects and actions by birds is a subject of much interest, for associations of this description contain the rudiments of intelligent speech. Professor

[1] G. J. Romanes, "Animal Life and Intelligence," pp. 355, 356; also "Animal Intelligence," p. 266; "Memory," p. 270; "Emotions and General Intelligence," p. 310.

Morgan states that a parrot belonging to a friend of his, when he sees vegetables on the table, calls out, "Polly wants potatoes"; when tea is being served, this bird repeats the phrase, "Polly wants cake." The parrot referred to as belonging to our friend has been taught by his mistress, when she was dressed for her afternoon drive, to say, "Grannie going out"; whenever the bird sees his mistress in her shawl and bonnet he calls out at once, "Grannie going out."

As regards actions, our greatly esteemed friend, the late Professor C. Stewart (Conservator of the Museum of the R.C.S.), stated that a small parrot he was acquainted with, was much attached to a little dog that lived in the same house. The bird did not care for sugar, but the dog was very fond of it. The parrot was allowed full liberty, and was given to perching on the handle of a cruet-stand during meals. No sooner did the little dog enter the room than the parrot was in the habit of flying to the sugar-basin and taking a lump of sugar in its beak, which he placed in such a position that his small canine friend could easily reach it, to his great satisfaction.

Romanes' parrot when he saw the coachman come for orders, would at once exclaim "Half-past two"; the bird having repeatedly heard this order given, had imitated the sound, and associated the words with the man who received the order. This bird at dinner-time had been accustomed to have savoury morsels of food given to her, and had been at these times taught to say, "Give me a bit," which the bird constantly repeated, but only and appropriately at dinner-time. The bird associated the expression with something to eat. This power of association of sounds with objects is probably one of the most rudimentary manifestations of mental activities. We notice the same faculty in an infant long before he has attained the power to think or to reason. Sir Samuel Wilks has drawn attention to the fact that his parrot has been known to invent sounds of its own contrivance, to be used as designative of objects and qualities, or expressive of desires—sounds which may be either imitative of the things designated, or wholly arbitrary. As Romanes observes, this is a most important feature, for it seems still more closely to connect the faculty of vocal sign-making in animals with the faculty of speech in man.[1]

One of the most remarkable accounts we have met with of a parrot's intellectual powers is given in *La Presse* for the 16th March 1903. We are informed that M. Hachet Souplet, writing on the intelligence of animals, makes the following statement with reference to a parrot in his possession.

He had taught this bird to repeat the words, "cupboard and ladder," and as he climbed the ladder he succeeded in inducing the bird to articulate the word "climb." Every day when the bird was brought into the laboratory, a small cupboard was opened and Polly helped herself to hemp seed. One day, however, instead of the cupboard being placed where she could reach it, it was hauled up near the ceiling, and the ladder was placed among several other articles in the corner of the room.

The question to be decided was whether the bird, seeing that the cupboard was out of M. Hachet Souplet's reach, would have sufficient intelligence to use words

[1] "Mental Evolution in Man," by G. J. Romanes, pp. 132-135.

it knew in their proper sequence. The first day's experiment was a failure. The parrot screeched "Cupboard," "Cupboard," beating its wings and biting the bars of its cage in anger, but it got no farther. That day the bird received millet, which it did not care for; the hemp seed, of which it was very fond, being locked up in the cupboard.

Next day Polly was in a greater temper than ever, and after a desperate effort to break through the bars of her cage she finally caught sight of the cupboard near the ceiling. Instantly came the words "Ladder—climb—cupboard," and Polly, having learned her lesson, the cupboard was brought down, and she was rewarded with some hemp seed.

M. Hachet Souplet looked upon this incident as a proof of the association of ideas in the bird's mind, as no one had ever taught the parrot the phrase she created.

CHAPTER X

Those nervous areas of the brain which, on the one hand, receive psychical impulses, and on the other hand govern the action of the muscles of the vocal apparatus in man, are described—The destruction of the living matter of these areas of the brain abolish this power.

WITH few exceptions, a progressive advance in the development of the psychical areas of the cerebrum may be traced through the ascending orders of mammalia, which attains its highest point in human beings, so that in man the mental powers have come to predominate over the action of the nervous matter of his basal ganglia, medulla oblongata, and spinal cord (p. 154).

The cortex of the cerebrum dips down into its numerous sulci or furrows, so that the visible external surface of the brain affords us no reliable information as to the extent of this most important layer of nervous matter (p. 155). It has been calculated that in the human cerebrum there is about twice as much sunken as exposed surface of the cortex, and that in an average European this layer measures in all about 200,000 square mm., its thickness being some 2½ mm. We merely refer to these figures in order to draw attention to the vast number of nerve-cells with their living contents which enter into the formation of the cortical areas of a man's cerebrum.[1]

[1] M. Maeterlinck states that the brain of a bee constitutes the 174th of the weight of its body, the brain of an ant the 296th part of the

As far back as the year 1830, M. Bouillaud taught that if the anterior or frontal lobes of the brain were destroyed, an animal thus mutilated while retaining its sensory faculties, lost its intellectual powers. He came to the conclusion therefore, that the intellectual and sensory faculties of these animals were located in separate parts of the hemispheres of their brains. M.

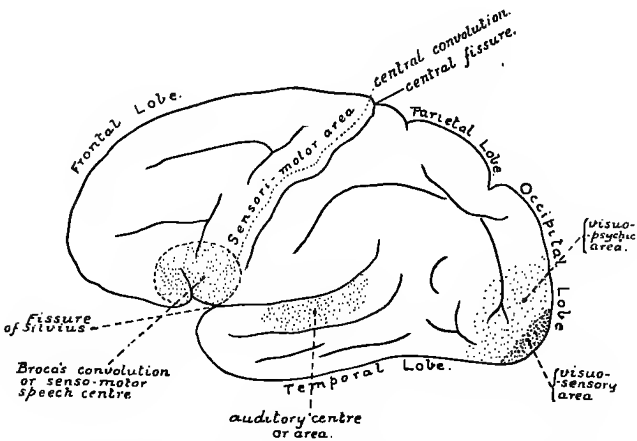

FIG. 37.—Diagram of left cerebral hemisphere (outer surface) of human brain. (From Halliburton's "Handbook of Physiology," p. 688.)

Bouillaud held that in certain cases which had come under his observation, in which human beings had lost their power of speech, that the anterior lobes of their brains were the seat of disease (Fig. 37). From these observations he formed the opinion that the "faculty of

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weight of the rest of its body. In man the relative weight of his brain to his body is about 1 to 37 (see note, p. 153). "The Life of the Bee," p. 99, by M. Maeterlinck; also Prof. Elliot Smith, Cat. Roy. Coll. Sgns., section Nervous System, p. 142. See also this catalogue for description of the spiny ant-eater's brain, p. 145, vol. ii.

language" in man was located in the anterior or frontal lobe of his brain.[1]

In 1861 M. Aubertin brought this subject before the Anthropological Society of Paris, and gave further proof of the correctness of M. Bouillaud's ideas. Some months later, M. Paul Broca, the famous French anthropologist and surgeon, published his memorable paper on the human brain with reference to the "faculty of speech."[2]

Broca stated that in his opinion it was not sufficient to connect the faculty of speech with the frontal lobes of the brain. He argued that if there were any truth in the idea that our power of articulate language was the result of work done directly, or indirectly, by the nerve-cells of the brain, it followed that our other mental faculties must be attributable to a like cause located in a definite area of the cerebrum. When Broca published this opinion, nothing was known concerning the existence of sensory and motor brain centres; he was in search of information on this subject, and was thus led to study cases in which people, from the effects of disease or injury, had lost their power of articulate speech, their intellects and vocal powers remaining unimpaired. Such persons are said to suffer from motor aphasia.

A person suffering from this form of aphasia has lost the power of speech but is not wordless, in that he can comprehend the meaning of words spoken to him, and can generally express his ideas in signs, often in writing; he points to objects named, and recognises drawings.

[1] *Journ. de Physiol.*, Expérim., 1830, t. x. p. 19.

[2] "Remarques sur le siège de la faculté du langage articule," p. 330; "Bulletin de la Société Anatomique," t. vi., 1861.

The aphasic person has not necessarily any defect of vision, hearing, touch, or the other senses, and after a time may regain some power of speech. In these cases the muscles and other constituent parts of the vocal apparatus are in working order, but are not called into play, because the motor area of nervous matter which regulates their action has been put out of gear. This area, or cortical brain centre, as we shall proceed to explain, is located in the left third frontal convolution of the brain (Fig. 37).

Broca believed that the frontal and other parts of the cerebral hemispheres formed the mechanism through means of which our intellectual faculties are elaborated. In 1861 he made an attempt to analyse all the cases of aphasia he could collect, and from this examination was disposed to think, that the symptoms were the result of disease of the left second or third frontal convolutions of the brain. He remarks, "It is therefore possible the faculty of language is located in one or other of these two convolutions;" but he could not be sure of this because pathologists (up to the year 1861) had not clearly defined the area of the frontal lobe they found to be diseased in the cases which they had recorded.[1]

Fifteen years after having expressed this opinion from the results of his own practice, and the experience gained by other observers, M. Broca stated that "we now know that a restricted and well-defined portion of the brain governs the function of articulate speech, which area I call the *organ of speech*. The organ occupies the posterior two-fifths of the third frontal convolution" (Fig. 37).

[1] *Revue d'Anthropologie*, 1876.

Broca proceeded to describe this area of the brain, and the position it occupies with relation to the external surface of the skull. He was, however, a surgeon working with other aims than those of defining the area of the brain which controls man's power of intelligent speech; he felt sure, if his conclusions on this subject were correct, that he could in certain cases in which aphasia was one of the symptoms, hope to benefit the patient by removing the cause of the disease.

Broca acted up to his convictions in a case of disease of the description referred to, and he opened the patient's skull over the position of the third frontal convolution. His diagnosis was correct, and as long as the man lived his power of speech was distinctly improved by the removal of the immediate cause of aphasia.

As we have before stated, in cases of uncomplicated motor aphasia the muscles of the vocal apparatus are not paralysed, although the motor centre on the left side of the brain which controls their co-ordinate action is destroyed. In these circumstances we should have expected the muscles of the opposite, or right side, of the larynx would only be affected, but this is not the case. The reason is that the action of the motor centres of speech are bilateral, so that if the left centre is destroyed, the corresponding centre on the right side controls the innervation of the muscles on both sides of the larynx which are concerned in vocalisation. The importance of the left over the right "organ of speech" is to be explained by the fact, that the right side of the body among civilised people, from inherited tendencies and imitation, is more largely used in voluntary motor actions than the left side. The opposite, or left motor centre therefore, as a rule, is more highly developed than the right side as an 'organ of speech.' But in some remarkable cases of left-handed people, it has been shown that the right third frontal convolution is used more freely than the left as an organ of speech! Beyond this in some cases of aphasia, although loss of speech has been complete for a time, the power of articulate language has subsequently returned. This can be accounted for by the recovery from the abnormal action which had affected the left centre; in other cases it seems clear, that even after the adult period of life, the right centre may be educated to such an extent as to supplement the disabled left centre of speech.

In the year 1878 Dr Dodds published, in the *Journal of Anatomy and Physiology*, a remarkably able series of articles on the location of the functions of the brain. After an exhaustive analysis of all the evidence, for and against, the ideas propounded by Broca and others, as to the existence of a definite area in the brain which controlled man's power of articulate speech, he arrived at the conclusion: "Negatively no absolute proof has been advanced against Broca's views, positively it has been demonstrated that disease of the left supposed centre of speech can produce, and almost invariably does cause aphasia, and it has also been shown that in rare cases aphasia can likewise be caused by disease of the right supposed centre of speech." Dr Dodds adds: "We conclude that it cannot now be reasonably doubted that the special centre (for speech) is included in the island of Reil, the lower part of the ascending frontal, and the posterior part of the third frontal convolution of either hemisphere, destruction of which region must cause aphasia."

Under the heading of Aphasia we find the following remarks in a standard work on the practice of medicine. A certain spot in the left hemisphere of the human brain contains machinery without the use of which a person cannot utter words or convey his thoughts in speech. The authors of this work add, that since a part of the third frontal convolution was described by Broca as being the nerve centre for articulate speech, thousands of cases have demonstrated the correctness of his conclusions.[1]

Dr Ferrier, referring to disease or injury of the nervous substance which forms Broca's area, remarks, "I take it as established beyond all possibility of doubt, that lesions of the region indicated do in the overwhelming majority of instances cause aphasia, and the problem before us is to explain why such lesions should cause aphasia and leave other faculties intact. It is utterly beside the point to argue that loss of speech is not in all cases due to localised disease of this nature, naturally whatever causes paralysis of the muscles of articulation will cause inability to speak; and whatever

"A Text-Book of Medicine," by Drs Fagg and Pye-Smith, p. 743; also Dr D. Ferrier on "The Functions of the Brain," second edition, p. 444, and Dr Charlton Bastian remarks that the third left frontal convolution "is intimately concerned with the physical expression given to thought in articulate speech"; cf. "A Dictionary of Medicine," edited by Richard Quain, edition 1894. Article on "Aphasia," by Dr Bastian. During the present year (1908) Dr A. Church of Chicago University has issued a translation from "Die Deutsche Klinik," under the general supervision of Dr J. Salinger, in which, on p. 13, the following remark will be found: "In man the third, or Broca's, frontal convolution must be born in mind; here closely joined are localised the centres for muscle groups brought into play in *motor speech functions*, the destruction of which therefore produces the well-known picture of *motor aphasia*, with its various modifications."—"Diseases of the Nervous System," edited by Archibald Church, M.D. See also Dr J. W. Russell, p. 113, *The Medical Chronicle*, May 1908.

interrupts the process of ideation and thought, such as sudden shocks of emotion or the like, will also cause inability to speak. Such states cannot properly be classed under the head of aphasia, where we have a definite condition of loss of speech, while all the other faculties—sensation, emotion, thought, and volition—remain practically unimpaired" ("The Functions of the Brain," by Dr D. Ferrier, second edition, 1886, p. 445).

The term aphasia signifies "speechlessness," which may be divided into, first, speechlessness arising from the want of power from defect of memory to recall words previously learnt; or else from the destruction of those parts of the cerebral cortex or centres for hearing, on which the impressions made by word sounds had been registered (Amnesia); and secondly, *motor* aphasia in which the loss of speech depends on a lesion of the nervous matter which constitutes Broca's centre of speech, or in its conducting fibres, passing through the basal ganglia to the nuclei of the nerves which control the action of the muscles of the vocal apparatus.

Although there is an almost universal consensus of opinion in favour of the idea, that the nervous matter forming the posterior part of the third frontal convolution constitutes the centres for articulate speech, nevertheless there are exceptions to this rule, notably in the case of Professor Pierre Marie, who, although he admits the existence of cases of "pure motor aphasia," and that in half his cases of aphasia lesions of the third frontal convolution existed, holds that in other cases aphasia occurs without any observable lesion of Broca's area of nervous matter. We can understand this state of affairs because, if from any cause, the fibres which conduct impressions from the motor centre of speech to the nuclei of the nerves located in the medulla oblongata are destroyed, no message could pass from this centre to the muscles of the vocal apparatus. Beyond this, as we shall give evidence to show, if the centre for hearing located in the superior convolution of the temporal lobes are destroyed, speechlessness follows because the impressions made by word sounds are obliterated with the nervous matter of this region. But here again Dr Marie does not assent to the conclusions arrived at by almost all other pathologists, and he discards the idea of a nervous centre for hearing.[1]

Ideas coming from so experienced and able a physician as Dr Marie however, demand serious consideration, and we have devoted much time during the past eighteen months to re-examining, not only his published work, but a great deal of other literature bearing on the subject of aphasia, together with pathological specimens.

After a careful and unbiassed study of all the materials at our command, we feel convinced that the symptoms above described as being characteristic of motor aphasia, depend on lesions in and about those regions of the brain described by Broca as the "organ of speech." In the following pages we give some of our reasons for holding this opinion, but the clinical and pathological sides of the question are outside the scope of this book.

Dr F. Moutier, a pupil of Professor Marie, has lately published a work in which he expounds and extends Dr Marie's teaching, and adduces evidence, not only in favour of the idea that the posterior parts of the third frontal convolutions do not form the centres of articulate

[1] "La Semaine Médicale," 1906, pp. 241, 492, 555.

speech, but he appears to regard the whole conception of cerebral localisation as having collapsed.[1]

Dr Ferrier in the year 1876, described the nature and results of experiments he had made on the brains of living animals; his plan was to apply a weak electric current to various parts of the outer or cortical layers of the cerebrum. He found that by stimulating cer-

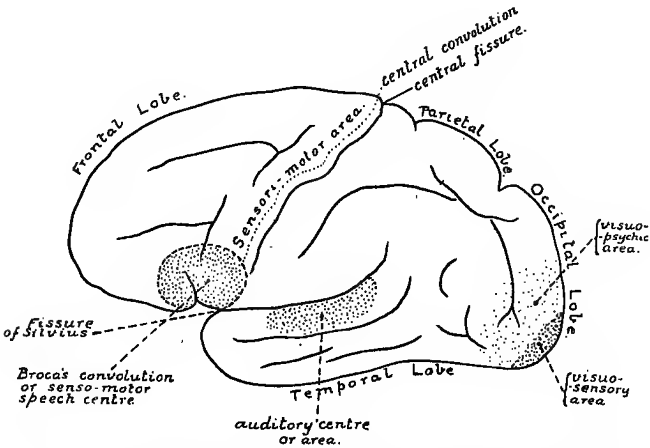

FIG. 37, p. 155.—Diagram of left cerebral hemisphere (outer surface) of human brain. (From Halliburton's "Handbook of Physiology," p. 688)

tain areas of the brain of monkeys and other animals, definite groups of muscles were brought into action. These cerebral areas in fact constituted the sensory-motor centres which regulate the action of the muscles of the animal's body, including those which work the vocal apparatus. Dr Ferrier located the motor centres of the

[1] "L'Aphasie de Broca. Travail de Laboratoire de M. le Professeur Pierre Marie," par Dr F. Moutier, Paris, 1908.

cerebrum in that part which is known as the central convolution (Fig. 37).

Professors Sherrington and Grünbaum have carried out a series of experiments on the brains of sixteen living anthropoid apes, and have confirmed the accuracy of Dr Ferrier's conclusions as to the position and action of the sensory-motor centres of the cerebrum in these animals. Fig. 42 represents the position of the motor centres in anthropoid apes.[1]

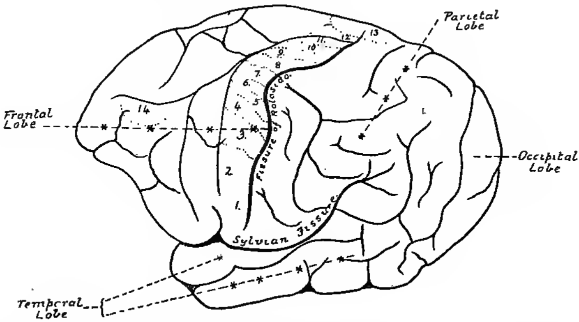

FIG. 42.—1, centre for tongue; 2, centre for mouth; 3, lower lip; 4, ear; 5, eyelid; 6, neck; 7, thumb; 8, index finger; 9, wrist and elbow; 10, shoulder; 11, body; 12, 13, leg; 14, eyes. (From paper by Profs. Sherrington and Grünbaum, *Brit. Med. Journal*, Sept. 1902.)

That part of the cerebral cortex which is included in the central convolution or motor area (Fig. 37), besides

[1] See *British Medical Journal* for 1st Dec. 1900 and 13th Sept. 1902, also 15th August 1903. It is well to observe, with reference to these sensory-motor centres, that in human beings their capacity bears a relation to the extent of skilled movements which the muscles they control are called upon to execute. For instance, the nervous centres which regulate the movements of the thumbs and first fingers are as large as the centre which controls all the muscles of the trunk of the body. This is accounted for by the extensive range, and the delicacy of the motor and sensory impulses which continually pass from the thumb and index finger to the corresponding brain centres.

giving origin to efferent or motor fibres, also receives a vast number of afferent or sensory fibres from tactile, muscular, and other sense-organs, so that this area is described as a sensory-motor cortical area (somæsthetic area).

The sensory-motor centre for *Visual* impressions occupies part of the lateral surface of the occipital region, and a part of the mesial surface (Fig. 37). The *Auditory* sensory-motor centre is located on the lateral surface of the temporal lobe. The sensory fibres from the eyes and ears in human beings, reach these centres by paths which lead through the basal ganglia with which they are brought into relation. The tracts followed by the motor fibres of these centres are not well defined, but there can be no doubt that fibres from these centres conduct nervous energy through the sensory-motor area to groups of muscles, including those of the vocal apparatus.

Some of the nerve-cells of the sensory-motor area are of great size, and give off fibres which extend along the spinal cord as far as the neurons which control the action of the lower limbs. A vast number of nerve fibres also pass from the living matter of the cells forming the motor cortical area to the neurons of the basal ganglia, and to the nuclei of the nerves arising in the medulla oblongata and upper part of the spinal cord, and thus, as above stated, bring the muscles of respiration, the larynx and mouth into play.[1]

If we glance at Figs. 36 and 42, it is evident that the sensory-motor cortical centres are separated from one another by considerable areas of cerebral nervous

[1] We do not propose to refer to the gustatory and olfactory cerebral centres, as they are not so directly concerned in the mechanism by which spoken words are produced as the centres above mentioned.

matter; indeed no less than two-thirds of the whole of the hemispheres of the human brain are occupied by such matter. These parts of the cerebrum, when stimulated by an electric current, do not give rise to muscular action or to any other recognisable form of response. This large part of the nervous matter of the cerebral hemispheres is known as its *association area*, because an important part of its work consists in conducting, by means of its fibres, nervous energy from one sensory-motor centre to another; its function, in fact, is largely to bring these centres into harmonious or correlated action. Those parts of the association area which perform this function are perhaps best described as its *correlating cortical areas*, to distinguish them from those parts of this area whose province it is to interpret the higher psychical states and more complex processes of thought.[1] These latter nervous centres it seems well to distinguish as *the psychical cortical areas*, formed of "consciousness-nervous" matter (Fig. 36, p. 154).

The psychical cortical areas are divided into anterior, middle, and posterior areas. They are closely connected to one another and to the sensory-motor centres by means of a multitude of communicating fibres, but each division of these areas seems to be endowed with somewhat different functions. For instance, within the past few years surgeons have with success been able to remove portions of the human skull and excise tumours from the cortical layers of the brain. The existence and position within the skull occupied by such growths, have been determined by the symp-

[1] Professor J. B. Johnston, "The Nervous System of Vertebrates," p. 354.

toms they have produced in those suffering from disease of this kind.[1] Professor F. Durante has published an account of some remarkable cases of this description. The history of these cases was written for the instruction of members of the medical profession, but we may quote one of the remarks made by Professor Durante, as it directly bears on the intellectual side of our subject. He remarks "that lesions of the frontal lobes of the brain in man are nearly always accompanied by grave phenomena of altered intelligence, which proves that the frontal lobes, and particularly the prefrontal, must be considered as the seat of the most elevated functions of the mind." This observation is based on the history of persons who up to a definite period of their lives had possessed sound moral and intellectual faculties. Profound alterations and an almost total perversion of their sense of morality had manifested itself, which, together with other symptoms, were attributed to the pressure caused on the prefrontal lobes of the brain by a tumour. The pressure having been removed, the perverted mental symptoms disappeared, "the patients being restored to their right mind." This idea regarding the functions of the prefrontal lobes was expressed long ago by M. Paul Broca.[2]

As before stated, our ideas regarding the properties of external objects are derived from impressions

[1] An interesting paper on this subject was read by Dr J. S. Risien Russell at the annual meeting of the British Medical Association, and reported in the Journal of the Association for October 26, 1907, together with the discussion which followed and Dr Russell's reply.

[2] Dr B. Hollander referred to a remarkable case of this kind in his address to the British Phrenological Society on October 8th, 1907, reported in the *Morning Post* of October 9th, 1907.

received by the living matter of the sensory-motor centres from their corresponding sense organs (p. 156). Impressions thus brought to the sensory-motor areas come into relation with the psychical nervous matter which immediately surrounds these centres. In this way correct ideas are formed regarding the nature of the objects which have in the first place acted as stimuli to the nervous matter of the sense organs. The function performed by the larger part of the mass of the psychical cortical association areas, is to bring these ideas into relation with one another and with consciousness. That this is the correct interpretation of the action of this field of nervous matter is demonstrated, by the mental symptoms which follow in cases of disease or injury affecting these areas of the cortex. If in cases of disease of portions of the higher psycho-cortical areas, the sensory-motor centres remain in working order, the ideas formed of objects can no longer be associated with one another so as to form a conception of the properties of the object. Such an individual is mind-blind, mind-deaf, and so on; he cannot correct his ideas, reason, or form a right judgment concerning them; he is no longer able to recognise objects or to give proper names to things.[1]

When describing the structure of neurons (p. 150, Fig. 35), we stated that until the axis-cylinder or neurite of the nerve-cell had received its myelin sheath, the neuron of which it formed a part was unable to perform its proper functions. It is well known that the myelinisation of the nerve fibres of the cerebral hemispheres takes place at different periods of

[1] "The Nervous System of Vertebrates," by J. B. Johnston, p. 354.

an individual's life. The fibres of the senso-motor centres which first become myelinated are those which conduct impulses from the limbs, and this accords with the evident importance in infant life of the tactile impressions received through the limbs.

The fibres of the visual and auditory centres receive their myelin rather later than the greater part of the fibres of the somæsthetic area. The sensory fibres always become myelinated before the corresponding motor fibres, and the myelinisation of the cortex spreads from the sensory-motor centres into the surrounding areas, while the fibres of what we have described as the higher psychical areas remain without myelin sheaths until a later period of life. In some individuals these fibres are not fully developed until after adult age. When this is the case, the mental powers of such a person must be late in becoming completely developed.

As the fibres of the sensory-motor and surrounding association areas are myelinated in early life, "the perception of these zones will provide for the combination of simple sense impressions into perceptions of slight complexity. Thus, the general image of form based upon the examination of various objects by the hand, may be localised in the border zone of the association area *adjoining* the sensory-motor centre, which as we have stated, reaches its full state of functional activity before the *higher* psychical nervous matter has attained its full working powers."[1]

[1] Professor J. B. Johnston, "The Nervous System of Vertebrates," p. 353. In the year 1869 Dr Charlton Bastian stated that in his opinion certain areas of the cerebral cortex were to be regarded as perceptive centres, in which primary impressions made on the organs

The border zones of nervous matter surrounding the sensory-motor centres, provide for the relatively simple association of sense impressions from nearly related regions of the body. Impressions having this character reach the psychical areas of the cortex and are there brought into relation with consciousness.

No part of the human brain is more intimately associated, by means of communicating fibres with the various sensory-motor and psychical centres, than that part of the cerebral cortex which is included in Broca's centre for speech.

With facts of this kind at our command, aided by the knowledge we have acquired concerning the nature of vocal sounds, we can realise the idea that the amount of psychical energy which becomes incorporated with

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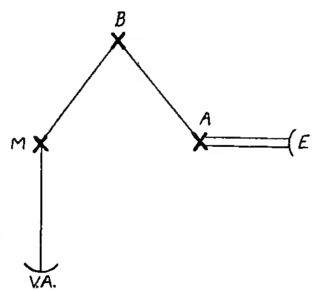
of sense are converted into "perceptions proper." They there receive their intellectual elaboration, and this implies an intimate cell and fibre communication between each perceptive centre, since one of the principal features of a perceptive act is, that it tends to associate as it were, into one state of consciousness much of the knowledge which had been derived at different times and in different ways concerning any particular object or perception. An impression of an object, therefore, made on any single sense centre, on reaching the cerebral hemispheres, though it strikes first upon the perceptive centre corresponding, immediately radiates to other perceptive centres, there to strike on functionally related cells, all taking place almost simultaneously.[1] Sir W. Broadbent, in the year 1872, expressed his concurrence in the above views, but was of opinion that the higher elaboration, the fusion of various perceptions together, and the evolution of an idea out of them will be accompanied, not by radiation of an impression from one perceptive centre to all the others, but by conveyance of impressions from various perceptive centres upon a common intermediate cell area, in which a process analogous to the translation of an impression into a sensation, and a sensation into a primary perception, will take place.—*Royal Med.-Chirg. Soc. Journ.*, 1872.

[1] *Brit. Med. Journal*, May 1869.

the words we utter, will be in proportion to the amount and perfection of the specialised nervous matter contained in the psychical areas of our brain.[1] We do not overlook the fact that the gross amount of living nervous matter in a man's brain does not always indicate the amount of his intellectual capacity, for the inherited quality, and the training which this matter receives influences to a large extent its working power.[2] The hemispheres of the human brain, however, are far larger in proportion to the rest of the central nervous system than those possessed by any other animal. Consequently in human beings the intellectual powers come to occupy a dominant influence in the words men utter; our articulate language thus comes to be the means by which we give expression to our ideas and other intellectual processes.



We may perhaps make our meaning on this subject clearer by representing them in a diagrammatic form. We may imagine that in the above figure the letter E represents the nervous structures of the ear which receive and

[1] Prof. Villa states that the term "psychical energy" can only be used to indicate briefly the aggregate of psychical processes ("Contemporary Psychology," p. 361).

[2] We have had the pleasure of knowing one of the greatest of English artists of the past century, and a no less eminent man of science and letters. Both of these individuals happen to have probably smaller heads than the average number of their countrymen of about the same stature.

transmutes energy from the external world, and bring into action the nervous elements constituting the sensory-motor auditory centre A. The living matter of this centre comes to retain impressions thus made upon its elements, and to reproduce them when stimulated by an appropriate form of energy. Impulses thus formed pass to a nervous centre, B, in which concepts are elaborated; the impulse passing from A thus becomes endowed with intelligence, and by an act of the will passes to M. Broca's sensory-motor area of speech, and becomes manifest by the action of the living matter of this centre on the muscles of the vocal apparatus, V, A. If either of the nervous centres A, B, M are destroyed, or if the nerve fibres which connect these centres and along which nervous energy passes are damaged, the power of intelligent speech is impaired, and in most cases completely lost, unless the injured nervous matter or communication is repaired. We have stated in general terms the foundation on which the above opinion rests. It is, however, advisable to give if possible, some further evidence in support of the conclusions at which we have arrived.

In the first place we may affirm, that the existence of the layers of neurons and fibres we have described as being present in the cerebral cortex, can be demonstrated by anyone possessing a good microscope. The course of the protoplasmic fibrils proceeding to and from the living matter of these cells, has been accurately mapped out in preparations made from human brains. Beyond this it has been proved, that when the living matter of the nerve-cells forming the various cerebral centres have been destroyed, the fibres proceeding from this matter degenerate throughout their whole length. These degenerated fibres can be traced from end to end. Dr F. W. Mott and other observers have for some years past been engaged in working on this and kindred subjects connected with the pathology of the nervous system. He states that "psycho-motor neurons lie in small groups in the cortex" of the cerebrum, and these groups are brought into intimate relation with one another, their number and complexity becoming greater the higher we rise in the zoological scale. Dr Mott adds that such cortical groups of nerve-cells "are the effective agents of the will, regulating and adjusting by reciprocal innervation of special neurons the out-going currents to muscles, and in-coming currents connected with reflex muscular tonus." [1]

Having referred to the evidence which has led us to form the opinion that the stimuli received through the various sense-organs of our bodies are followed by a discharge of nervous energy, which becomes manifest in intelligent speech, the question arises how human beings have come to acquire the power of making use of words as symbols of their thoughts.

The articulate sounds or words to which we give utterance when we make use of intelligent language, evidently depend on the healthy action of the living matter of the nerve-cells forming Broca's centre of speech, and the nervous centres connected with it. We have assumed that words, like other sounds, result from repeated impressions made through our ears on the living matter of the nerve-cells of a definite area

[1] "Archives of Neurology of the Pathological Laboratory of the London County Asylum, 1903," p. 318.

of the cerebral cortex, which area we call the centre for hearing. If this be true, it follows that if this matter or the centres for hearing (right and left) were destroyed, in the case of an adult human being, the word-impression he had previously acquired would be abolished, and such a person therefore would be deaf and wordless; he would have no power of expressing his thoughts in intelligent language, because he would have no words at his command wherewith to give expression to his mental activities. As a matter of fact, a case such as we have supposed has been recorded. Both the cerebral centres (right and left) of hearing having been completely destroyed by disease, the person so affected was absolutely deaf and speechless, and gradually lost all power of thought or reasoning, although the sense of sight, touch, taste, and smell were retained.[1]

From cases of this kind we understand how aphasia, or loss of power to express our thoughts in articulate speech, may occur from the absence of the words which are employed for this purpose, as well from a fault in the nervous substance which controls the action of the muscles of the vocal apparatus (Broca's "Organ of Speech"). It may be well to observe that the course and relations of auditory conducting fibres are well demonstrated in the cerebral hemispheres; after birth they become fully developed at an earlier age than any of the other fibres of the region in which they are situated. These fibres may be traced from the ears through the auditory nuclei and basal ganglia, to terminate in relation with ganglionic nerve-cells located in the

[1] Dr F. W. Mott, "Bilateral Lesion of the Auditory Cortical Centre, Complete Deafness, and Aphasia," *Brit. Med. Journal*, August 10, 1907, p. 315.

superior convolutions of the temporal lobes of the brain (Fig. 37). It is in this well-defined area of the cerebrum, as Dr C. Bastian has shown, that the primary revival of spoken words during thought takes place, for word-deafness can alone explain the loss of speech which occurs in the case of persons whose centres of hearing have been destroyed by disease.[1]

In the child, words are first learnt by hearing certain sounds associated with certain objects, and simple thoughts connected therewith are acquired before the child has the power to articulate them. He sees an object before he can name it; he must revive those auditory impressions which he had previously heard associated with it, otherwise how can we explain the fact that a child in full possession of speech even as late as the fifth, sixth, or seventh year, if he becomes completely deaf, will certainly become dumb unless he is trained by lip reading—that is, unless the primary incitation to articulate speech is transferred from the auditory to the visual word centres? The rule is that auditory images constitute the most potent representations of words, while visual images form the most potent representations of ordinary external objects.

Dr J. Hinshelwood has shown that word-blindness sometimes occurs in several members of the same family.[2] He states that children suffering from this defective cerebral condition have difficulty in learning to read, although in other respects they are quite as intelligent as other members of the family. The memory of these word-blind children, except for words and

[1] See Dr Mott's case, *Brit. Med. Journal*, August 10, 1907, p. 317.

[2] "Letter, Word and Mind Blindness," by J. Hinshelwood, M.D. Also see *Brit. Med. Journal*, Nov. 2, 1907, p. 1229.

letters, is good; they learn to count well, and to write and copy correctly. As Dr Hinshelwood states, the difficulty in the case of these children arises from a defect in the nervous structures forming a limited portion of their cerebral centres, in which the visual memory of words and letters are established in ordinary people, but in other respects their nervous mechanism may be in good working order.

The cortex of the brain has not only been mapped out into definite areas by means of electrical currents, but recent investigations have demonstrated that the form and relation of the nerve fibres and cells in the various motor and sensory cortical centres possess well-defined characters. Dr A. W. Campbell has made some important additions to our knowledge in this branch of science.[1] He describes "the distinguishing characters of the cortex in various regions, and indicates that, given for examination an unlabelled specimen of cerebral cortex stained for nerve fibres only, the form, the calibre, the number and arrangement of the contained fibres proclaim, within rough limits, the locality from which it comes"; and he has shown that by utilising these peculiarities in fibre arrangements as a working basis, it was possible to map out definite physiological areas of the cortex. In a communication to us on this subject, Dr Campbell remarks, "in the anthropoid apes we have a reproduction in miniature of human characters." The difference is in the extent and not in structure as compared with human beings. Our own observations on the nerve-fibres and cells of the

[1] Dr A. W. Campbell, Pathologist, County Asylum, Rainhill, Liverpool, on the "Medullated Nerve-Fibres of the Cerebral Cortex," Liverpool Medico-Chirurgical Society, October 1902.

parietal opercula of man, and of the orang and chimpanzee, confirm the opinions expressed by Dr Campbell on this subject; and the extensive connections of these cortical areas with the lower centres and the psychical areas of the cortex, were demonstrated by the late Sir William Broadbent in a communication to the Royal Medico-Chirurgical Society, as far back as the year 1872.

In the preceding pages we have endeavoured to adduce evidence which leads us to conclude, that waves of articulate sound passing repeatedly through an individual's ear, reach the living matter forming his centre of hearing in such a form that they become impressed on this matter. These sensory-motor auditory centres are brought into close relation with the living matter of psychical areas of the brain, in which ideas, feelings, and other intellectual processes are elaborated. Fibres innumerable pass from these psychical cerebral areas to the sensory-motor nervous substance forming the centre for speech. The living matter of the nerve-cells forming the centre of speech play upon the nuclei of the nerves supplying the muscles of the vocal apparatus. By training and constant use, the congenitally specialised nervous matter forming this mechanism has gradually become perfected, and may not only be set in motion by auditory, but by visual, tactile, and other forms of energy.

If any one of the links in the chain of cerebral actions above referred to is thrown out of gear, the function it exercised no longer forms a part of the spoken words. Thus, if the living matter of the cells forming the sensory-motor speech centre is destroyed, an individual so affected may hear and possess intellectual capacity, but he cannot give vent to it in articulate language, though he may do so in writing, or by facial or manual signs. If the psychical areas of the cerebral cortex are extensively damaged or removed, intelligence ceases, but the individual may hear and utter word sounds, parrot-like (p. 183). If the auditory centres are destroyed the individual is not only deaf, but is also wordless, because the nervous matter of his cerebrum in which words have become impressed no longer exists, and he cannot therefore employ them to express his intellectual processes.

Action such as that referred to however, can only be carried on in living nervous matter which is constantly supplied with a store of potential energy, and is otherwise in a condition to act as a transformer of one mode of energy into another. If the fundamental activities of the living nervous matter are hindered by the presence of various chemical substances in the blood, such as a moderate dose of chloroform, the whole of the psychical and other functions performed by the nervous matter of the cortical cerebral hemispheres are dormant for the time being; but the functions performed by the living matter of other parts of the brain may still be carried on, such as that of the nervous matter which controls the muscles of respiration, etc.

We conclude, therefore, that words are the agents by means of which we give expression to our psychical activities or thoughts. But we can make use of signs, such as movements of the fingers, or of the muscles of the face, to give expression to our feelings. The reason of this is that all the sensory and psychical nervous centres are in close relation with one another; impressions therefore, made on one centre may call into play impressions existing in other centres; and, by means of the synaptic system, not only is the constant flow of energy from without regulated, but neurons may receive from different sources a form of energy which so affects their living matter that it discharges only one description of nerve force (see p. 161).

Dr Ferrier states concerning persons suffering from aphasia, that "sounds, actual or revived, fail to excite appropriate articulation. The individual is speechless, the motor part of his sensory-motor cohesion sound articulation being broken. Ideally revived sights, sounds, touches, tastes, and smells fail to call up symbolic articulation; hence the aphasic individual cannot express his ideas in language, and so far as language, or internal speech is necessary to complex trains of thought, in that proportion is thought impaired. Thought, however, may be carried on without language; but it is thought in particulars, and is as cumbrous and limited as mathematical calculations without algebraical signs." [1]

[1] "The Functions of the Brain," second edition, p. 447, by Dr D. Ferrier.

CHAPTER XI

It is in consequence of the defective development of a sensory-motor area of speech in the brain of anthropoid apes and a certain class of idiots that they are prevented from expressing in intelligent language any thoughts they may be able to elaborate.

In the following chapter we propose to substantiate the conclusions we arrived at in the preceding pages, concerning the way in which the living matter of the various cortical cerebral centres operates, so as to produce intelligent speech. In the first place, it would seem only natural that the man-like apes (anthropoid), possessing as they do, brains in many respects similar to those of human beings, should express their psychical actions in intelligent speech. We have only to watch the facial and other muscular movements made by apes to express their feelings, to be sure that they possess intelligence, but are only able to give vent to consciousness by signs and incoherent vocal sounds.

Professor Huxley, in his work on "Man's Place in Nature," published in the year 1863, states "that the surface of a monkey's brain exhibits a sort of skeleton map of man's, and in the man-like apes the details become more filled in, until it is only in minor characters, such as the greater excavation of the anterior lobes, the constant presence of fissures usually absent in man, and the different disposition and proportion of some convolutions, that the chimpanzee or the orang's brain can be structurally distinguished from man."

This statement cannot be controverted, but since it was made at least one important difference has been established between the structure of the brain of man and that of any known form of anthropoid ape. The difference to which we refer is as regards the absence in an ape's brain of that part of the frontal convolution which in man contains Broca's "organ of speech," or the "machinery without the use of which a person cannot utter the words used in speech." Broca, as far back as the year 1878, in his description of the brain of a gorilla, gave a fairly accurate account of the anatomy of the animal's inferior frontal convolution, as compared with that of a human being.[1] It was not, however, until Eberstaller's work appeared in 1890 that a really accurate account was given of the anatomical relations of the third frontal convolution in man and apes.[2] Professor Vogts, writing to Dr Bateman of Norwich about the year 1890, states that comparative anatomy comes in aid of M. Broca's doctrine "of aphasia"; he adds: "In man the third frontal convolution is extraordinarily developed, and covers partly the Insula; in apes, on the other hand, the third frontal convolution is but slightly developed." Professor Harteman contradicted Professor Vogts' statement, and observes: "Far from being feebly developed in the chimpanzee, the orang, and the gibbon, or even entirely absent in most apes, as asserted by Bischoff, the third frontal convolution is well developed in apes."[3] This conflict of opinion has now been set at rest by Professor D. J.

[1] "Etude sur le cerveau du gorille," *Revue d'Anthrop.*, 1878, 2e Série.

[2] "Das Stirnhirn," Wien und Leipzig, 1890.

[3] "Aphasia and Socialization of the Faculty of Speech," by Dr F. Bateman, second edition, p. 382.

Cunningham,[1] who has demonstrated incontrovertibly that there is a well-marked difference between the brain of an adult human being and of any of the anthropoid apes. He states that "the frontal and orbital opercula of the human brain are entirely absent in the anthropoid cerebrum." [2] He further remarks, "these opercula belong to the lower and back part of the frontal lobe, and are to be looked upon as being more or less directly called into evidence in connection with the acquisition of articulate speech." [3]

The development of the brain in the human embryo and of anthropoid apes proceeds upon the same general plan up to a certain stage of their existence; at this period an arrest of growth of the opercula and of the island of Reil occurs in the brain of apes as compared with man. But, as we have explained, even fully developed third frontal convolutions are far from being all that is necessary for the production of intelligent speech.

In order that we may realise the difference that exists between men and apes, as regards the area of the brain in which the "organ of speech" is located, it is desirable to compare a side view of this part of their respective hemispheres. (See Fig. 37, p. 203, and Fig. 42, p. 204).

Professor Marchand, in the year 1893, published a work on the cerebral hemispheres of the anthropoid apes. His conclusions are practically the same as those

[1] Royal Irish Academy. "Cunningham Memoirs," No. vii.: "Contributions to the Surface Anatomy of the Cerebral Hemispheres," by D. J. Cunningham, M.D.; with a chapter upon Cranio-cerebral Topography, by Victor Horsley, F.R.S., 1892.

[2] Royal Irish Academy. "Cunningham Memoirs," p. 159.

[3] Address as President of Anthropological Section of British Association, for the year 1901.

previously described by Professor Cunningham, which are now admitted to be accurate by almost all competent observers.[1] Professor Marchand states that, "in the case of the man-like apes the lower portion of the third frontal convolution, which to a large extent in man covers the island of Reil, does not exist."

Lastly, Professors Sherrington and Grünbaum state that "no constant movements followed stimulation of the inferior frontal convolutions in either hemispheres (of anthropoid apes), only occasionally were movements induced in the larynx, distinguishable from the rhythmical movements of respiration, suggesting either that there is no Broca's speech centre in these anthropoid brains, or that direct faradisation of Broca's speech centre is insufficient to produce vocalisation, or both."[2]

Professors Cunningham and Marchand, however, demonstrated in a satisfactory manner that there is a tendency, especially in the gorilla's brain, for the third frontal convolution to assume the human form.[3] We might almost venture to state that a rather higher development of the frontal opercula in these animals would endow them with that part of the brain in which the organ of language is located in man. But if they possessed a centre for speech, those parts of the hemispheres of their brains which form the mechanism by which intelligence is elaborated are so ill-developed, as compared with the rest of their bodies, that we cannot conceive, even with more perfect frontal convolutions,

[1] "Die Morphologie des Stirnlappen und der Insel der Anthropomorphen," von Professor Dr Marchand, June 1893.

[2] *British Med. Journ.*, 5th August 1903.

[3] This condition is well demonstrated in the series of specimens of the brains of anthropoid apes contained in the Physiological Series of the Museum of the Royal College of Surgeons of England.

that these animals could formulate ideas expressible in intelligent speech. The hemispheres of an ape's brain, as compared with the rest of his cerebrum, or of his body, are not sufficiently developed to enable him to think or reason, unless in a rudimentary form; on the other hand, we shall attempt to explain in the following chapter that it is largely through the use of the organ of speech that the hemispheres of the human brain have been fully exercised, and have thus attained their remarkable dimensions.[1]

In proof of the above-mentioned idea that an ape, if provided with fully developed frontal lobes and a sensory-motor centre for speech, would be unable to formulate his intellectual activities in words in consequence of his defective psychical cortical areas, we may refer to the case of those unfortunate human beings, known as microcephalic idiots; some of these poor creatures have well-developed bodies and limbs, but their brains, as compared with those of the average of their fellow beings are extremely small, and that part of the brain in which Broca's "organ of speech" is located, as a rule is deficient, and as in the anthropoid apes may be entirely wanting.

In the year 1903 we reported the history of a case of this kind, and gave a description of the brain of this

[1] The statements made in this chapter regarding the structure of the human brain and that of anthropoid apes, as well as the near approach in form of their third frontal convolutions, may be verified by reference to specimens in the Hunterian Museum of the Royal College of Surgeons, Lincoln's Inn Fields. The admirably illustrated and complete "Catalogue of the Physiological Nervous Series of Comparative Anatomy contained in the Museum," vol. ii., gives an account of the brain of the idiot referred to in this chapter, No. D 683, and also a collection of the brains of anthropoid apes, and of man from the fœtal to the adult period of life.

unfortunate microcephalic idiot.[1] In this case the individual died when he had reached the age of twenty-two years. He was 4 feet 8½ inches in height, and

FIG. 43.

broad in proportion to his stature; his features were large, coarse, and devoid of expression. His long arms

[1] *Journal of Anatomy and Physiology*, January 1903, vol. xxxviii., p. 258. See also "Scientific Transactions of the Royal Dublin Society, vol. v., series ii.; "The Brain of Microcephalic Idiots," by Professor D. J. Cunningham.

and small head, with its remarkably receding forehead gave him an ape-like appearance (Fig. 43).

This poor lad had never been able to speak, but expressed such wants and ideas as his mind could formulate by signs and inarticulate sounds. He attached himself to those persons who were kind to him, and followed them about from place to place. His power of sight, hearing, touch, and taste were all good; but it was impossible, notwithstanding the most patient and careful efforts, to teach him to speak, or do such work as that of sweeping out a room. The intellectual power possessed by this individual was inferior to that of some of the lower animals. His habits were dirty, and he was very passionate; when out of temper he became violent, throwing himself on the ground and uttering loud, inarticulate sounds. His general health was good until he reached the age of twenty-one, when he contracted disease of the lungs, from which he died some twelve months later.

On examination after death, it was found that the weight of this youth's brain was under 20 ounces (the average weight of adult Englishmen's brains being from 48 to 50 ounces), and that part of the frontal lobe in which the "organ of speech" is located had not been developed, so that the part of the brain (Island of Reil) which in man is covered by the posterior part of the third frontal convolution, was in the case of this idiot exposed. It is unnecessary for us to enter into a further anatomical description of this brain, which has been elsewhere fully described. But we may observe, that the form and size of this idiot's brain differs less from that of the brain of an anthropoid ape, than it does from the cerebrum of a normal adult European. We may go beyond this, and state that the brain of this individual is more nearly allied to that of an adult male chimpanzee, than it is to that of an average human cerebrum.[1]

Our attention has thus far been directed principally to the action of impressions made on the auditory nervous centre through the ear; but it is equally clear that the form of energy we recognise as light, may, in like manner, be brought to act on aggregations of specialised living nervous matter located in the occipital lobes of the cerebrum.

If we refer to the diagram (p. 211) we have only, in place of the letter E, to substitute the letter V, visual sense-organ; and VC, visual centre, for A, auditory centre, and we may then diagrammatically follow the path which energy entering through the retina follows in reaching the visual centre, and extending to B, acts on the sensory-motor centre of speech, M.

We must, however, bear in mind that a diagram such as that referred to, is simply intended to give us an idea as to the course followed by stimuli passing from the auditory and visual receptors to their respective nervous centres, and from thence to the psychical areas of the brain, and on to the living matter of the senso-motor centre for speech. In reality the action of one nerve-centre on another, and the intricate nature of

[1] The frontal opercula, in which Broca's "organ of language" is located, and which are characteristic features of the human brain, were not developed in the case of this idiot's brain. The hemispheres of his brain also were less capacious than in some of the anthropoid apes. We can therefore understand his inability to formulate intelligent ideas, or, could he have done so, to have given expression to them in intelligent speech. This brain is preserved in the Museum of the Royal College of Surgeons, Physiological Series, D 683.

their connections with one another and other centres of the cerebrum, basal ganglia, cerebellum, medulla and spinal-cord, form about as intricate a subject as it is possible for the human mind to tackle. From the evidence given in the preceding pages we arrive at the following conclusions:—

The living matter which forms the nervous substance of the various sense-organs of the human body, transmutes the impressions it receives from external objects into a form which, in the corresponding sensory-motor centres, becomes manifest in the appreciation of the properties possessed by these objects (p. 156). Impressions thus made through sensory centres pass into relation with the living matter of the psychical areas of the cerebral cortex, where they come into relation with conscious processes, and through the agency of the centre of speech are expressed in the form either of silent or of articulate language.

The cerebral hemispheres of man are far more perfectly developed than those of any other animal, and are characterised by possessing a sensory-motor centre through means of which conscious processes become manifest in intelligent speech. Destruction of the nervous matter which forms a man's speech-centres, abolishes his power to express his thoughts in articulate language, although he may still be able to reason and to express his ideas in writing or by manual signs.

Word sounds, when more or less frequently repeated, especially in the case of young children, become impressed on the living nervous matter of definite cortical areas, known as the auditory centres. Impressions thus registered may be brought into action by various stimuli and pass to psychical centres, and through the action of these latter centres on Broca's motor organ of speech, are manifested in the form of intelligent language. If a person's auditory centres are destroyed he becomes not only deaf, but also wordless, because he has lost that part of his cerebral cortex in which word sounds had become registered, and he is unable to acquire a new vocabulary in the absence of the inherited specific form of nervous matter which constitutes the auditory centres.

If the nervous substance which, under ordinary conditions, forms the sensory-motor centres for speech and the psychical areas of a man's cerebrum are imperfectly developed, although the other sensory-motor centres and parts of his brain are in working order, such a person is unable either to formulate intelligent ideas, to think, reason, or to make use of articulate language. This fact is demonstrated in the case of certain idiots and anthropoid apes.

CHAPTER XII

Anatomical and physiological evidence is adduced in favour of the idea, that the living matter of the psychical areas of the human brain have become gradually developed, through the exercise of the power man possesses of expressing his thoughts in spoken language.

In previous chapters we have endeavoured to describe the properties possessed by living protoplasm, and have followed this matter through one form of its progressive development into the formation of the nervous structures which constitute the human brain. We have explained how it has come to pass that through the action of this matter the human brain has acquired the power of elaborating mental processes, and of giving expression to these processes in articulate language. We now propose to demonstrate the fact, that the acquisition by human beings of the power of employing words to express their mental processes, has led to the development of the living matter of their cerebral hemispheres, and therefore of their intellectual capacities.

In order to appreciate this fact we must in the first place endeavour to form some idea as to the structure and capacity of the brains of pre-historic men. We are aware that the existing evidence on this subject rests on limited materials, but from the nature of the case it could hardly have been otherwise, considering the long period of time which has elapsed since man appeared on the face of our earth. If the evidence however on this subject at our command is good, although very limited in amount, we may make use of it, and from it endeavour to draw some information concerning the processes which have led to the development of man's intellectual capacities. It is quite certain that the brains of primitive man have long since perished, but the dimensions of their brains have been preserved and handed down to us in the form and size of their skulls; for the human brain during life very nearly fills the interior of the skull. In the year 1894 Dr Eugène Dubois, who was then engaged by his Government to examine the fossil-bearing strata of Java, discovered in a well-defined tertiary formation, the skull-cap (calvaria), a thigh bone, and two teeth, belonging, as he believed, to a human being. These bones were found close to one another in the same geological formation, and were all in a similar condition of fossilisation, and therefore in all probability were part of one skeleton. Dr Dubois brought these bones to Europe and submitted them for examination to our leading anatomists. After much controversy it is now generally admitted that Dr Dubois was correct in the opinion he had formed regarding these bones, and that they are part of an ape-like human being who lived in the later tertiary period. Dr Dubois holds the opinion, from impressions he finds on the inner surface of this calvaria, that the brain it once contained possessed inferior frontal convolutions, *i.e.* that portion of the cerebral hemispheres in which Broca's organ of speech is located. He holds that this area of the brain, in the Tertiary period human being, was less than half the size of the corresponding portion of the brain of existing Europeans.

This statement suggests the idea that this tertiary being possessed to some degree the power of articulate language, but from the capacity of his brain as a whole we feel convinced that his intellectual powers were of a rudimentary character as compared with those of civilised human beings of the present day. We make this statement on the estimated capacity of the Java skull, which amounts to 950 c.c., as compared with that of average educated Englishmen, who have an average cranial capacity of 1500 c.c. The capacity of a full-grown male gorilla's cranium is some 600 c.c., the weight of this animal's body being about the same as that of an average adult human being. This great difference in the capacity of a human and a gorilla's skull, represents the difference that exists between the dimensions of the hemispheres of their brains. We shall not, therefore, be far wrong in assuming that the difference in the capacity of the hemispheres of the brain of a gorilla, of the Java skull, and of an educated Englishman, may be represented by the figures 600, 950, 1500. From this it appears that the dimensions of the Tertiary-period man were nearer to those of a gorilla than of an up-to-date Englishman. Beyond this, if we assume that Dr Dubois' opinions are correct as regards the size and form of the third frontal convolution of the tertiary man's brain, it was more nearly allied to that of a gorilla than to a civilised human being.[1]

We may assume that the well-known Neanderthal group of skulls represents the crania of the human inhabitants of Europe in the inter-glacial, or it may

[1] Prof. T. H. Huxley, "Evidence of Man's Place in Nature," p. 136. See also "The Origin and Character of the British People," by N. C. Macnamara, p. 28.

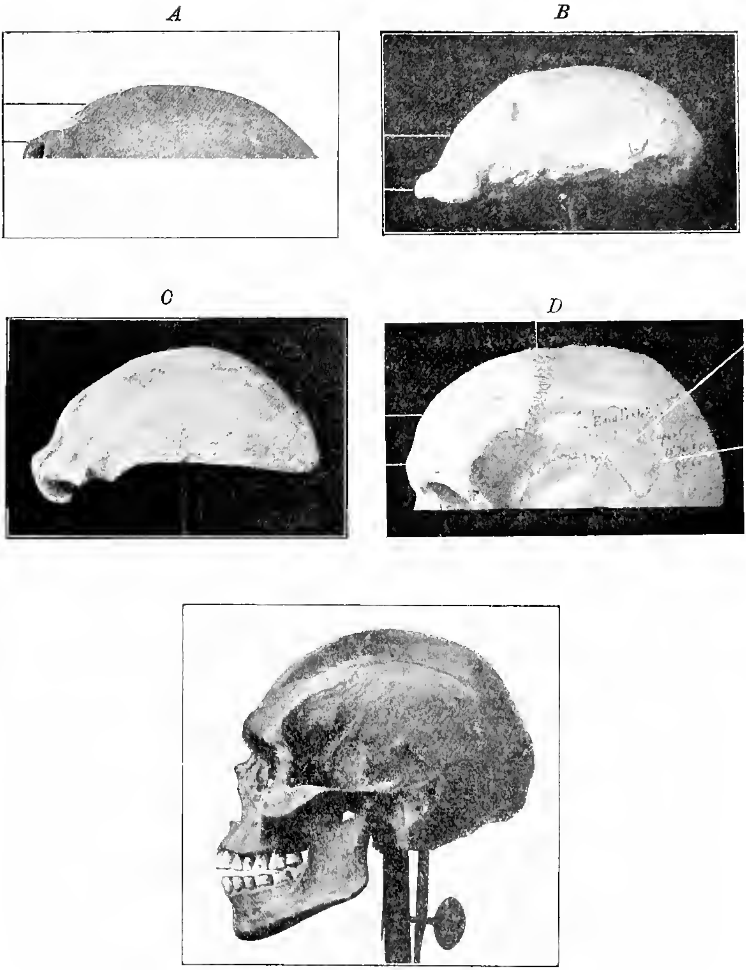


Fig. 44.—*A*, Skull-cap of a Chimpanzee. *B*, Skull-cap of a Neanderthaler. *C*, Skull-cap of the Java skull. *D*, Skull-cap of an existing European. *E*, Skull of a native of Australia.

be the early post-glacial, epoch.[1] Not only does the form of these crania approximate to that of the Java calvaria, but their average cranial capacity is restricted to 1230 c.c.[2] We have then, as regards cranial capacity or the dimensions of the brain: Gorilla, 600; Tertiary man, 950; early Quaternary European, 1250; existing European, 1500.

It is impossible for us to know the extent or the form of language employed by the men of the Neanderthal age, but a considerable proportion of an existing low race of savages have a form, and cranial capacity which resemble those of these pre-historic people. We assume, therefore, that the intellectual capacities and the linguistic acquirements of the Neanderthalers and some of the existing native Australians (the natives to which we refer) are not far removed from one another (see Fig. 44). We find that the capacity of the skulls of 115 natives of Australia in the museum of the Royal College of Surgeons average 1298 c.c. Of this number 36 skulls are of a distinctly low type, such as that represented in Fig. 44, taken from a photograph of the skull described and figured by Huxley in his work on "Man's Place in Nature," p. 154.[3] It is, however

[1] We include in the Neanderthal group the two Spy and th Neanderthal skulls.

[2] "Archiv für Anthropologie," ix., 1903. "Kraniologischer Beweis für die Stellung des Menschen in der Natur," N. C. Macnamara. See also Hunterian Oration for 1901, by N. C. Macnamara (Smith Elder).

[3] See Cat. Mus. R.C.S., England, Osteological Series, second ed., pp. 314, 423, and Prof. Huxley on "Man's Place in Nature," p. 154, from which we quote the following sentences: "The Australian skull is remarkable for its narrowness and for the thickness of its walls, especially in the region of the supraciliary ridge, which is frequently, though not by any means invariably, solid throughout, the frontal sinuses remaining undeveloped. The nasal depression, again, is ex-

necessary to be guarded in arriving at more than general ideas regarding the racial characters of the skulls of the natives of Australia, from the measurements of collections of their crania to be found in most of our museums, because it is not possible to be sure that all these skulls are specimens of purely native Australians. New South Wales was constituted a penal settlement in the year 1788, and from that time until 1840 some 60,700 convicts were sent from England and landed in New South Wales; of this number 8700 were females. Convicts, after they had served their term of banishment or had been pardoned, frequently settled in Australia, and in their turn received fresh batches of prisoners as their bond-servants. From the evidence of persons who visited

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tremely sudden, so that the brows overhang and give the countenance a peculiar, lowering, threatening expression. The occipital region of the skull, also, not unfrequently becomes less prominent, so that it not only fails to project beyond a line drawn perpendicular to the hinder extremity of the glabello-occipital line, but even, in some cases, begins to shelve away from it, forwards, almost immediately. In consequence of this circumstance, the parts of the occipital bone which lie above and below the tuberosity make a much more acute angle with one another than is usual, whereby the hinder part of the base of the skull appears obliquely truncated. Many Australian skulls have a considerable height, quite equal to that of the average of any other race, but there are others in which the cranial roof becomes remarkably depressed, the skull, at the same time, elongating so much that probably its capacity is not diminished. The majority of skulls possessing these characters, which I have seen, are from Port Adelaide, and have been used by the natives as water vessels. Fig. 31 represents the contour of a skull of this kind from Western Port, with the jaw attached, and of the Neanderthal skull, both reduced to one-third of the size of nature. A small additional amount of flattening and lengthening, with a corresponding increase of the supraciliary ridge, would convert the Australian brain case into a form identical with that of the aberrant fossil."

Australia during the first forty years of the last century, we learn that the social and moral condition of the European male population of Australia, outside the towns, was as a rule in a deplorable condition, many of them cohabiting freely with native women, the result being a population containing native children having a strain of the European racial character. Succeeding generations of these natives are not altogether free from the influence of the mixture of the two races, and it is more than probable that their skulls are to be found in our museums labelled and described as specimens of the crania of natives of Australia. In one such skull the cranial capacity is 1380 c.c., nearly 100 c.c. higher than that of genuine native Australian crania.

It is therefore necessary to be cautious in working out the typical form and cranial capacity of the natives of Australia; but due regard having been paid in selecting our specimens from reliable sources, we find, as Sir W. Flower states, that the average cranial capacity of the male natives of Australia does not exceed 1298 c.c., and is therefore lower than that of any other known existing race of people whose stature does not fall below that of the average Europeans of the present time. Further, among a well-authenticated collection of the skulls of the natives of Australia a considerable number of them will be found, as Professor Huxley states, which, "with a small additional amount of flattening and lengthening, with a corresponding increase of supraciliary ridge, would convert the Australian brain case into a form identical with the aberrant fossil" skull known as the Neanderthal cranium.

Many of the stone implements employed by the natives of Australia resemble in character those used by pre-historic man in Europe. We mention this fact merely to corroborate the inference we draw from the capacity and form of their skulls, that their intellectual development was probably up to much the same standard.

The genuine or unmixed natives of Australia, and the now extinct aborigines of Tasmania, form some of the lowest known types of savages. The skulls of these people and their language in all parts of Australia are so much alike, that it seems more than probable they belong to one and the same family of human beings. We judge from the uniform conformation of their skulls and language, with the exception of the classes we have referred to, that they have mixed but little, if at all, with other races of men. Their language is of the agglutinative type, and they have no words for numerals above three.[1] Dr Routh has determined the value of no less than 213 manual signs, which are used by the natives of the north-west Queensland district, and serve all the purposes of a *lingua franca*; these signs are capable of expressing a wide range of objects, persons, feelings, and so on. The natives "observe no settled order or arrangement of words in the construction of their sentences, but convey in a supplementary fashion by tone, manner, and gesture those modifications of meaning which we express by word, tense, number, etc.[2]

[1] Professor Sayce states when referring to the isolating and agglutinative types of language, that what we really mean when we say that one language is more advanced than another, is that it is better adapted to express thought, and that the thought to be expressed is itself better. It is a grave question whether from this point of view the three classes of language can really be set one against another.—"Introduction to the Science of Language," vol. i. p. 374.

[2] "Man, Past and Present," by A. H. Keane, p. 156.

As before stated, in consequence of the similarity of form and capacity of the crania of so many of the true natives of Australia, with the crania of the Neanderthal group of men, we are disposed to think that the intellectual capacities and the language used by these two families of human beings were of a similar type. The question therefore arises, as to why the languages now used by Europeans have developed from a simple into their existing comprehensive forms; whereas the language employed by the natives of Australia has remained stationary, we know not for how long because we are ignorant of the origin and the history of these people.

The bones of the trunk and limbs of palæolithic man, and of existing races of Europeans do not differ essentially in form. It is the spine parts above, and especially the crania of Europeans which, since the post-glacial epoch in Europe, have developed so much, especially in the frontal and parietal regions. There is no great difference in the stature of palæolithic and of the existing races of Europeans and Australians. In seeking, therefore, to explain the increase that has taken place in the crania, or rather the hemispheres of the brain of modern Europeans, as compared with their progenitors, we must look to their environment, and contrast it with that of the natives of Australia.

From a study of the form and dimensions of their skulls, together with their stone, bronze, and other implements, we learn that the inhabitants of Europe in pre-historic times were often invaded by men from Asia and Africa. In consequence, the primitive inhabitants of Europe must have been forced to devise means to protect themselves and their pasture lands from intruders on their soil. Added to this, as the number of inhabitants of our continent increased, and its forests, and the deer and other wild animals they contained decreased in number, the people were compelled to cultivate the soil and to grow corn and other cereals.[1] Beyond this, from the change in the form of their skulls, we learn that in early pre-historic ages there was an intermingling of races, and probably, therefore, of language among the people inhabiting Europe. All this necessitated on their part the acquisition of new names for things and acts in common use; and "each name learnt gave birth to new thoughts," in other words, to the exercise of the psychical areas of their brains, and consequently to their increased development. Their environment compelled these people not only to exercise the psychical elements of their brains, but also forced them to employ their mental powers and their hands in various forms of skilled labour, and, consequently, as we have explained, to increased development of the sensory-motor cortical centres controlling their thumbs and fingers (see note, p. 204). A process of this kind going on for very many centuries has necessarily led to a greater capacity of the structures constituting their cerebral hemispheres. Nor is it possible to conceive that the pre-historic people of Europe could have made the progress they have done, unless through the instrumentality and use of intelligent speech.

If we turn to the other side of the picture it tends to confirm this idea. The genuine natives of Australia have not been subjected to invasion by other and more

[1] "The Origin and Character of the British People," by N. C. Macnamara.

vigorous races of men. They have not been called on to protect their lands from the grasp of foreigners or from their own people, for there was room for them all in the vast country they inhabited, and largely in consequence of their own barbarous customs their numbers do not seem to have increased to any great extent. Their language, therefore, has continued up to the present time in its primitive form, and in consequence their brains have retained the capacity and form reached by the glacial inhabitants of Europe.[1]

The character of the skulls of the pre-historic people of Egypt, as compared with those of the present time, tends to support the above ideas; for the form of the skulls of the ancient and modern Egyptians are of the same type, but the cubic capacity of the skulls of the large number of pre-historic human crania lately discovered in Upper Egypt are, on an average, less than that of the modern fellah. In recent times,

[1] We concur with Professors Obersteiner, Donaldson, and other authorities in the opinion that "the skull-case and skull contents mutually influence one another's growth." In the man-like apes the lines between the various bones forming the skull-cap become united by the end of the first year of the animal's life, whereas in man they do not unite completely until the individual is well advanced in years. In some exceptional cases we find the bones of the skull on one side have united early in life, and in these cases corresponding parts of the brain are restricted in their growth, whereas the other side where the lines of union of the bones have remained open, the brain has reached its normal size. The line of union of the frontal bones in Europeans is found open after the adult period of life in one of nine skulls, but in the natives of Australia they unite at an early period of life. The soft substance of the brain can hardly be exempt from the action of mechanical laws, and if, therefore, the laws of growth are such as to lead to early consolidation of the lines of union of the bones of the skull in the case of apes, or of certain races of human beings, it would seem that the development of the brains of these animals must likewise be limited.

Broca found that the skulls of a number of Frenchmen of the twelfth century had a less capacity by 35 c.c. than the same number of skulls of nineteenth-century Frenchmen. Among our own countrymen there is evidence favouring the idea, that the average skulls of the adult educated classes of Englishmen, are as much as 50 c.c. more capacious than those of an equal number of the uneducated classes of men.

An anatomical description of the brains of some 140 men have been recorded, who, during their lifetime, had been distinguished in some branch of art, science, literature, etc. Examinations of this kind have been made, with the object of ascertaining if any part of the cortical matter of the brains of these intellectually distinguished men was more highly developed than the corresponding areas of the brains of ordinary people.

From these researches we learn that greater mental capability is associated with greater areas of grey nervous matter, this matter being in excess of that demanded by the size of the body with which the brain is associated. This excess of cortical nervous matter

[1] The average weight of the hrain of a full-grown elephant is some five times heavier than that of a human being. This may he accounted for by the fact of the great size of the animal's body, which necessitates a corresponding growth of the cerebral hemispheres, these being closely related to the extent of the tactile sensor impressions proceeding from the whole surface of the animal's body. Largely protected by the nature of the external covering of its hody from tactile impressions, the hippopotamus has a comparatively small brain. The intelligence of this animal as compared with an elephant is small, indeed so low that this family of beings could hardly have survived in the struggle for existence had they not adopted habits of life which place them outside any necessity for a severe effort to maintain their species. See remarks hy Professor G. Elliot Smith, M.D., "Descriptive Catalogue of Physiological Series of Comparative Anatomy," of the Royal College of Surgeons of England, vol. ii., second edition, p. 466.

was conspicuous, in that the brains of these men were more richly and more deeply convoluted than the average human brain. Recently a step forward in these investigations has been made by Professor Spitzka, of the Jefferson Medical College of Philadelphia,[1] who has deduced some very interesting conclusions from the results of his examination of the brains of six distinguished Americans. The brains he examined were those of J. Leidy, biologist and teacher; E. D. Cope, palæontologist and morphologist; P. Leidy, surgeon and organiser; A. J. Parker, morphologist; R. Allen, surgeon and zoologist; and W. Pepper, a distinguished physician. Professor Spitzka's examination of these brains, which were associated during life with very exceptional faculties, confirms all that was previously known regarding richness and depth of convolutions and amount of grey matter. It shows in addition that white matter, and particularly the association fibres, also preponderate in the brains of distinguished men, as contrasted with the brains of men of smaller mental calibre. This preponderance of white matter, which, as Professor Spitzka points out, is so necessary for the happy and brilliant utilisation of the records deposited in the numerous cells of the abundant grey matter, is most strikingly and convincingly shown in the relatively great size which the corpus callosum attains in the brains of unusually capable men. Professor Spitzka, however, goes still further, for he believes he is able to show that some faculties can be definitely localised, and that, taking two men, both of great but

[1] "A Study of the Brains of Six Eminent Scientists and Scholars belonging to the American Anthropometric Society," by E. W. Spitzka, M.D.

of different mental capabilities, not the same but different areas of their brains will preponderate. He supports his contention by reference to the brains of Professor Cope and Professor J. Leidy. The former was "more creative, constructive, philosophic," and he was brilliant in abstract generalisations. The latter "was a far keener observer," quick at seeing analogies, an excellent systematiser, and he had a splendid power of memorising and recalling visual impressions. In association with these differences of mental power Professor Cope's brain shows a relatively preponderant development in the area in front of the precuneus, whilst in Professor J. Leidy's brain the precuneal and cuneal areas are relatively enormously large. Whether or not further observations will confirm Professor Spitzka's views the future alone can tell, but his observations are suggestive and should stimulate further research.[1]

If we turn to the other side of the picture we find, from Dr Flachmann's reports, that the brains of certain of the natives of Australia which he has examined, present fissures or sulci not to be found on the cerebral hemispheres of Europeans, but which are characteristic features of the brains of anthropoid apes.[2]

We may here briefly refer to the opinion of philologists, and ascertain how far they coincide with our ideas as to the origin and development of intelligent speech.

The late Max Müller states that the explanation of

[1] The above paragraph is copied from *The British Medical Journal*, Feb. 15, 1908.

[2] N. C. Macnamara, "Beweisschrift betreffend die gemeinsame Abstammung der Menschen und der anthropoiden Affen," *Archiv für Anthropologie*, Neue Folge, Band iii. Heft 2.

the origin of root-words must be of a more or less hypothetical character, like the solution of all problems which carry us back to times when man can hardly be said to have been man, when language was not language, and reason not reason.[1] Signs were doubtless largely employed by our progenitors, such as pointing with the fingers, gestures and looks being used to supplement the few roots or vowel sounds which embodied the conscious and creative social acts of men, which are frequently accompanied by various natural sounds, and that these are the true germs of the concepts embodied in language.[2] He states that whenever our senses are excited and our muscles hard at work we feel a kind of relief in uttering sounds. This is particularly the case when people work together, when peasants dig or thrash straw, when sailors row, when women spin, when soldiers march, they are inclined to accompany their occupation with certain rhythmical utterances. Grunts, noises, shouts, or songs are a kind of natural reaction against the inward disturbance caused by muscular effort. They are almost involuntary vibrations of the voice, corresponding to more or less regular movements of our whole bodily frame. These sounds are therefore the signs of repeated acts, acts performed by ourselves, perceived therefore and known by ourselves, and continuing in our memory as signs of such acts. The sounds being uttered from the beginning, not by solitary individuals only, but by men associated in a common work and united by a common purpose, possess the advantage of being understood by all. The primitive roots of speech mostly express such acts, and

[1] "Science of Thought," by F. Max Müller, p. 552.
[2] *Idem*, p. 318.

most of the acts such as might be supposed to be familiar to the inhabitants of cave-dwellings, such as cutting, rubbing, pulling, striking, and so on.[1] The sounds above referred to were the signs or symbols of a repeated act, and became the true realisation of what we call a root, embodying a concept comprehending the many acts as one which was understood by all. In addition to the origin of roots from natural sounds, Max Müller would refer the derivation of other roots used by primitive races of men to their having imitated the sounds uttered by animals or by man. He states that roots meaning to shout, to sing, to call, etc., form clearly a class by themselves, and are more numerous, because less generalised, than any other class of roots.

From natural sounds of this description a series of local phonetic impulses arose, from which future languages are said to have developed. In the course of time these languages came to react on one another, and increased in complexity according to the work they were called on to perform. According to our idea, it was rather the other way round; the work they had to perform necessitated the use of new words, and therefore of new thoughts.

It appears, however, that Max Müller, who devoted a long and laborious life to the study of languages, also arrived at the conclusion that the origin of intelligent speech can be traced back to a series of almost involuntary vocal sounds uttered by men when engaged in laborious work, and to their power of imitating the calls of various animals. Word-roots thus came to be used to signify certain things and acts. The habit thus acquired enabled these primitive people

[1] "Science of Thought," Max Müller, pp. 300, 307.

to communicate their ideas to one another, and were doubtless supplemented, as they are to-day among the natives of Australia, by manual and other signs. This was one of the first steps taken by human beings to enable them to combine for mutual protection, and so to lay the foundation of social life with all its consequences.

This view of the origin of articulate speech appears, from a study of the roots of words, therefore to coincide with the conclusions we have arrived at from another point of view, as to the connection of this faculty with the development of our intellectual capacities; simple, natural sounds among a primitive race of men coming to be recognised as appropriate symbols or names of things and acts. These people only possessed rudimentary organs of language and cerebral hemispheres of a low type, nearer to that of an ape than to existing races of civilised people (p. 232). From the palæolithic period onward the struggle for existence of the inhabitants of Europe has increased, and with it the necessity for a fuller and more complete vocabulary, which has resulted in a great development of their cerebral hemispheres and of their intellectual powers. This development may be traced in the change of form and capacity of the skulls of the inhabitants of Europe in successive periods, and in the probable development of the language they employed, the former indicating the expansion of the hemispheres of their brains, and the latter the intellectual development following on this higher cerebral organisation.

The growth of man's inventive powers appears to have been developed in proportion to the mental power he acquired through means of the use of intelligent speech. We can follow the development of these powers by means of the stone, the bronze, and the iron he successively employed wherewith to construct weapons of defence, and implements for agricultural and other purposes. From our point of view, instruments and tools represent an amplification of the sense-organs, differing, however, from these organs in that they do not perish with the death of their inventor, but remain to be used and improved by succeeding generations of beings. The sense-organs of primitive man, and those possessed by civilised human beings are, in all probability, similar in structure and functions, and are not superior to those possessed by some of the lower animals. Man, however, for reasons we have explained, is the only creature who is enabled to express his thoughts in intelligent speech, or who can devise and make use of instruments which greatly augment the natural power of his sense-organs (as, for instance, the telescope, microscope, and telephone). The use of these instruments has reacted through the sense organs on the living substance of the psychical areas of his brain, and has thus stimulated the development of his mental faculties, and we have good reason to suppose that processes of this description will continue to raise the human race to a still higher state of civilisation than it has yet reached.[1]

[1] "The tools of technique and the means of communication through which division of labour is possible, in short, the products of civilisation, are the new organs of man, and their development in the struggle for existence continues in a direct biological line the progress of the animal. The tool in its widest sense was indeed the greatest step forward, as it means an extension of the physiological arc (sense-organ-brain-muscles) at both ends."—Pp. 77, 78, "Psychology and Life," by Professor Hugo Münsterberg.

CHAPTER XIII

The histories of certain deaf and dumb children are referred to in order to demonstrate the fact, that to bring the living matter of the psychical areas of the human brain into play it must be stimulated by energy received, through the corresponding sense organs. From this we draw the conclusion, that to develop the mental powers of children efficiently, it is necessary systematically to exercise the psychical nervous matter of their brains, through means of their various sense-organs.

We have shown reason to believe that words result from the stimulation of impressions made on specialised nervous centres through means of the various organs of sense, and that it is by the exercise of man's power to express his ideas in silent and spoken language, that the hemispheres of his brain have gradually reached their existing state of perfection. We now propose considering further evidence bearing on this subject, which finally leads us to refer to the system of training which is best calculated to develop the intellectual powers of young children.[1]

It is evident that the use of words reacts powerfully on the mental department of our brains, for without

[1] Professor J. Sully states that "the growth of a child's speech means a concurrent progress in the mastery of word-forms and in the acquisition of ideas. In this each of the two factors aid the other, the advance of ideas pushing the child to new use of sounds, and the growing faculty in word-formation reacting powerfully on the ideas, giving them definiteness of outline and fixity of structure."—"Studies of Children," by Professor J. Sully, p. 160,

their use our intellectual powers, even with well-developed brains, fail to elaborate feelings or thoughts. That the use of silent and spoken words is closely connected with the development of our mental powers, is demonstrated by the history of certain young children whose faculty of naming things and acts had been suspended early in life in consequence of the loss of their organs of vision and hearing from the result of disease.

A well-known instance of this kind is that of Laura Bridgeman. This case was reported by Dr Howe, at the time, President of the Institution of the Blind in Boston, U.S.A. Dr Howe informs us that this girl was a healthy infant and grew in body and in intelligence until she had reached her second year of age, when she was attacked by scarlet fever, which completely destroyed her eye-sight and her power of hearing.[1] Laura's mother was devoted to her unfortunate child, but in spite of all her efforts she was unable to teach the child to speak or to notice any sound. Laura Bridgeman, in fact, from her second until between her seventh and eighth year of age was dumb as well as deaf and blind. Dr Howe states that until Laura was over seven years of age she "occupied a place in her home no higher than that of an intelligent animal, upon whose instruction much labour had been bestowed." Her intellectual capacity, so far as an opinion could be formed, remained undeveloped; her sense of touch, however, was unimpaired, and she was thus able by the use of her hands to feel her way about the house in which she lived. Before entering the institution for

[1] *American Journal of Psychology*, vol. iii. p. 294, Prof. H. H. Donaldson, on Laura Bridgeman's brain.

the blind, which she did when seven years of age, L. Bridgeman had been taught by means of her sense of touch, that is, through moving the tips of her fingers over raised letters, to recognise words which were attached to a number of articles in common use, such as knives, forks, spoons, and so on. Laura B. seems to have learnt that the crooked lines composing the word spoon differed from those of the word fork, as the shape of one article differed from the other. She also learnt by feeling the raised letters on a label to place the proper label with the article named on it. She had, however, no conception of anything beyond this mechanical form of knowledge, the result of which Dr Howe observes "was about as great as if one had taught a number of tricks to a clever dog. The poor child sat in mute astonishment and patiently imitated everything she could learn by her sense of touch."

After long and patient teaching so as to exercise her sense of touch as highly as possible, Dr Howe states Laura B. seemed to have gained ideas that the symbols she was employing meant definite things to her mind, and that by their use she could present what was in her mind to that of another person. "Immediately Laura Bridgeman realised this, her countenance beamed with human reason; she could no longer be compared to a parrot or a dog." We would only here remark that this case seems clearly to illustrate the fact that by careful training the tactile sense had come to replace the lost sense of sight and of hearing in the development of sensations, ideas, and, lastly, intellectual processes.

Another remarkable case of a similar description to the above is reported by Mr E. Chamberlin, and subsequently by H. Keller herself.[1]

H. Keller was born in the year 1880; she was evidently rather forward in intelligence for her age, but in her nineteenth month of life was seized with a fever, through the effects of which she completely lost her sight and hearing. Her other special senses were unimpaired. From the time of this illness until she reached the age of seven years, H. Keller states that her life was a blank, meaningless—and, concerning the events which took place before she reached the age when her regular education commenced, she remembers little or nothing; she lived during this period, as she expresses it, in a condition of mental fog. Those who knew H. Keller during these years state that the predominant features in her character were her excitable, passionate nature, and love of mischief. When she was rather over seven years of age she came under the influence of a wise and experienced teacher, and under her instruction she passed through a preliminary course, similar in principle to that followed by Laura Bridgeman. As her sense of touch became more delicate, her tutor, by signs made with her fingers in the palms of her pupil's hands, spelt words in common use for things. Referring, however, to this period of her life, H. Keller remarks that "in the still dark world in which I lived there was no sentiment, no tenderness." The signs made and received by means of finger touches and movements were, as in the case of Laura B., mechanical, the outcome of work done by the living matter of her

[1] *The Ladies' Home Journal* for April 1902, and following numbers; *Harper's Monthly Magazine* for June 1903, p. 150; also "The Story of the Life of Helen Keller," by H. Keller, 1903.

basal ganglia, the hemispheres of the brain were as yet hardly brought into play through the centres of touch. This condition of things continued for a considerable time. One day, however, H. Keller and her tutor came to a stream of water into which the latter placed her pupil's hands, and while there traced on them the letters w-a-t-e-r. H. Keller states: "I stood still, my whole attention being fixed upon the motion of the water and the motion of my instructor's fingers. Suddenly I felt a misty consciousness of something forgotten. I knew that w-a-t-e-r meant something that was flowing over my hands." "I then recognised," she adds, "that the signs made by my tutor in my hands was known as water." The thing had a name; having once grasped this fact H. Keller soon realised that "everything had a name, *and each name I learnt gave birth to new thought*."

Mr M. Anagnos, Principal of the Perkins Institution for the Blind, has kindly informed us that H. Keller commenced her work in that school in 1888, and studied there until 1893, after which she left his care and he has not had the opportunity of watching her further education. But she acquired the power of lip deciphering, *i.e.* by placing her fingers on the lips and throat of a person while they were articulating. She not only came to know the word they uttered, but was ultimately able to reply in articulate speech.[1]

From the histories of these deaf and blind people we learn that from their second to their seventh or eighth year of age they were unable to name things either in

[1] From "The Story of the Life of H. Keller," written by herself, we learn much that is most interesting regarding her mental development, which attained to quite a high standard, so much so as to enable her to gain a university degree.

silent or articulate language. Their power of memory or of forming ideas were rudimentary, their intelligence being of a no higher order, as Dr Howe remarks, than that possessed by a well-trained dog. Mr Chamberlin states that H. Keller "knows less of her early childhood than any other person of good intelligence whom I have ever known." He states "that I have frequently endeavoured to extract from her some clear information regarding the character of her actual impressions and recollections of the mysterious period before she had any knowledge of words. She invariably answers—'I remember nothing, I have only impressions—vague impressions.' No other words than impressions to characterise her experience of that period have I ever been able to get out of her."[1] H. Keller herself states that for six years before her education commenced her intellectual faculties were in a condition which she likens to that of a dense fog. Dr Howe, describing Laura Bridgeman's mental condition at this period of her life, states that she "imitated everything she could learn by the sense of touch, but until a certain period of her education she had no understanding."

With the evidence of independent and reliable witnesses such as those above quoted, we conclude that after these children had lost their sight and hearing, and consequently their power to receive impressions and gain ideas regarding external objects through their eyes and ears, their intellectual powers had ceased to develop. We say ceased to develop, because until they lost their sight and hearing they were as intelligent as most other children of the same age. Taking this fact, and also that of their subsequent histories into con-

[1] *Ladies' Home Journal*, p. 9, May 1899.

sideration, we conclude that the brains of these beings possessed the mechanism by which they might have expressed their thoughts in intelligent speech, but the machine failed to work. Their sensory-motor, auditory, visual, and tactile centres were, in conjunction with the psychical areas of their cerebral hemispheres, capable of performing their ordinary functions, but the two former important receptors of energy had been destroyed, so that the sensations and ideas which children usually acquire through these sense-organs were not formed, the psychical areas of these sightless and deaf children therefore remained to a large extent unemployed, and their living matter passed functionally into a dormant state.

L. Bridgeman lived to be sixty years of age. After her death Prof. H. H. Donaldson made a careful examination of her brain. He reports that the areas of the unused sensory-motor centres (visual and auditory) were imperfectly developed, but that the psychical areas of the brain, which for many years had been exercised by ideas gained through means of tactile sense-organs, were of their normal size and structure.[1]

The description of L. Bridgeman's brain confirms the opinion above expressed regarding the failure of her intellectual processes during a certain period of her childhood. The inherited properties and working power of the living matter of her cerebral hemispheres was in all probability similar to that possessed by her progenitors, but from the second to the seventh year of her life its psychical areas had only been brought into

[1] *American Journal of Psychology*, vol. iii. Press-mark in the Library of the British Museum, P.P. 1247.d.

a very imperfect mode of operation, having been cut off from the action of the flow of sensations and resulting ideas, which naturally reach them through the visual and auditory sensory-motor centres. The consequence was that the functions of the psychical areas of her brain remained undeveloped, until they had been stimulated into action by the continued skilful training of her tactile sense-organs, and their corresponding sensory-motor nervous centres. This training consisted in the persevering exercise of the nervous matter forming the tactile sense-organs of the fingers, and thus in bringing the corresponding sensory-motor cerebral centres into a high state of physiological perfection. In the sensory-psychical centres impressions received from external objects were combined into ideas concerning their properties, and through the instrumentality of the higher psychical areas of the brain came into relation with the phenomenon of consciousness. By a process of this kind the dormant intellectual powers of the child were brought into play, and she gradually came to comprehend, that external things could be specified by definite symbols or movements made with her fingers; *i.e.*, that it was possible for her to express her thoughts in manual signs. When H. Bridgeman grasped this fact, Dr Howe states "her countenance beamed with human reason; she could no longer be compared to a parrot or a dog."

In the same way when, after careful training of her tactile sense organs, H. Keller learnt that the sensation produced by water on her hands could be expressed by the use of a definite manual sign, her mental faculties were brought into play, and she states that "each name I learnt gave birth to new thoughts." It was by the use of symbols or signs to express her ideas that she gained the power of reasoning and of thinking, and in this way to the development of her intellectual processes.

It is evident that H. Keller employed manual signs in the act of thinking, for Mr Churchill states that she "commonly accompanies her thoughts, when left alone, with incessant spelling with her fingers, making rapid manual signs for a great many words. She only uses the manual alphabet for *thinking* or for shaping sentences before she writes them, as all her communication of her own thoughts to the hearing world is now by speech; her power of cogitation is slow, because she thinks in manual signs."[1]

We are informed that L. Bridgeman when dreaming was in the habit of involuntarily moving her fingers in signs expressive of the incoherent ideas passing through her brain. This is a remarkable statement, and bears directly on the idea that signs or words usually employed to specify objects and acts, by frequent repetition, are impressed on the living matter of the sensory-psychical areas of the cerebrum (p. 209). Symbols of this kind are voluntarily employed by our conscious processes for the purpose of reasoning, of thought, etc.; the outcome of these processes becoming manifest in intelligent speech, or it may be by manual or other signs.

In dreams the impressions received through the

[1] Prof. Baldwin states that when he wishes "to speak in any language but English, the German words come first to his mind, but when he sits down to write in a foreign language, French invariably present themselves." He adds, "This means that my German is speech-motor and auditory, having been learnt conversationally in German, while French, which was acquired at school by reading and exercise-writing, is visual and hand-motor."—"Mental Development," second edition, p. 435.

various sense-organs still exist, while the living substance forming the large mass of the psychical cerebral areas is at work, excreting effete materials, and building up fresh matter, and thus a renewed store of potential energy. During sleep, when these changes are going on, our conscious processes are to a large extent inoperative, or, as in the case of L. Bridgeman in her dreams, are performing their natural functions in an incoherent manner.[1]

It seems clear in the cases of L. B. and H. K., that until they had been educated through means of tactile impressions, neither their wills nor any other mental power they possessed sufficed to bring the psychical areas of their brains into active operation. It was the exercise of their sense organs of touch, and the motion of their fingers which brought the inherent power of their psychical nervous centres into play. We therefore realise the fact, that the use of words or other symbols are all-important in developing the functions of those areas of the brain in which conscious processes are manifested, and these latter areas of the brain are absolutely necessary in order that our words should be endowed with intelligence.

H. Keller learnt by means of her sense of touch to imitate the movements of the lips, tongue, and throat of another person in the act of speaking, so that she came to employ similar movements and thus to give expression to her thoughts in articulate language. It was by impressions made on her tactile sense-organs that ideas were formed in corresponding sensory-psychical

[1] "Metabolism," by Adolph Magnus-Levy. "Metabolism and Medical Practice," by Carl von Noorden, edited in English by T. W. Hall, vol. i. p. 204.

centres of her cerebrum, and these ideas being brought into relation with conscious processes in the higher psychical centres, became manifest through the action of her "organ of speech," in the form of intelligent language. We can readily follow this line of nervous action, knowing as we do that the cerebral centres involved are in close connection with one another by means of their association fibres.

In previous chapters we have shown, that the movements of unicellular beings are effected by the response of the sensitive living matter of the external layers of their bodies to various stimuli. And in the simplest classes of multicellular animals the action of the environment on their sensitive ectodermal layer has led to the development of muscle and of nerve-cells. A differentiation of the sensitive living matter of the external layer of cells is thus effected, and structures formed capable of discharging the complicated movements of the animal's body which are necessary for obtaining its food and securing its reproduction.

We also explained that it was by the action of stimuli received through the specialised substance of the sense organs that, after nerve-cells had been produced, they became aggregated in the lowest forms of animals into cerebral ganglia, and in higher classes into a cerebrum containing differentiated nervous centres. In close connection with the sensory-motor centres of certain invertebrate animals we found that masses of living matter, having a peculiar structure, made their appearance. These nervous structures, in proportion to other parts of the brain, were of small extent in the sea-mouse, more extensive in the crayfish (Figs. 32, 33), and reached their maximum proportions in insects such as the bee.

As we stated, there is good reason for holding the opinion that these nervous structures are concerned in maturing the animal's intellectual processes; in fact their functions are analogous to those performed by the cortical living matter of the cerebral hemispheres in the higher classes of animals, which, as we have shown, have been developed under the action of forces similar to those which have brought about the evolution of the psychical areas of the brain in the lower animals.

We have referred to the fact, that the phenomena of consciousness are manifested by the higher classes of invertebrates, and endeavoured to show that in an ascending series of animals the elements constituting "consciousness-matter" have become differentiated and developed in response to stimuli received from the inflow of energy through the various sense-organs. But we have not attempted to discuss the content of consciousness which, Professor Villa states, consists of a series of processes which are not merely reproductions of external phenomena, but are the result of impressions perceived with the effort of will, called "attention" or "apperception," and therefore voluntary acts. It is beyond the scope of our work to discuss this question, but let us imagine that we are living in a quiet country home, and after a morning's work on some rather stiff subject, we go out in the afternoon and play a round of golf. After dinner and subsequently some light reading we retire to rest, and to sleep until the following morning, scarcely moving a limb or having even the suspicion of a dream during the night. The "consciousness-matter" of our brain and the muscles of the body it controls, during our hours of sleep, so far as its specialised functions are concerned, are at rest, but this matter still carries on its metabolic and other fundamental processes; in this way it stores up a supply of potential energy for future use.

At sunrise I awake; not a sound is to be heard in my room. I close my eyes, and in this way exclude all fresh auditory or visual impressions from passing to my brain. Experience has taught me that under these conditions I can best reason out the issues of an intricate question, and without any appreciable effort on my part, my thoughts revert to the subject which had occupied my attention during the previous morning. I recall ideas I had formed, and the opinions I had read on this subject, it may be years ago, and endeavour to reason out their bearing on the question I wish to solve. The train of thoughts I thus follow is my own, but so also is my brain, and, like my thumb-marks or my face, its molecular architecture differs from that of every other human being. Were it otherwise, we should probably all think exactly alike, a condition of things which might have its advantages, but would result in a dull world of men and women.

The process of reasoning I have carried on under the conditions above described, has been effected through means of the use I make of inarticulate silent language, the words I employ being symbols of my thoughts. I cannot reason without words, a fact demonstrated by cases such as those to which I have referred in the preceding pages of this chapter, and more especially in the case of the individual who, as a result of disease, had lost those sensory-motor areas of the brain (auditory centres) in which word sounds are received and registered. This individual was not only deaf, but also speechless, because she had no words at her command,

and for this same reason she soon became incapable of thinking or of reasoning, although her other sense organs continued to work. If, however, the auditory sensory-motor centres of the brain are in working order a person may lose the power of expressing his thoughts in articulate language through disease or injury of the nervous matter constituting Broca's "organ of speech," but he can still employ silent words and therefore think and reason, and in many cases express his mental processes by means of writing or by manual and facial signs.[1]

Supposing I have, wholly or in part, solved the question which has occupied my attention, my mind turns to some other subject upon which I have full power either to dwell, or refuse to consider; as a rule I select a subject for consideration which experience has taught me it is necessary for me to think out. Intellectual processes of this kind, however, are dependent on the efficient working of the living matter of definite areas of my brain, for if the action of this matter is suspended its power of choice and other mental faculties ceases.

For instance, if while my mind is actively at work I inhale a moderate dose of chloroform, some of its vapour passes into my blood and reaches my brain. It there acts chemically on the living matter of certain nerve-cells and interferes with their metabolic processes, and consequently with their supply of potential energy, and therefore power to perform their specific functions, so long as I remain under the influence of the anæsthetic. If the dose of chloroform has not been excessive the living matter of the brain centres which control the

[1] P. 196.

muscles of the vascular and respiratory organs continue to carry on their accustomed work. And as soon as the effects of the chloroform has passed from my body, my brain, as a whole, resumes its working power. Facts such as these, and the long string of evidence we have adduced in the preceding pages of this work, show that "mental and physical proceed together as undivided twins." Mental life, "like life itself, is the result of a peculiar organisation and combination of elements which constitute life."[1]

It seems to us, that if we rightly appreciate the bearing of the evidence given in this work, we can form definite conclusions regarding the cause of the mental phenomena to which we have above alluded ; and by methods such as those we have followed, we arrive at conclusions not far removed from those expressed by so able and judicious a scientist as Dr Ladd, who, at the conclusion of his work on "Physiological Psychology," states that all intercourse between material objects and consciousness or self involves three processes :—

"The *physical* process consists in the action of the appropriate modes of energy upon end-organs of sense. These modes of energy are brought to bear upon the nervous portion of these organs by means of mechanical contrivances, such, for example, as the contrivances for forming an image upon the retina of the eye, or for conveying the modified acoustic impulses to the inner ear."

"The second process consists in transmuting the physical energy into *physiological* processes, a nerve-commotion within the nervous system, and in propagating this nerve-commotion along the proper tracts

[1] P. 77.

and diffusing it over the various areas of the brain."

"The third process is *psychical.* It is a process which is a psychical event, a forthputting of the peculiar energy of the mind. It is directly correlated with the physiological process only when the latter has been realised in certain central areas. The psychical process cannot be explained wholly as a resultant of the cerebral physiological process. Yet it is an activity of the mind which is conditioned upon that process. When, for example, the particular mental process is the perception of some 'external' object, it is no less truly a psychical process."

Professor Ladd further remarks that the mind has a real existence (being) which can be acted upon by the brain, and which can act on the body through the brain, and that this is the only assumption which is compatible with all the facts of experience.[1]

Englishmen, as a rule, before applying their minds to the study of a subject are likely to inquire if it leads to any useful results. They justly pride themselves on being a race of practical men and women. We hold that information regarding the properties and potentialities of the living matter which forms our bodies must be useful, and is doubtless of absorbing interest to all educated persons. Beyond this, its study among other things enables us to arrive at something approaching to what may be considered sound ideas regarding the course which should be followed in the preliminary education of our children.

We have explained that the development and growth

[1] "Outlines of Physiological Psychology," by Professor G. T. Ladd. Fourth edition, pp. 476-77.

of the living matter of the brain in the lower animals and in human beings, depends on the stimuli it receives through the various sense-organs, our intellectual faculties being exercised by ideas derived from sensations proceeding mainly from the external world; in other words, we know and learn from what we feel, hear, taste, and smell.

It is, however, equally certain that the living matter of the brain, rightly to appreciate impressions made upon it, must be in good working order, which means that it must be capable of carrying on its fundamental processes effectively. And to this end not only must it consist of a sound basic material, but it must also, especially in its growing stages of existence, be nourished by a proper and a sufficient supply of food, and be placed in favourable hygienic conditions. These conditions include pure fresh air, sunlight, cleanliness, and physical exercise; without an environment of this description we may look in vain for a sound mind in a sound body.

We must also recognise the fact, that as the organs of sense are the portals through which the nervous system receives its impressions from the outer world, defects in these organs materially affect the nature of the impressions which the living matter of the cerebral hemispheres receive. Instances such as those we have described demonstrate this fact, and also the influence which such important sense organs as the eyes and ears, exercise on the development of the intellectual faculties.[1]

[1] Defects of sight are by no means rare, especially among children reared in the narrow dark streets of many of our large towns, a subject which was ably discussed by Mr Brudnell Carter some years

Fundamental principles such as those to which we have referred having, so far as circumstances will allow, been complied with, our efforts as regards the education of young children should be directed to developing, and training the living matter forming their various cerebral nervous centres, through means of the proper exercise of the corresponding sense organs.

Young children are, above all things, imitative beings; they gain not only their powers of articulate language by imbibing through their ears the sounds they hear, but their religious and moral characters are formed to a large extent, by what they constantly see, hear, and feel. There can be no question, as we have shown from a mass of evidence in the preceding pages, that the inherited qualities of the organic matter forming the bodies of living beings, together with the nature of

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ago, and has since attracted the attention of other authorities on this subject. These defects of vision for the most part depend on errors of refraction, or in those parts of the eye which bring rays of light to a focus on the retina. Errors of this kind when detected may be overcome by the use of proper lenses, unless thus neutralised they may lead to difficulty in defining small objects, such as printed letters, and thus prevent a child learning to read or to appreciate what he reads, as quickly as children who have no such defects of vision. Again, we know that the association fibres of the psychical areas of the brain attain to a state of perfection at varying periods in the lives of different children. If the myelinisation of these fibres is delayed, the intellectual processes of such a child will be slow in developing; it may be until he is 15 or 16 years of age or even later in life, but may then attain a high degree of perfection. After years of persistent agitation by the medical profession the Educational Department of the Government have come to the conclusion that the physical state of the children they undertake to educate is a matter of some consideration, and have recently appointed medical inspectors to report, and we may hope act, so as to bring about a more satisfactory state of affairs than those which have hitherto prevailed.

their environment, have a decided influence in moulding its structure and functions. These influences are equally potent in the higher orders of beings; habits acquired by the young—that is, during the time the living matter of their brains is freely open to receive, and retain impressions made on it through the sense organs—exercise a vast, and often an abiding influence on the future line of conduct which these beings follow throughout the remainder of their lives. This consideration leads us to appreciate the great influence for good or evil, which teachers in our elementary and other schools exercise over the rising generation of children, who one and all, among the lower orders of our countrymen, are compelled to spend the greater part of their day under the supervision of their respective masters and mistresses. It is therefore absolutely necessary, if the work of efficient education is to be carried on in our State-supported schools, that the masters and mistresses who preside over these schools should not only be properly trained teachers, but by their conduct and bearing towards the young beings committed to their care, set an example of a life influenced by religion, patriotism, and love of their neighbours—conduct, in fact, such as that which has regulated the lives of the best of their countrymen in this and many preceding generations. The bearing and action of those placed in charge of our elementary schools, in their manner and intercourse with those under their care is something very real and lasting, often exercising a decided influence on the after lives of these children.

So far as teaching is concerned, our system of primary education should be directed towards developing the inherent power of the living matter which forms the nervous substance of the cerebral hemispheres. This object can only be attained by means of a systematic training of the nervous centres through the regular exercise of their corresponding sense-organs. As Froebel insisted in his work on the education of children, it is not the training of memory, nor learning by rote, but through the example set by teachers, and a familiarity with the appearance of things, by means of actions, and with objects—in fact, it is through the medium of the various organs of sense, that we must train the intellectual faculties of young people, so as to bring a blessing upon the individual, and thereby a blessing upon the community to which he belongs.[1]

[1] Froebel's "Letters on Kindergarten," pp. 224, 254, 291. See also "Froebel and Education by Self-Activity," by H. Courthope Bowen, pp. 91, 98, 103, 129.

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