The Evolution of Man, V.1.

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THE EVOLUTION OF MAN

A POPULAR SCIENTIFIC STUDY

BY

ERNST HAECKEL

VOLUME 1.

HUMAN EMBRYOLOGY OR ONTOGENY.

TRANSLATED FROM THE FIFTH (ENLARGED) EDITION BY JOSEPH MCCABE.

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GLOSSARY.

ACRANIA: animals without skull (cranium).

ANTHROPOGENY: the evolution (genesis) of man (anthropos).

ANTHROPOLOGY: the science of man.

ARCHI-: (in compounds) the first or typical--as, archi-cytula, archi-gastrula, etc.

BIOGENY: the science of the genesis of life (bios).

BLAST-: (in compounds) pertaining to the early embryo (blastos = a bud); hence:--
Blastoderm: skin (derma) or enclosing layer of the embryo.
Blastosphere: the embryo in the hollow sphere stage.
Blastula: same as preceding.
Epiblast: the outer layer of the embryo (ectoderm).
Hypoblast: the inner layer of the embryo (endoderm).

BRANCHIAL: pertaining to the gills (branchia).

CARYO-: (in compounds) pertaining to the nucleus (caryon); hence:--
Caryokineses: the movement of the nucleus.
Caryolysis: dissolution of the nucleus.
Caryoplasm: the matter of the nucleus.

CENTROLECITHAL: see under LECITH-.

CHORDARIA and CHORDONIA: animals with a dorsal chord or back-bone.

COELOM or COELOMA: the body-cavity in the embryo; hence:--
Coelenterata: animals without a body-cavity.
Coelomaria: animals with a body-cavity.
Coelomation: formation of the body-cavity.

CYTO-: (in compounds) pertaining to the cell (cytos); hence:--
Cytoblast: the nucleus of the cell.

Cytodes: cell-like bodies, imperfect cells.
Cytoplasm: the matter of the body of the cell.
Cytosoma: the body (soma) of the cell.

CRYPTORCHISM: abnormal retention of the testicles in the body.

DEUTOPLASM: see PLASM.

DUALISM: the belief in the existence of two entirely distinct principles (such as matter and spirit).

DYSTELEOLOGY: the science of those features in organisms which refute the "design-argument."

ECTODERM: the outer (ekto) layer of the embryo.

ENTODERM: the inner (ento) layer of the embryo.

EPIDERM: the outer layer of the skin.

EPIGENESIS: the theory of gradual development of organs in the embryo.

EPIPHYSIS: the third or central eye in the early vertebrates.

EPISOMA: see SOMA.

EPITHELIA: tissues covering the surface of parts of the body (such as the mouth, etc.)

GONADS: the sexual glands.

GONOCHORISM: separation of the male and female sexes.

GONOTOMES: sections of the sexual glands.

GYNECOMAST: a male with the breasts (masta) of a woman (gyne).

HEPATIC: pertaining to the liver (hepar).

HOLOBLASTIC: embryos in which the animal and vegetal cells divide equally (holon = whole).

HYPERMASTISM: the possession of more than the normal breasts (masta).

HYPOBRANCHIAL: underneath (hypo) the gills.

HYPOPHYSIS: sensitive-offshoot from the brain in the vertebrate.

HYPOSOMA: see SOMA.

LECITH-: pertaining to the yelk (lecithus); hence:--
Centrolecithal: eggs with the yelk in the centre.
Lecithoma: the yelk-sac.
Telolecithal: eggs with the yelk at one end.

MEROBLASTIC: cleaving in part (meron) only.

META-: (in compounds) the "after" or secondary stage; hence:--
Metagaster: the secondary or permanent gut (gaster).

Metaplasm: secondary or differentiated plasm.
Metastoma: the secondary or permanent mouth (stoma).
Metazoa: the higher or later animals, made up of many cells.
Metovum: the mature or advanced ovum.

METAMERA: the segments into which the embryo breaks up.

METAMERISM: the segmentation of the embryo.

MONERA: the most primitive of the unicellular organisms.

MONISM: belief in the fundamental unity of all things.

MORPHOLOGY: the science of organic forms (generally equivalent to anatomy).

MYOTOMES: segments into which the muscles break up.

NEPHRA: the kidneys; hence:--
Nephridia: the rudimentary kidney-organs.
Nephrotomes: the segments of the developing kidneys.

ONTOGENY: the science of the development of the individual (generally equivalent to embryology).

PERIGENESIS: the genesis of the movements in the vital particles.

PHAGOCYTES: cells that absorb food (phagein = to eat).

PHYLOGENY: the science of the evolution of species (phyla).

PLANOCYTES: cells that move about (planein).

PLASM: the colloid or jelly-like matter of which organisms are composed; hence:--
Caryoplasm: the matter of the nucleus (caryon).
Cytoplasm: the matter of the body of the cell.
Deutoplasm: secondary or differentiated plasm.
Metaplasm: secondary or differentiated plasm.
Protoplasm: primitive or undifferentiated plasm.

PLASSON: the simplest form of plasm.

PLASTIDULES: small particles of plasm.

POLYSPERMISM: the penetration of more than one sperm-cell into the ovum.

PRO- or PROT: (in compounds) the earlier form (opposed to META); hence:--
Prochorion: the first form of the chorion.
Progaster: the first or primitive stomach.
Pronephridia: the earlier form of the kidneys.
Prorenal: the earlier form of the kidneys.
Prostoma: the first or primitive mouth.
Protists: the earliest or unicellular organisms.
Provertebrae: the earliest phase of the vertebrae.
Protophyta: the primitive or unicellular plants.
Protoplasm: undifferentiated plasm.
Protozoa: the primitive or unicellular animals.

RENAL: pertaining to the kidneys (renes).

SCATULATION: packing or boxing-up (scatula = a box).

SCLEROTOMES: segments into which the primitive skeleton falls.

SOMA: the body; hence:--
Cytosoma: the body of the cell (cytos).
Episoma: the upper or back-half of the embryonic body.
Somites: segments of the embryonic body.
Hyposoma: the under or belly-half of the embryonic body.

TELEOLOGY: the belief in design and purpose (telos) in nature.

TELOLECITHAL: see LECITH-.

UMBILICAL: pertaining to the navel (umbilicus).

VITELLINE: pertaining to the yelk (vitellus).

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PREFACE.

[BY JOSEPH MCCABE.]

The work which we now place within the reach of every reader of the English tongue is one of the finest productions of its distinguished author. The first edition appeared in 1874. At that time the conviction of man's natural evolution was even less advanced in Germany than in England, and the work raised a storm of controversy. Theologians--forgetting the commonest facts of our individual development--spoke with the most profound disdain of the theory that a Luther or a Goethe could be the outcome of development from a tiny speck of protoplasm. The work, one of the most distinguished of them said, was "a fleck of shame on the escutcheon of Germany." To-day its conclusion is accepted by influential clerics, such as the Dean of Westminster, and by almost every biologist and anthropologist of distinction in Europe. Evolution is not a laboriously reached conclusion, but a guiding truth, in biological literature to-day.

There was ample evidence to substantiate the conclusion even in the first edition of the book. But fresh facts have come to light in each decade, always enforcing the general truth of man's evolution, and at times making clearer the line of development. Professor Haeckel embodied these in successive editions of his work. In the fifth edition, of which this is a translation, reference will be found to the very latest facts bearing on the evolution of man, such as the discovery of the remarkable effect of mixing human blood with that of the anthropoid ape. Moreover, the ample series of illustrations has been considerably improved and enlarged; there is no scientific work published, at a price remotely approaching that of the present edition, with so abundant and excellent a supply of illustrations. When it was issued in Germany, a few years ago, a distinguished biologist wrote in the Frankfurter Zeitung that it would secure immortality for its author, the most notable critic of the idea of immortality. And the Daily Telegraph reviewer described the English

version as a "handsome edition of Haeckel's monumental work," and "an issue worthy of the subject and the author."

The influence of such a work, one of the most constructive that Haeckel has ever written, should extend to more than the few hundred readers who are able to purchase the expensive volumes of the original issue. Few pages in the story of science are more arresting and generally instructive than this great picture of "mankind in the making." The horizon of the mind is healthily expanded as we follow the search-light of science down the vast avenues of past time, and gaze on the uncouth forms that enter into, or illustrate, the line of our ancestry. And if the imagination recoils from the strange and remote figures that are lit up by our search-light, and hesitates to accept them as ancestral forms, science draws aside another veil and reveals another picture to us. It shows us that each of us passes, in our embryonic development, through a series of forms hardly less uncouth and unfamiliar. Nay, it traces a parallel between the two series of forms. It shows us man beginning his existence, in the ovary of the female infant, as a minute and simple speck of jelly-like plasm. It shows us (from analogy) the fertilised ovum breaking into a cluster of cohering cells, and folding and curving, until the limb-less, head-less, long-tailed foetus looks like a worm-shaped body. It then points out how gill-slits and corresponding blood-vessels appear, as in a lowly fish, and the fin-like extremities bud out and grow into limbs, and so on; until, after a very clear ape-stage, the definite human form emerges from the series of transformations.

It is with this embryological evidence for our evolution that the present volume is concerned. There are illustrations in the work that will make the point clear at a glance. Possibly TOO clear; for the simplicity of the idea and the eagerness to apply it at every point have carried many, who borrow hastily from Haeckel, out of their scientific depth. Haeckel has never shared their errors, nor encouraged their superficiality. He insists from the outset that a complete parallel could not possibly be expected. Embryonic life itself is subject to evolution. Though there is a general and substantial law--as most of our English and American authorities admit--that the embryonic series of forms recalls the ancestral series of forms, the parallel is blurred throughout and often distorted. It is not the obvious resemblance of the embryos of different animals, and their general similarity to our extinct ancestors in this or that organ, on which we must rest our case. A careful study must be made of the various stages through which all embryos pass, and an effort made to prove their real identity and therefore genealogical relation.

This is a task of great subtlety and delicacy. Many scientists have worked at it together with Professor Haeckel--I need only name our own Professor Balfour and Professor Ray Lankester--and the scheme is fairly complete. But the general reader must not expect that even so clear a writer as Haeckel can describe these intricate processes without demanding his very careful attention. Most of the chapters in the present volume (and the second volume will be less difficult) are easily intelligible to all; but there are points at which the line of argument is necessarily subtle and complex. In the hope that most readers will be induced to master even these more difficult chapters, I will give an outline of the characteristic argument of the work. Haeckel's distinctive services in regard to man's evolution have been:

1. The construction of a complete ancestral tree, though, of course, some of the stages in it are purely conjectural, and not final.

2. The tracing of the remarkable reproduction of ancestral forms in the embryonic development of the individual. Naturally, he has not worked alone in either department.

The second volume of this work will embody the first of these two achievements; the present one is mainly concerned with the latter. It will be useful for the reader to have a synopsis of the argument and an explanation of some of the chief terms invented or employed by the author.

The main theme of the work is that, in the course of their embryonic development, all animals, including man, pass roughly and rapidly through a series of forms which represents the succession of their ancestors in the past. After a severe and extensive study of embryonic phenomena, Haeckel has drawn up a "law" (in the ordinary scientific sense) to this effect, and has called it "the biogenetic law," or the chief law relating to the evolution (genesis) of life (bios). This law is widely and increasingly accepted by embryologists and zoologists. It is enough to quote a recent declaration of the great American zoologist, President D. Starr Jordan: "It is, of course, true that the life-history of the individual is an epitome of the life-history of the race"; while a distinguished German zoologist (Sarasin) has described it as being of the same use to the biologist as spectrum analysis is to the astronomer.

But the reproduction of ancestral forms in the course of the embryonic development is by no means always clear, or even always present. Many of the embryonic phases do not recall ancestral stages at all. They may have done so originally, but we must remember that the embryonic life itself has been subject to adaptive changes for millions of years. All this is clearly explained by Professor Haeckel. For the moment, I would impress on the reader the vital importance of fixing the distinction from the start. He must thoroughly familiarise himself with the meaning of five terms.

BIOGENY is the development of life in general (both in the individual and the species), or the sciences describing it.

ONTOGENY is the development (embryonic and post-embryonic) of the individual (on), or the science describing it.

PHYLOGENY is the development of the race or stem (phulon), or the science describing it.

Roughly, ontogeny may be taken to mean embryology, and phylogeny what we generally call evolution.

Further, the embryonic phenomena sometimes reproduce ancestral forms, and they are then called PALINGENETIC (from palin = again): sometimes they do not recall ancestral forms, but are later modifications due to adaptation, and they are then called CENOGENETIC (from kenos = new or foreign).

These terms are now widely used, but the reader of Haeckel must understand them thoroughly.

The first five chapters are an easy account of the history of embryology and evolution. The sixth and seventh give an equally clear account of the sexual elements and the process of conception. But some of the succeeding chapters must deal with embryonic processes so unfamiliar, and pursue them through so wide a range of animals in a brief space, that, in spite of the 200 illustrations, they will offer difficulty to many a reader. As our aim is to secure, not a superficial acquiescence in conclusions, but a fair comprehension of the truths of science, we have retained these chapters. However, I will give a brief and clear outline of the argument, so that the reader with little leisure may realise their value.

When the animal ovum (egg-cell) has been fertilised, it divides and subdivides until we have a cluster of cohering cells, externally not unlike a raspberry or mulberry. This is the morula (= mulberry) stage. The cluster becomes hollow, or filled with fluid in the centre, all the cells rising to the surface. This is the blastula (hollow ball) stage. One half of the cluster then bends or folds in upon the other, as one might do with a thin indiarubber ball, and we get a vase-shaped body with hollow interior (the first stomach, or "primitive gut"), an open mouth (the first or "primitive mouth"), and a wall composed of two layers of cells (two "germinal layers"). This is the gastrula (stomach) stage, and the process of its formation is called gastrulation. A glance at the illustration (Figure 1.29) will make this perfectly clear.

So much for the embryonic process in itself. The application to evolution has been a long and laborious task. Briefly, it was necessary to show that ALL the multicellular animals passed through these three stages, so that our biogenetic law would enable us to recognise them as reminiscences of ancestral forms. This is the work of Chapters 1.8 and 1.9. The difficulty can be realised in this way: As we reach the higher animals the ovum has to take up a large quantity of yelk, on which it may feed in developing. Think of the bird's "egg." The effect of this was to flatten the germ (the morula and blastula) from the first, and so give, at first sight, a totally different complexion to what it has in the lowest animals. When we pass the reptile and bird stage, the large yelk almost disappears (the germ now being supplied with blood by the mother), but the germ has been permanently altered in shape, and there are now a number of new embryonic processes (membranes, blood-vessel connections, etc.). Thus it was no light task to trace the identity of this process of gastrulation in all the animals. It has been done, however; and with this introduction the reader will be able to follow the proof. The conclusion is important. If all animals pass through the curious gastrula stage, it must be because they all had a common ancestor of that nature. To this conjectural ancestor (it lived before the period of fossilisation begins) Haeckel gives the name of the Gastraea, and in the second volume we shall see a number of living animals of this type ("gastraeads").

The line of argument is the same in the next chapter. After laborious and careful research (though this stage is not generally admitted in the same sense as the previous one), a fourth common stage was discovered, and given the name of the Coelomula. The blastula had one layer of cells, the blastoderm (derma = skin): the gastrula two layers, the ectoderm ("outer skin") and entoderm ("inner skin"). Now a third layer (mesoderm = middle skin) is formed, by the growth inwards of two pouches or folds of the skin. The pouches blend together, and

form a single cavity (the body cavity, or coelom), and its two walls are two fresh "germinal layers." Again, the identity of the process has to be proved in all the higher classes of animals, and when this is done we have another ancestral stage, the Coelomaea.

The remaining task is to build up the complex frame of the higher animals--always showing the identity of the process (on which the evolutionary argument depends) in enormously different conditions of embryonic life--out of the four "germinal layers." Chapter 1.9 prepares us for the work by giving us a very clear account of the essential structure of the back-boned (vertebrate) animal, and the probable common ancestor of all the vertebrates (a small fish of the lancelet type). Chapters 1.11 to 1.14 then carry out the construction step by step. The work is now simpler, in the sense that we leave all the invertebrate animals out of account; but there are so many organs to be fashioned out of the four simple layers that the reader must proceed carefully. In the second volume each of these organs will be dealt with separately, and the parallel will be worked out between its embryonic and its phylogenetic (evolutionary) development. The general reader may wait for this for a full understanding. But in the meantime the wonderful story of the construction of all our organs in the course of a few weeks (the human frame is perfectly formed, though less than two inches in length, by the twelfth week) from so simple a material is full of interest. It would be useless to attempt to summarise the process. The four chapters are themselves but a summary of it, and the eighty fine illustrations of the process will make it sufficiently clear. The last chapter carries the story on to the point where man at last parts company with the anthropoid ape, and gives a full account of the membranes or wrappers that enfold him in the womb, and the connection with the mother.

In conclusion, I would urge the reader to consult, at his free library perhaps, the complete edition of this work, when he has read the present abbreviated edition. Much of the text has had to be condensed in order to bring out the work at our popular price, and the beautiful plates of the complete edition have had to be omitted. The reader will find it an immense assistance if he can consult the library edition.

JOSEPH MCCABE.

Cricklewood, March, 1906.

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HAECKEL'S CLASSIFICATION OF THE ANIMAL WORLD.

UNICELLULAR ANIMALS (PROTOZOA).

1. Unnucleated.

Bacteria.
Protamoebae.

Monera.

2. Nucleated.

2A. Rhizopoda.

Amoebina.
Radiolaria.

2B. Infusoria.

Flagellata.
Ciliata.

3. Cell-Colonies.

Catallacta.
Blastaeada.

MULTICELLULAR ANIMALS (METAZOA).

1. COELENTERIA, COELENTERATA, OR ZOOPHYTES.
Animals without body-cavity, blood or anus.

1A. Gastraeads.

Gastremaria.
Cyemaria.

1B. Sponges.

Protospongiae.
Metaspongiae.

1C. Cnidaria (Stinging Animals).

Hydrozoa.
Polyps.
Medusae.

1D. Platodes (Flat-Worms).

Platodaria.
Turbellaria.
Trematoda.
Cestoda.

2. COELOMARIA OR BILATERALS.
Animals with body-cavity and anus, and generally blood.

2A. Vermalia (Worm-Like).

Rotatoria.
Strongylaria.
Prosopygia.
Frontonia.

2B. Molluscs.

Cochlides.
Conchades.
Teuthodes.

2C. Articulates.

Annelida.
Crustacea.
Tracheata.

2D. Echinoderms.

Monorchonia.
Pentorchonia.

2E. Tunicates.

Copelata.
Ascidiae.
Thalidiae.

2F. Vertebrates.

2F.1. Acrania-Lancelet (Without Skull).

2F.2. Craniota (With Skull).

2F.2A. Cyclostomes. ("Round-Mouthed").

2F.2B. Fishes.

Selachii.
Ganoids.
Teleosts.
Dipneusts.

2F.2C. Amphibia.

2F.2D. Reptiles.

2F.2E. Birds.

2F.2F. Mammal.

Monotremes.

Marsupials.

Placentals:--
Rodents.
Edentates.
Ungulates.
Cetacea.
Sirenia.
Insectivora.
Cheiroptera.
Carnassia.
Primates.

(This classification is given for the purpose of explaining Haeckel's use of terms in this volume. The general reader should bear in mind that it differs very considerably from more recent schemes of classification. He should compare the scheme framed by Professor E. Ray Lankester.)

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THE EVOLUTION OF MAN.

CHAPTER 1.1. THE FUNDAMENTAL LAW OF ORGANIC EVOLUTION.

The field of natural phenomena into which I would introduce my readers in the following chapters has a quite peculiar place in the broad realm of scientific inquiry. There is no object of investigation that touches man more closely, and the knowledge of which should be more acceptable to him, than his own frame. But among all the various branches of the natural history of mankind, or anthropology, the story of his development by natural means must excite the most lively interest. It gives us the key of the great world-riddles at which the human mind has been working for thousands of years. The problem of the nature of man, or the question of man's place in nature, and the cognate inquiries as to the past, the earliest history, the present situation, and the future of humanity--all these most important questions are directly and intimately connected with that branch of study which we call the science of the evolution of man, or, in one word, "Anthropogeny" (the genesis of man). Yet it is an astonishing fact that the science of the evolution of man does not even yet form part of the scheme of general education. In fact, educated people even in our day are for the most part quite ignorant of the important truths and remarkable phenomena which anthropogeny teaches us.

As an illustration of this curious state of things, it may be pointed out that most of what are considered to be "educated" people do not know that every human being is developed from an egg, or ovum, and that this egg is one simple cell, like any other plant or animal egg. They are equally ignorant that in the course of the development of this tiny, round egg-cell there is first formed a body that is totally different from the human frame, and has not the remotest resemblance to it. Most of them have never seen such a human embryo in the earlier period of its development, and do not know that it is quite indistinguishable from other animal embryos. At first the embryo is no more than a round cluster of cells, then it becomes a simple hollow sphere, the wall of which is composed of a layer of cells. Later it approaches very closely, at one period, to the anatomic structure of the lancelet, afterwards to that of a fish, and again to the typical build of the amphibia and mammals. As it continues to develop, a form appears which is like those we find at the lowest stage of mammal-life (such as the duck-bills), then a form that resembles the marsupials, and only at a late stage a form that has a resemblance to the ape; until at last the definite human form emerges and closes the series of transformations. These suggestive facts are, as I said, still almost unknown to the general public--so completely unknown that, if one casually mentions them, they are called in question or denied outright as fairy-tales. Everybody knows that the butterfly emerges from the pupa, and the pupa from a quite different thing called a larva, and the larva from the butterfly's egg. But few besides medical men are aware that MAN, in the course of his individual formation, passes through a series of transformations which are not less surprising and wonderful than the familiar metamorphoses of the butterfly.

The mere description of these remarkable changes through which man

passes during his embryonic life should arouse considerable interest. But the mind will experience a far keener satisfaction when we trace these curious facts to their causes, and when we learn to behold in them natural phenomena which are of the highest importance throughout the whole field of human knowledge. They throw light first of all on the "natural history of creation," then on psychology, or "the science of the soul," and through this on the whole of philosophy. And as the general results of every branch of inquiry are summed up in philosophy, all the sciences come in turn to be touched and influenced more or less by the study of the evolution of man.

But when I say that I propose to present here the most important features of these phenomena and trace them to their causes, I take the term, and I interpret my task, in a very much wider sense than is usual. The lectures which have been delivered on this subject in the universities during the last half-century are almost exclusively adapted to medical men. Certainly, the medical man has the greatest interest in studying the origin of the human body, with which he is daily occupied. But I must not give here this special description of the embryonic processes such as it has hitherto been given, as most of my readers have not studied anatomy, and are not likely to be entrusted with the care of the adult organism. I must content myself with giving some parts of the subject only in general outline, and must not enter upon all the marvellous, but very intricate and not easily described, details that are found in the story of the development of the human frame. To understand these fully a knowledge of anatomy is needed. I will endeavour to be as plain as possible in dealing with this branch of science. Indeed, a sufficient general idea of the course of the embryonic development of man can be obtained without going too closely into the anatomic details. I trust we may be able to arouse the same interest in this delicate field of inquiry as has been excited already in other branches of science; though we shall meet more obstacles here than elsewhere.

The story of the evolution of man, as it has hitherto been expounded to medical students, has usually been confined to embryology--more correctly, ontogeny--or the science of the development of the individual human organism. But this is really only the first part of our task, the first half of the story of the evolution of man in that wider sense in which we understand it here. We must add as the second half--as another and not less important and interesting branch of the science of the evolution of the human stem--phylogeny: this may be described as the science of the evolution of the various animal forms from which the human organism has been developed in the course of countless ages. Everybody now knows of the great scientific activity that was occasioned by the publication of Darwin's Origin of Species in 1859. The chief direct consequence of this publication was to provoke a fresh inquiry into the origin of the human race, and this has proved beyond question our gradual evolution from the lower species. We give the name of "Phylogeny" to the science which describes this ascent of man from the lower ranks of the animal world. The chief source that it draws upon for facts is "Ontogeny," or embryology, the science of the development of the individual organism. Moreover, it derives a good deal of support from paleontology, or the science of fossil remains, and even more from comparative anatomy, or morphology.

These two branches of our science--on the one side ontogeny or embryology, and on the other phylogeny, or the science of

race-evolution--are most vitally connected. The one cannot be understood without the other. It is only when the two branches fully co-operate and supplement each other that "Biogeny" (or the science of the genesis of life in the widest sense) attains to the rank of a philosophic science. The connection between them is not external and superficial, but profound, intrinsic, and causal. This is a discovery made by recent research, and it is most clearly and correctly expressed in the comprehensive law which I have called "the fundamental law of organic evolution," or "the fundamental law of biogeny." This general law, to which we shall find ourselves constantly recurring, and on the recognition of which depends one's whole insight into the story of evolution, may be briefly expressed in the phrase: "The history of the foetus is a recapitulation of the history of the race"; or, in other words, "Ontogeny is a recapitulation of phylogeny." It may be more fully stated as follows: The series of forms through which the individual organism passes during its development from the ovum to the complete bodily structure is a brief, condensed repetition of the long series of forms which the animal ancestors of the said organism, or the ancestral forms of the species, have passed through from the earliest period of organic life down to the present day.

The causal character of the relation which connects embryology with stem-history is due to the action of heredity and adaptation. When we have rightly understood these, and recognised their great importance in the formation of organisms, we can go a step further and say: Phylogenesis is the mechanical cause of ontogenesis.* (* The term "genesis," which occurs throughout, means, of course, "birth" or origin. From this we get: Biogeny = the origin of life (bios); Anthropogeny = the origin of man (anthropos); Ontogeny = the origin of the individual (on); Phylogeny = the origin of the species (phulon); and so on. In each case the term may refer to the process itself, or to the science describing the process.--Translator.) In other words, the development of the stem, or race, is, in accordance with the laws of heredity and adaptation, the cause of all the changes which appear in a condensed form in the evolution of the foetus.

The chain of manifold animal forms which represent the ancestry of each higher organism, or even of man, according to the theory of descent, always form a connected whole. We may designate this uninterrupted series of forms with the letters of the alphabet: A, B, C, D, E, etc., to Z. In apparent contradiction to what I have said, the story of the development of the individual, or the ontogeny of most organisms, only offers to the observer a part of these forms; so that the defective series of embryonic forms would run: A, B, D, F, H, K, M, etc.; or, in other cases, B, D, H, L, M, N, etc. Here, then, as a rule, several of the evolutionary forms of the original series have fallen out. Moreover, we often find--to continue with our illustration from the alphabet--one or other of the original letters of the ancestral series represented by corresponding letters from a different alphabet. Thus, instead of the Roman B and D, we often have the Greek Beta and Delta. In this case the text of the biogenetic law has been corrupted, just as it had been abbreviated in the preceding case. But, in spite of all this, the series of ancestral forms remains the same, and we are in a position to discover its original complexion.

In reality, there is always a certain parallel between the two evolutionary series. But it is obscured from the fact that in the embryonic succession much is wanting that certainly existed in the

earlier ancestral succession. If the parallel of the two series were complete, and if this great fundamental law affirming the causal connection between ontogeny and phylogeny in the proper sense of the word were directly demonstrable, we should only have to determine, by means of the microscope and the dissecting knife, the series of forms through which the fertilised ovum passes in its development; we should then have before us a complete picture of the remarkable series of forms which our animal ancestors have successively assumed from the dawn of organic life down to the appearance of man. But such a repetition of the ancestral history by the individual in its embryonic life is very rarely complete. We do not often find our full alphabet. In most cases the correspondence is very imperfect, being greatly distorted and falsified by causes which we will consider later. We are thus, for the most part, unable to determine in detail, from the study of its embryology, all the different shapes which an organism's ancestors have assumed; we usually--and especially in the case of the human foetus--encounter many gaps. It is true that we can fill up most of these gaps satisfactorily with the help of comparative anatomy, but we cannot do so from direct embryological observation. Hence it is important that we find a large number of lower animal forms to be still represented in the course of man's embryonic development. In these cases we may draw our conclusions with the utmost security as to the nature of the ancestral form from the features of the form which the embryo momentarily assumes.

To give a few examples, we can infer from the fact that the human ovum is a simple cell that the first ancestor of our species was a tiny unicellular being, something like the amoeba. In the same way, we know, from the fact that the human foetus consists, at the first, of two simple cell-layers (the gastrula), that the gastraea, a form with two such layers, was certainly in the line of our ancestry. A later human embryonic form (the chordula) points just as clearly to a worm-like ancestor (the prochordonia), the nearest living relation of which is found among the actual ascidiae. To this succeeds a most important embryonic stage (acrania), in which our headless foetus presents, in the main, the structure of the lancelet. But we can only indirectly and approximately, with the aid of comparative anatomy and ontogeny, conjecture what lower forms enter into the chain of our ancestry between the gastraea and the chordula, and between this and the lancelet. In the course of the historical development many intermediate structures have gradually fallen out, which must certainly have been represented in our ancestry. But, in spite of these many, and sometimes very appreciable, gaps, there is no contradiction between the two successions. In fact, it is the chief purpose of this work to prove the real harmony and the original parallelism of the two. I hope to show, on a substantial basis of facts, that we can draw most important conclusions as to our genealogical tree from the actual and easily-demonstrable series of embryonic changes. We shall then be in a position to form a general idea of the wealth of animal forms which have figured in the direct line of our ancestry in the lengthy history of organic life.

In this evolutionary appreciation of the facts of embryology we must, of course, take particular care to distinguish sharply and clearly between the primitive, palingenetic (or ancestral) evolutionary processes and those due to cenogenesis.* (* Palingenesis = new birth, or re-incarnation (palin = again, genesis or genea = development); hence its application to the phenomena which are recapitulated by heredity from earlier ancestral forms. Cenogenesis = foreign or

negligible development (kenos and genea); hence, those phenomena which come later in the story of life to disturb the inherited structure, by a fresh adaptation to environment.--Translator.) By palingenetic processes, or embryonic recapitulations, we understand all those phenomena in the development of the individual which are transmitted from one generation to another by heredity, and which, on that account, allow us to draw direct inferences as to corresponding structures in the development of the species. On the other hand, we give the name of cenogenetic processes, or embryonic variations, to all those phenomena in the foetal development that cannot be traced to inheritance from earlier species, but are due to the adaptation of the foetus, or the infant-form, to certain conditions of its embryonic development. These cenogenetic phenomena are foreign or later additions; they allow us to draw no direct inference whatever as to corresponding processes in our ancestral history, but rather hinder us from doing so.

This careful discrimination between the primary or palingenetic processes and the secondary or cenogenetic is of great importance for the purposes of the scientific history of a species, which has to draw conclusions from the available facts of embryology, comparative anatomy, and paleontology, as to the processes in the formation of the species in the remote past. It is of the same importance to the student of evolution as the careful distinction between genuine and spurious texts in the works of an ancient writer, or the purging of the real text from interpolations and alterations, is for the student of philology. It is true that this distinction has not yet been fully appreciated by many scientists. For my part, I regard it as the first condition for forming any just idea of the evolutionary process, and I believe that we must, in accordance with it, divide embryology into two sections--palingenesis, or the science of recapitulated forms; and cenogenesis, or the science of supervening structures.

To give at once a few examples from the science of man's origin in illustration of this important distinction, I may instance the following processes in the embryology of man, and of all the higher vertebrates, as palingenetic: the formation of the two primary germinal layers and of the primitive gut, the undivided structure of the dorsal nerve-tube, the appearance of a simple axial rod between the medullary tube and the gut, the temporary formation of the gill-clefts and arches, the primitive kidneys, and so on.* (* All these, and the following structures, will be fully described in later chapters.--Translator.) All these, and many other important structures, have clearly been transmitted by a steady heredity from the early ancestors of the mammal, and are, therefore, direct indications of the presence of similar structures in the history of the stem. On the other hand, this is certainly not the case with the following embryonic forms, which we must describe as cenogenetic processes: the formation of the yelk-sac, the allantois, the placenta, the amnion, the serolemma, and the chorion--or, generally speaking, the various foetal membranes and the corresponding changes in the blood vessels. Further instances are: the dual structure of the heart cavity, the temporary division of the plates of the primitive vertebrae and lateral plates, the secondary closing of the ventral and intestinal walls, the formation of the navel, and so on. All these and many other phenomena are certainly not traceable to similar structures in any earlier and completely-developed ancestral form, but have arisen simply by adaptation to the peculiar conditions of embryonic life (within the foetal membranes). In view of these facts, we may now

give the following more precise expression to our chief law of biogeny: The evolution of the foetus (or ontogenesis) is a condensed and abbreviated recapitulation of the evolution of the stem (or phylogenesis); and this recapitulation is the more complete in proportion as the original development (or palingenesis) is preserved by a constant heredity; on the other hand, it becomes less complete in proportion as a varying adaptation to new conditions increases the disturbing factors in the development (or cenogenesis).

The cenogenetic alterations or distortions of the original palingenetic course of development take the form, as a rule, of a gradual displacement of the phenomena, which is slowly effected by adaptation to the changed conditions of embryonic existence during the course of thousands of years. This displacement may take place as regards either the position or the time of a phenomenon.

The great importance and strict regularity of the time-variations in embryology have been carefully studied recently by Ernest Mehnert, in his Biomechanik (Jena, 1898). He contends that our biogenetic law has not been impaired by the attacks of its opponents, and goes on to say: "Scarcely any piece of knowledge has contributed so much to the advance of embryology as this; its formulation is one of the most signal services to general biology. It was not until this law passed into the flesh and blood of investigators, and they had accustomed themselves to see a reminiscence of ancestral history in embryonic structures, that we witnessed the great progress which embryological research has made in the last two decades." The best proof of the correctness of this opinion is that now the most fruitful work is done in all branches of embryology with the aid of this biogenetic law, and that it enables students to attain every year thousands of brilliant results that they would never have reached without it.

It is only when one appreciates the cenogenetic processes in relation to the palingenetic, and when one takes careful account of the changes which the latter may suffer from the former, that the radical importance of the biogenetic law is recognised, and it is felt to be the most illuminating principle in the science of evolution. In this task of discrimination it is the silver thread in relation to which we can arrange all the phenomena of this realm of marvels--the "Ariadne thread," which alone enables us to find our way through this labyrinth of forms. Hence the brothers Sarasin, the zoologists, could say with perfect justice, in their study of the evolution of the Ichthyophis, that "the great biogenetic law is just as important for the zoologist in tracing long-extinct processes as spectrum analyses is for the astronomer."

Even at an earlier period, when a correct acquaintance with the evolution of the human and animal frame was only just being obtained--and that is scarcely eighty years ago!--the greatest astonishment was felt at the remarkable similarity observed between the embryonic forms, or stages of foetal development, in very different animals; attention was called even then to their close resemblance to certain fully-developed animal forms belonging to some of the lower groups. The older scientists (Oken, Treviranus, and others) knew perfectly well that these lower forms in a sense illustrated and fixed, in the hierarchy of the animal world, a temporary stage in the evolution of higher forms. The famous anatomist Meckel spoke in 1821 of a "similarity between the development of the embryo and the series of animals." Baer raised the question in 1828

how far, within the vertebrate type, the embryonic forms of the higher animals assume the permanent shapes of members of lower groups. But it was impossible fully to understand and appreciate this remarkable resemblance at that time. We owe our capacity to do this to the theory of descent; it is this that puts in their true light the action of heredity on the one hand and adaptation on the other. It explains to us the vital importance of their constant reciprocal action in the production of organic forms. Darwin was the first to teach us the great part that was played in this by the ceaseless struggle for existence between living things, and to show how, under the influence of this (by natural selection), new species were produced and maintained solely by the interaction of heredity and adaptation. It was thus Darwinism that first opened our eyes to a true comprehension of the supremely important relations between the two parts of the science of organic evolution--Ontogeny and Phylogeny.

Heredity and adaptation are, in fact, the two constructive physiological functions of living things; unless we understand these properly we can make no headway in the study of evolution. Hence, until the time of Darwin no one had a clear idea of the real nature and causes of embryonic development. It was impossible to explain the curious series of forms through which the human embryo passed; it was quite unintelligible why this strange succession of animal-like forms appeared in the series at all. It had previously been generally assumed that the man was found complete in all his parts in the ovum, and that the development consisted only in an unfolding of the various parts, a simple process of growth. This is by no means the case. On the contrary, the whole process of the development of the individual presents to the observer a connected succession of different animal-forms; and these forms display a great variety of external and internal structure. But WHY each individual human being should pass through this series of forms in the course of his embryonic development it was quite impossible to say until Lamarck and Darwin established the theory of descent. Through this theory we have at last detected the real causes, the efficient causes, of the individual development; we have learned that these mechanical causes suffice of themselves to effect the formation of the organism, and that there is no need of the final causes which were formerly assumed. It is true that in the academic philosophies of our time these final causes still figure very prominently; in the new philosophy of nature we can entirely replace them by efficient causes. We shall see, in the course of our inquiry, how the most wonderful and hitherto insoluble enigmas in the human and animal frame have proved amenable to a mechanical explanation, by causes acting without prevision, through Darwin's reform of the science of evolution. We have everywhere been able to substitute unconscious causes, acting from necessity, for conscious, purposive causes.* (* The monistic or mechanical philosophy of nature holds that only unconscious, necessary, efficient causes are at work in the whole field of nature, in organic life as well as in inorganic changes. On the other hand, the dualist or vitalist philosophy of nature affirms that unconscious forces are only at work in the inorganic world, and that we find conscious, purposive, or final causes in organic nature.)

If the new science of evolution had done no more than this, every thoughtful man would have to admit that it had accomplished an immense advance in knowledge. It means that in the whole of philosophy that tendency which we call monistic, in opposition to the dualistic, which has hitherto prevailed, must be accepted.* (* Monism is neither purely

materialistic nor purely spiritualistic, but a reconciliation of these two principles, since it regards the whole of nature as one, and sees only efficient causes at work in it. Dualism, on the contrary, holds that nature and spirit, matter and force, the world and God, inorganic and organic nature, are separate and independent existences. Cf. The Riddle of the Universe chapter 12.) At this point the science of human evolution has a direct and profound bearing on the foundations of philosophy. Modern anthropology has, by its astounding discoveries during the second half of the nineteenth century, compelled us to take a completely monistic view of life. Our bodily structure and its life, our embryonic development and our evolution as a species, teach us that the same laws of nature rule in the life of man as in the rest of the universe. For this reason, if for no others, it is desirable, nay, indispensable, that every man who wishes to form a serious and philosophic view of life, and, above all, the expert philosopher, should acquaint himself with the chief facts of this branch of science.

The facts of embryology have so great and obvious a significance in this connection that even in recent years dualist and teleological philosophers have tried to rid themselves of them by simply denying them. This was done, for instance, as regards the fact that man is developed from an egg, and that this egg or ovum is a simple cell, as in the case of other animals. When I had explained this pregnant fact and its significance in my History of Creation, it was described in many of the theological journals as a dishonest invention of my own. The fact that the embryos of man and the dog are, at a certain stage of their development, almost indistinguishable was also denied. When we examine the human embryo in the third or fourth week of its development, we find it to be quite different in shape and structure from the full-grown human being, but almost identical with that of the ape, the dog, the rabbit, and other mammals, at the same stage of ontogeny. We find a bean-shaped body of very simple construction, with a tail below and a pair of fins at the sides, something like those of a fish, but very different from the limbs of man and the mammals. Nearly the whole front half of the body is taken up by a shapeless head without face, at the sides of which we find gill-clefts and arches as in the fish. At this stage of its development the human embryo does not differ in any essential detail from that of the ape, dog, horse, ox, etc., at a corresponding period. This important fact can easily be verified at any moment by a comparison of the embryos of man, the dog, rabbit, etc. Nevertheless, the theologians and dualist philosophers pronounced it to be a materialistic invention; even scientists, to whom the facts should be known, have sought to deny them.

There could not be a clearer proof of the profound importance of these embryological facts in favour of the monistic philosophy than is afforded by these efforts of its opponents to get rid of them by silence or denial. The truth is that these facts are most inconvenient for them, and are quite irreconcilable with their views. We must be all the more pressing on our side to put them in their proper light. I fully agree with Huxley when he says, in his "Man's Place in Nature": "Though these facts are ignored by several well-known popular leaders, they are easy to prove, and are accepted by all scientific men; on the other hand, their importance is so great that those who have once mastered them will, in my opinion, find few other biological discoveries to astonish them."

We shall make it our chief task to study the evolution of man's bodily frame and its various organs in their external form and internal structures. But I may observe at once that this is accompanied step by step with a study of the evolution of their functions. These two branches of inquiry are inseparably united in the whole of anthropology, just as in zoology (of which the former is only a section) or general biology. Everywhere the peculiar form of the organism and its structures, internal and external, is directly related to the special physiological functions which the organism or organ has to execute. This intimate connection of structure and function, or of the instrument and the work done by it, is seen in the science of evolution and all its parts. Hence the story of the evolution of structures, which is our immediate concern, is also the history of the development of functions; and this holds good of the human organism as of any other.

At the same time, I must admit that our knowledge of the evolution of functions is very far from being as complete as our acquaintance with the evolution of structures. One might say, in fact, that the whole science of evolution has almost confined itself to the study of structures; the evolution of FUNCTIONS hardly exists even in name. That is the fault of the physiologists, who have as yet concerned themselves very little about evolution. It is only in recent times that physiologists like W. Engelmann, W. Preyer, M. Verworn, and a few others, have attacked the evolution of functions.

It will be the task of some future physiologist to engage in the study of the evolution of functions with the same zeal and success as has been done for the evolution of structures in morphogeny (the science of the genesis of forms). Let me illustrate the close connection of the two by a couple of examples. The heart in the human embryo has at first a very simple construction, such as we find in permanent form among the ascidiae and other low organisms; with this is associated a very simple system of circulation of the blood. Now, when we find that with the full-grown heart there comes a totally different and much more intricate circulation, our inquiry into the development of the heart becomes at once, not only an anatomical, but also a physiological, study. Thus it is clear that the ontogeny of the heart can only be understood in the light of its phylogeny (or development in the past), both as regards function and structure. The same holds true of all the other organs and their functions. For instance, the science of the evolution of the alimentary canal, the lungs, or the sexual organs, gives us at the same time, through the exact comparative investigation of structure-development, most important information with regard to the evolution of the functions of these organs.

This significant connection is very clearly seen in the evolution of the nervous system. This system is in the economy of the human body the medium of sensation, will, and even thought, the highest of the psychic functions; in a word, of all the various functions which constitute the proper object of psychology. Modern anatomy and physiology have proved that these psychic functions are immediately dependent on the fine structure and the composition of the central nervous system, or the internal texture of the brain and spinal cord. In these we find the elaborate cell-machinery, of which the psychic or soul-life is the physiological function. It is so intricate that most men still look upon the mind as something supernatural that cannot be explained on mechanical principles.

But embryological research into the gradual appearance and the formation of this important system of organs yields the most astounding and significant results. The first sketch of a central nervous system in the human embryo presents the same very simple type as in the other vertebrates. A spinal tube is formed in the external skin of the back, and from this first comes a simple spinal cord without brain, such as we find to be the permanent psychic organ in the lowest type of vertebrate, the amphioxus. Not until a later stage is a brain formed at the anterior end of this cord, and then it is a brain of the most rudimentary kind, such as we find permanently among the lower fishes. This simple brain develops step by step, successively assuming forms which correspond to those of the amphibia, the reptiles, the duck-bills, and the lemurs. Only in the last stage does it reach the highly organised form which distinguishes the apes from the other vertebrates, and which attains its full development in man.

Comparative physiology discovers a precisely similar growth. The function of the brain, the psychic activity, rises step by step with the advancing development of its structure.

Thus we are enabled, by this story of the evolution of the nervous system, to understand at length THE NATURAL DEVELOPMENT OF THE HUMAN MIND and its gradual unfolding. It is only with the aid of embryology that we can grasp how these highest and most striking faculties of the animal organism have been historically evolved. In other words, a knowledge of the evolution of the spinal cord and brain in the human embryo leads us directly to a comprehension of the historic development (or phylogeny) of the human mind, that highest of all faculties, which we regard as something so marvellous and supernatural in the adult man. This is certainly one of the greatest and most pregnant results of evolutionary science. Happily our embryological knowledge of man's central nervous system is now so adequate, and agrees so thoroughly with the complementary results of comparative anatomy and physiology, that we are thus enabled to obtain a clear insight into one of the highest problems of philosophy, the phylogeny of the soul, or the ancestral history of the mind of man. Our chief support in this comes from the embryological study of it, or the ontogeny of the soul. This important section of psychology owes its origin especially to W. Preyer, in his interesting works, such as The Mind of the Child. The Biography of a Baby (1900), of Milicent Washburn Shinn, also deserves mention. [See also Preyer's Mental Development in the Child (translation), and Sully's Studies of Childhood and Children's Ways.]

In this way we follow the only path along which we may hope to reach the solution of this difficult problem.

Thirty-six years have now elapsed since, in my General Morphology, I established phylogeny as an independent science and showed its intimate causal connection with ontogeny; thirty years have passed since I gave in my gastraea-theory the proof of the justice of this, and completed it with the theory of germinal layers. When we look back on this period we may ask, What has been accomplished during it by the fundamental law of biogeny? If we are impartial, we must reply that it has proved its fertility in hundreds of sound results, and that by its aid we have acquired a vast fund of knowledge which we should never have obtained without it.

There has been no dearth of attacks--often violent attacks--on my conception of an intimate causal connection between ontogenesis and phylogenesis; but no other satisfactory explanation of these important phenomena has yet been offered to us. I say this especially with regard to Wilhelm His's theory of a "mechanical evolution," which questions the truth of phylogeny generally, and would explain the complicated embryonic processes without going beyond by simple physical changes--such as the bending and folding of leaves by electricity, the origin of cavities through unequal strain of the tissues, the formation of processes by uneven growth, and so on. But the fact is that these embryological phenomena themselves demand explanation in turn, and this can only be found, as a rule, in the corresponding changes in the long ancestral series, or in the physiological functions of heredity and adaptation.

CHAPTER 1.2. THE OLDER EMBRYOLOGY.

It is in many ways useful, on entering upon the study of any science, to cast a glance at its historical development. The saying that "everything is best understood in its growth" has a distinct application to science. While we follow its gradual development we get a clearer insight into its aims and objects. Moreover, we shall see that the present condition of the science of human evolution, with all its characteristics, can only be rightly understood when we examine its historical growth. This task will, however, not detain us long. The study of man's evolution is one of the latest branches of natural science, whether you consider the embryological or the phylogenetic section of it.

Apart from the few germs of our science which we find in classical antiquity, and which we shall notice presently, we may say that it takes its definite rise, as a science, in the year 1759, when one of the greatest German scientists, Caspar Friedrich Wolff, published his Theoria generationis. That was the foundation-stone of the science of animal embryology. It was not until fifty years later, in 1809, that Jean Lamarck published his Philosophie Zoologique--the first effort to provide a base for the theory of evolution; and it was another half-century before Darwin's work appeared (in 1859), which we may regard as the first scientific attainment of this aim. But before we go further into this solid establishment of evolution, we must cast a brief glance at that famous philosopher and scientist of antiquity, who stood alone in this, as in many other branches of science, for more than 2000 years: the "father of Natural History," Aristotle.

The extant scientific works of Aristotle deal with many different sides of biological research; the most comprehensive of them is his famous History of Animals. But not less interesting is the smaller work, On the Generation of Animals (Peri zoon geneseos). This work treats especially of embryonic development, and it is of great interest as being the earliest of its kind and the only one that has come down to us in any completeness from classical antiquity.

Aristotle studied embryological questions in various classes of animals, and among the lower groups he learned many most remarkable facts which we only rediscovered between 1830 and 1860. It is certain, for instance, that he was acquainted with the very peculiar mode of propagation of the cuttlefishes, or cephalopods, in which a yelk-sac

hangs out of the mouth of the foetus. He knew, also, that embryos come from the eggs of the bee even when they have not been fertilised. This "parthenogenesis" (or virgin-birth) of the bees has only been established in our time by the distinguished zoologist of Munich, Siebold. He discovered that male bees come from the unfertilised, and female bees only from the fertilised, eggs. Aristotle further states that some kinds of fishes (of the genus serranus) are hermaphrodites, each individual having both male and female organs and being able to fertilise itself; this, also, has been recently confirmed. He knew that the embryo of many fishes of the shark family is attached to the mother's body by a sort of placenta, or nutritive organ very rich in blood; apart from these, such an arrangement is only found among the higher mammals and man. This placenta of the shark was looked upon as legendary for a long time, until Johannes Muller proved it to be a fact in 1839. Thus a number of remarkable discoveries were found in Aristotle's embryological work, proving a very good acquaintance of the great scientist--possibly helped by his predecessors--with the facts of ontogeny, and a great advance upon succeeding generations in this respect.

In the case of most of these discoveries he did not merely describe the fact, but added a number of observations on its significance. Some of these theoretical remarks are of particular interest, because they show a correct appreciation of the nature of the embryonic processes. He conceives the development of the individual as a new formation, in the course of which the various parts of the body take shape successively. When the human or animal frame is developed in the mother's body, or separately in an egg, the heart--which he regards as the starting-point and centre of the organism--must appear first. Once the heart is formed the other organs arise, the internal ones before the external, the upper (those above the diaphragm) before the lower (or those beneath the diaphragm). The brain is formed at an early stage, and the eyes grow out of it. These observations are quite correct. And, if we try to form some idea from these data of Aristotle's general conception of the embryonic process, we find a dim prevision of the theory which Wolff showed 2000 years afterwards to be the correct view. It is significant, for instance, that Aristotle denied the eternity of the individual in any respect. He said that the species or genus, the group of similar individuals, might be eternal, but the individual itself is temporary. It comes into being in the act of procreation, and passes away at death.

During the 2000 years after Aristotle no progress whatever was made in general zoology, or in embryology in particular. People were content to read, copy, translate, and comment on Aristotle. Scarcely a single independent effort at research was made in the whole of the period. During the Middle Ages the spread of strong religious beliefs put formidable obstacles in the way of independent scientific investigation. There was no question of resuming the advance of biology. Even when human anatomy began to stir itself once more in the sixteenth century, and independent research was resumed into the structure of the developed body, anatomists did not dare to extend their inquiries to the unformed body, the embryo, and its development. There were many reasons for the prevailing horror of such studies. It is natural enough, when we remember that a Bull of Boniface VIII excommunicated every man who ventured to dissect a human corpse. If the dissection of a developed body were a crime to be thus punished, how much more dreadful must it have seemed to deal with the embryonic body still enclosed in the womb, which the Creator himself had

decently veiled from the curiosity of the scientist! The Christian Church, then putting many thousands to death for unbelief, had a shrewd presentiment of the menace that science contained against its authority. It was powerful enough to see that its rival did not grow too quickly.

It was not until the Reformation broke the power of the Church, and a refreshing breath of the spirit dissolved the icy chains that bound science, that anatomy and embryology, and all the other branches of research, could begin to advance once more. However, embryology lagged far behind anatomy. The first works on embryology appear at the beginning of the sixteenth century. The Italian anatomist, Fabricius ab Aquapendente, a professor at Padua, opened the advance. In his two books (De formato foetu, 1600, and De formatione foetus, 1604) he published the older illustrations and descriptions of the embryos of man and other mammals, and of the hen. Similar imperfect illustrations were given by Spigelius (De formato foetu, 1631), and by Needham (1667) and his more famous compatriot, Harvey (1652), who discovered the circulation of the blood in the animal body and formulated the important principle, Omne vivum ex vivo (all life comes from pre-existing life). The Dutch scientist, Swammerdam, published in his Bible of Nature the earliest observations on the embryology of the frog and the division of its egg-yelk. But the most important embryological studies in the sixteenth century were those of the famous Italian, Marcello Malpighi, of Bologna, who led the way both in zoology and botany. His treatises, De formatione pulli and De ovo incubato (1687), contain the first consistent description of the development of the chick in the fertilised egg.

Here I ought to say a word about the important part played by the chick in the growth of our science. The development of the chick, like that of the young of all other birds, agrees in all its main features with that of the other chief vertebrates, and even of man. The three highest classes of vertebrates--mammals, birds, and reptiles (lizards, serpents, tortoises, etc.)--have from the beginning of their embryonic development so striking a resemblance in all the chief points of structure, and especially in their first forms, that for a long time it is impossible to distinguish between them. We have known now for some time that we need only examine the embryo of a bird, which is the easiest to get at, in order to learn the typical mode of development of a mammal (and therefore of man). As soon as scientists began to study the human embryo, or the mammal-embryo generally, in its earlier stages about the middle and end of the seventeenth century, this important fact was very quickly discovered. It is both theoretically and practically of great value. As regards the THEORY of evolution, we can draw the most weighty inferences from this similarity between the embryos of widely different classes of animals. But for the practical purposes of embryological research the discovery is invaluable, because we can fill up the gaps in our imperfect knowledge of the embryology of the mammals from the more thoroughly studied embryology of the bird. Hens' eggs are easily to be had in any quantity, and the development of the chick may be followed step by step in artificial incubation. The development of the mammal is much more difficult to follow, because here the embryo is not detached and enclosed in a large egg, but the tiny ovum remains in the womb until the growth is completed. Hence, it is very difficult to keep up sustained observation of the various stages in any great extent, quite apart from such extrinsic considerations as the cost, the technical difficulties, and many other obstacles which we encounter when we

would make an extensive study of the fertilised mammal. The chicken has, therefore, always been the chief object of study in this connection. The excellent incubators we now have enable us to observe it in any quantity and at any stage of development, and so follow the whole course of its formation step by step.

By the end of the seventeenth century Malpighi had advanced as far as it was possible to do with the imperfect microscope of his time in the embryological study of the chick. Further progress was arrested until the instrument and the technical methods should be improved. The vertebrate embryos are so small and delicate in their earlier stages that you cannot go very far into the study of them without a good microscope and other technical aid. But this substantial improvement of the microscope and the other apparatus did not take place until the beginning of the nineteenth century.

Embryology made scarcely any advance in the first half of the eighteenth century, when the systematic natural history of plants and animals received so great an impulse through the publication of Linne's famous Systema Naturae. Not until 1759 did the genius arise who was to give it an entirely new character, Caspar Friedrich Wolff. Until then embryology had been occupied almost exclusively in unfortunate and misleading efforts to build up theories on the imperfect empirical material then available.

The theory which then prevailed, and remained in favour throughout nearly the whole of the eighteenth century, was commonly called at that time "the evolution theory"; it is better to describe it as "the preformation theory."* (* This theory is usually known as the "evolution theory" in Germany, in contradistinction to the "epigenesis theory." But as it is the latter that is called the "evolution theory" in England, France, and Italy, and "evolution" and "epigenesis" are taken to be synonymous, it seems better to call the first the "pre-formation theory.") Its chief point is this: There is no new formation of structures in the embryonic development of any organism, animal or plant, or even of man; there is only a growth, or unfolding, of parts which have been constructed or pre-formed from all eternity, though on a very small scale and closely packed together. Hence, every living germ contains all the organs and parts of the body, in the form and arrangement they will present later, already within it, and thus the whole embryological process is merely an evolution in the literal sense of the word, or an unfolding, of parts that were pre-formed and folded up in it. So, for instance, we find in the hen's egg not merely a simple cell, that divides and subdivides and forms germinal layers, and at last, after all kinds of variation and cleavage and reconstruction, brings forth the body of the chick; but there is in every egg from the first a complete chicken, with all its parts made and neatly packed. These parts are so small or so transparent that the microscope cannot detect them. In the hatching, these parts merely grow larger, and spread out in the normal way.

When this theory is consistently developed it becomes a "scatulation theory."* (* "Packing theory" would be the literal translation. Scatula is the Latin for a case or box.--Translator.) According to its teaching, there was made in the beginning one couple or one individual of each species of animal or plant; but this one individual contained the germs of all the other individuals of the same species who should ever come to life. As the age of the earth was generally believed at that time to be fixed by the Bible at 5000 or 6000 years, it seemed

possible to calculate how many individuals of each species had lived in the period, and so had been packed inside the first being that was created. The theory was consistently extended to man, and it was affirmed that our common parent Eve had had stored in her ovary the germs of all the children of men.

The theory at first took the form of a belief that it was the FEMALES who were thus encased in the first being. One couple of each species was created, but the female contained in her ovary all the future individuals of the species, of either sex. However, this had to be altered when the Dutch microscopist, Leeuwenhoek, discovered the male spermatozoa in 1690, and showed that an immense number of these extremely fine and mobile thread-like beings exist in the male sperm (this will be explained in Chapter 2.7). This astonishing discovery was further advanced when it was proved that these living bodies, swimming about in the seminal fluid, were real animalcules, and, in fact, were the pre-formed germs of the future generation. When the male and female procreative elements came together at conception, these thread-like spermatozoa ("seed-animals") were supposed to penetrate into the fertile body of the ovum and begin to develop there, as the plant seed does in the fruitful earth. Hence, every spermatozoon was regarded as a homunculus, a tiny complete man; all the parts were believed to be pre-formed in it, and merely grew larger when it reached its proper medium in the female ovum. This theory, also, was consistently developed in the sense that in each of these thread-like bodies the whole of its posterity was supposed to be present in the minutest form. Adam's sexual glands were thought to have contained the germs of the whole of humanity.

This "theory of male scatulation" found itself at once in keen opposition to the prevailing "female" theory. The two rival theories at once opened a very lively campaign, and the physiologists of the eighteenth century were divided into two great camps--the Animalculists and the Ovulists--which fought vigorously. The animalculists held that the spermatozoa were the true germs, and appealed to the lively movements and the structure of these bodies. The opposing party of the Ovulists, who clung to the older "evolution theory," affirmed that the ovum is the real germ, and that the spermatozoa merely stimulate it at conception to begin its growth; all the future generations are stored in the ovum. This view was held by the great majority of the biologists of the eighteenth century, in spite of the fact that Wolff proved it in 1759 to be without foundation. It owed its prestige chiefly to the circumstance that the most weighty authorities in the biology and philosophy of the day decided in favour of it, especially Haller, Bonnet, and Leibnitz.

Albrecht Haller, professor at Gottingen, who is often called the father of physiology, was a man of wide and varied learning, but he does not occupy a very high position in regard to insight into natural phenomena. He made a vigorous defence of the "evolutionary theory" in his famous work, Elementa physiologiae, affirming: "There is no such thing as formation (nulla est epigenesis). No part of the animal frame is made before another; all were made together." He thus denied that there was any evolution in the proper sense of the word, and even went so far as to say that the beard existed in the new-born child and the antlers in the hornless fawn; all the parts were there in advance, and were merely hidden from the eye of man for the time being. Haller even calculated the number of human beings that God must have created on the sixth day and stored away in Eve's ovary. He put the number at

200,000 millions, assuming the age of the world to be 6000 years, the average age of a human being to be thirty years, and the population of the world at that time to be 1000 millions. And the famous Haller maintained all this nonsense, in spite of its ridiculous consequences, even after Wolff had discovered the real course of embryonic development and established it by direct observation!

Among the philosophers of the time the distinguished Leibnitz was the chief defender of the "preformation theory," and by his authority and literary prestige won many adherents to it. Supported by his system of monads, according to which body and soul are united in inseparable association and by their union form the individual, or the "monad," Leibnitz consistently extended the "scatulation theory" to the soul, and held that this was no more evolved than the body. He says, for instance, in his Theodicee: "I mean that these souls, which one day are to be the souls of men, are present in the seed, like those of other species; in such wise that they existed in our ancestors as far back as Adam, or from the beginning of the world, in the forms of organised bodies."

The theory seemed to receive considerable support from the observations of one of its most zealous supporters, Bonnet. In 1745 he discovered, in the plant-louse, a case of parthenogenesis, or virgin-birth, an interesting form of reproduction that has lately been found by Siebold and others among various classes of the articulata, especially crustacea and insects. Among these and other animals of certain lower species the female may reproduce for several generations without having been fertilised by the male. These ova that do not need fertilisation are called "false ova," pseudova or spores. Bonnet saw that a female plant-louse, which he had kept in cloistral isolation, and rigidly removed from contact with males, had on the eleventh day (after forming a new skin for the fourth time) a living daughter, and during the next twenty days ninety-four other daughters; and that all of them went on to reproduce in the same way without any contact with males. It seemed as if this furnished an irrefutable proof of the truth of the scatulation theory, as it was held by the Ovulists; it is not surprising to find that the theory then secured general acceptance.

This was the condition of things when suddenly, in 1759, Caspar Friedrich Wolff appeared, and dealt a fatal blow at the whole preformation theory with his new theory of epigenesis. Wolff, the son of a Berlin tailor, was born in 1733, and went through his scientific and medical studies, first at Berlin under the famous anatomist Meckel, and afterwards at Halle. Here he secured his doctorate in his twenty-sixth year, and in his academic dissertation (November 28th, 1759), the Theoria generationis, expounded the new theory of a real development on a basis of epigenesis. This treatise is, in spite of its smallness and its obscure phraseology, one of the most valuable in the whole range of biological literature. It is equally distinguished for the mass of new and careful observations it contains, and the far-reaching and pregnant ideas which the author everywhere extracts from his observations and builds into a luminous and accurate theory of generation. Nevertheless, it met with no success at the time. Although scientific studies were then assiduously cultivated owing to the impulse given by Linne--although botanists and zoologists were no longer counted by dozens, but by hundreds, hardly any notice was taken of Wolff's theory. Even when he established the truth of epigenesis by the most rigorous observations, and demolished the airy structure of

the preformation theory, the "exact" scientist Haller proved one of the most strenuous supporters of the old theory, and rejected Wolff's correct view with a dictatorial "There is no such thing as evolution." He even went on to say that religion was menaced by the new theory! It is not surprising that the whole of the physiologists of the second half of the eighteenth century submitted to the ruling of this physiological pontiff, and attacked the theory of epigenesis as a dangerous innovation. It was not until more than fifty years afterwards that Wolff's work was appreciated. Only when Meckel translated into German in 1812 another valuable work of Wolff's on The Formation of the Alimentary Canal (written in 1768), and called attention to its great importance, did people begin to think of him once more; yet this obscure writer had evinced a profounder insight into the nature of the living organism than any other scientist of the eighteenth century.

Wolff's idea led to an appreciable advance over the whole field of biology. There is such a vast number of new and important observations and pregnant thoughts in his writings that we have only gradually learned to appreciate them rightly in the course of the nineteenth century. He opened up the true path for research in many directions. In the first place, his theory of epigenesis gave us our first real insight into the nature of embryonic development. He showed convincingly that the development of every organism consists of a series of NEW FORMATIONS, and that there is no trace whatever of the complete form either in the ovum or the spermatozoon. On the contrary, these are quite simple bodies, with a very different purport. The embryo which is developed from them is also quite different, in its internal arrangement and outer configuration, from the complete organism. There is no trace whatever of preformation or in-folding of organs. To-day we can scarcely call epigenesis a THEORY, because we are convinced it is a fact, and can demonstrate it at any moment with the aid of the microscope.

Wolff furnished the conclusive empirical proof of his theory in his classic dissertation on The Formation of the Alimentary Canal (1768). In its complete state the alimentary canal of the hen is a long and complex tube, with which the lungs, liver, salivary glands, and many other small glands, are connected. Wolff showed that in the early stages of the embryonic chick there is no trace whatever of this complicated tube with all its dependencies, but instead of it only a flat, leaf-shaped body; that, in fact, the whole embryo has at first the appearance of a flat, oval-shaped leaf. When we remember how difficult the exact observation of so fine and delicate a structure as the early leaf-shaped body of the chick must have been with the poor microscopes then in use, we must admire the rare faculty for observation which enabled Wolff to make the most important discoveries in this most difficult part of embryology. By this laborious research he reached the correct opinion that the embryonic body of all the higher animals, such as the birds, is for some time merely a flat, thin, leaf-shaped disk--consisting at first of one layer, but afterwards of several. The lowest of these layers is the alimentary canal, and Wolff followed its development from its commencement to its completion. He showed how this leaf-shaped structure first turns into a groove, then the margins of this groove fold together and form a closed canal, and at length the two external openings of the tube (the mouth and anus) appear.

Moreover, the important fact that the other systems of organs are

developed in the same way, from tubes formed out of simple layers, did not escape Wolff. The nerveless system, muscular system, and vascular (blood-vessel) system, with all the organs appertaining thereto, are, like the alimentary system, developed out of simple leaf-shaped structures. Hence, Wolff came to the view by 1768 which Pander developed in the Theory of Germinal Layers fifty years afterwards. His principles are not literally correct; but he comes as near to the truth in them as was possible at that time, and could be expected of him.

Our admiration of this gifted genius increases when we find that he was also the precursor of Goethe in regard to the metamorphosis of plants and of the famous cellular theory. Wolff had, as Huxley showed, a clear presentiment of this cardinal theory, since he recognised small microscopic globules as the elementary parts out of which the germinal layers arose.

Finally, I must invite special attention to the MECHANICAL character of the profound philosophic reflections which Wolff always added to his remarkable observations. He was a great monistic philosopher, in the best meaning of the word. It is unfortunate that his philosophic discoveries were ignored as completely as his observations for more than half a century. We must be all the more careful to emphasise the fact of their clear monistic tendency.

CHAPTER 1.3. MODERN EMBRYOLOGY.

We may distinguish three chief periods in the growth of our science of human embryology. The first has been considered in the preceding chapter; it embraces the whole of the preparatory period of research, and extends from Aristotle to Caspar Friedrich Wolff, or to the year 1759, in which the epoch-making Theoria generationis was published. The second period, with which we have now to deal, lasts about a century--that is to say, until the appearance of Darwin's Origin of Species, which brought about a change in the very foundations of biology, and, in particular, of embryology. The third period begins with Darwin. When we say that the second period lasted a full century, we must remember that Wolff's work had remained almost unnoticed during half the time--namely, until the year 1812. During the whole of these fifty-three years not a single book that appeared followed up the path that Wolff had opened, or extended his theory of embryonic development. We merely find his views--perfectly correct views, based on extensive observations of fact--mentioned here and there as erroneous; their opponents, who adhered to the dominant theory of preformation, did not even deign to reply to them. This unjust treatment was chiefly due to the extraordinary authority of Albrecht von Haller; it is one of the most astonishing instances of a great authority, as such, preventing for a long time the recognition of established facts.

The general ignorance of Wolff's work was so great that at the beginning of the nineteenth century two scientists of Jena, Oken (1806) and Kieser (1810), began independent research into the development of the alimentary canal of the chick, and hit upon the right clue to the embryonic puzzle, without knowing a word about Wolff's important treatise on the same subject. They were treading in his very footsteps without suspecting it. This can be easily proved from the fact that they did not travel as far as Wolff. It was not

until Meckel translated into German Wolff's book on the alimentary system, and pointed out its great importance, that the eyes of anatomists and physiologists were suddenly opened. At once a number of biologists instituted fresh embryological inquiries, and began to confirm Wolff's theory of epigenesis.

This resuscitation of embryology and development of the epigenesis-theory was chiefly connected with the university of Wurtzburg. One of the professors there at that time was Dollinger, an eminent biologist, and father of the famous Catholic historian who later distinguished himself by his opposition to the new dogma of papal infallibility. Dollinger was both a profound thinker and an accurate observer. He took the keenest interest in embryology, and worked at it a good deal. However, he is not himself responsible for any important result in this field. In 1816 a young medical doctor, whom we may at once designate as Wolff's chief successor, Karl Ernst von Baer, came to Wurtzburg. Baer's conversations with Dollinger on embryology led to a fresh series of most extensive investigations. Dollinger had expressed a wish that some young scientist should begin again under his guidance an independent inquiry into the development of the chick during the hatching of the egg. As neither he nor Baer had money enough to pay for an incubator and the proper control of the experiments, and for a competent artist to illustrate the various stages observed, the lead of the enterprise was given to Christian Pander, a wealthy friend of Baer's who had been induced by Baer to come to Wurtzburg. An able engraver, Dalton, was engaged to do the copper-plates. In a short time the embryology of the chick, in which Baer was taking the greatest indirect interest, was so far advanced that Pander was able to sketch the main features of it on the ground of Wolff's theory in the dissertation he published in 1817. He clearly enunciated the theory of germinal layers which Wolff had anticipated, and established the truth of Wolff's idea of a development of the complicated systems of organs out of simple leaf-shaped primitive structures. According to Pander, the leaf-shaped object in the hen's egg divides, before the incubation has proceeded twelve hours, into two different layers, an external serous layer and an internal mucous layer; between the two there develops later a third layer, the vascular (blood-vessel) layer.* (* The technical terms which are bound to creep into this chapter will be fully understood later on.--Translator.)

Karl Ernst von Baer, who had set afoot Pander's investigation, and had shown the liveliest interest in it after Pander's departure from Wurtzburg, began his own much more comprehensive research in 1819. He published the mature result nine years afterwards in his famous work, Animal Embryology: Observation and Reflection (not translated). This classic work still remains a model of careful observation united to profound philosophic speculation. The first part appeared in 1828, the second in 1837. The book proved to be the foundation on which the whole science of embryology has built down to our own day. It so far surpassed its predecessors, and Pander in particular, that it has become, after Wolff's work, the chief base of modern embryology.

Baer was one of the greatest scientists of the nineteenth century, and exercised considerable influence on other branches of biology as well. He built up the theory of germinal layers, as a whole and in detail, so clearly and solidly that it has been the starting-point of embryological research ever since. He taught that in all the vertebrates first two and then four of these germinal layers are

formed; and that the earliest rudimentary organs of the body arise by the conversion of these layers into tubes. He described the first appearance of the vertebrate embryo, as it may be seen in the globular yelk of the fertilised egg, as an oval disk which first divides into two layers. From the upper or animal layer are developed all the organs which accomplish the phenomena of animal life--the functions of sensation and motion, and the covering of the body. From the lower or vegetative layer come the organs which effect the vegetative life of the organism--nutrition, digestion, blood-formation, respiration, secretion, reproduction, etc.

Each of these original layers divides, according to Baer, into two thinner and superimposed layers or plates. He calls the two plates of the animal layer, the skin-stratum and muscle-stratum. From the upper of these plates, the skin-stratum, the external skin, or outer covering of the body, the central nervous system, and the sense-organs, are formed. From the lower, or muscle-stratum, the muscles, or fleshy parts and the bony skeleton--in a word, the motor organs--are evolved. In the same way, Baer said, the lower or vegetative layer splits into two plates, which he calls the vascular-stratum and the mucous-stratum. From the outer of the two (the vascular) the heart, blood-vessels, spleen, and the other vascular glands, the kidneys, and sexual glands, are formed. From the fourth or mucous layer, in fine, we get the internal and digestive lining of the alimentary canal and all its dependencies, the liver, lungs, salivary glands, etc. Baer had, in the main, correctly judged the significance of these four secondary embryonic layers, and he followed the conversion of them into the tube-shaped primitive organs with great perspicacity. He first solved the difficult problem of the transformation of this four-fold, flat, leaf-shaped, embryonic disk into the complete vertebrate body, through the conversion of the layers or plates into tubes. The flat leaves bend themselves in obedience to certain laws of growth; the borders of the curling plates approach nearer and nearer; until at last they come into actual contact. Thus out of the flat gut-plate is formed a hollow gut-tube, out of the flat spinal plate a hollow nerve-tube, from the skin-plate a skin-tube, and so on.

Among the many great services which Baer rendered to embryology, especially vertebrate embryology, we must not forget his discovery of the human ovum. Earlier scientists had, as a rule, of course, assumed that man developed out of an egg, like the other animals. In fact, the preformation theory held that the germs of the whole of humanity were stored already in Eve's ova. But the real ovum escaped detection until the year 1827. This ovum is extremely small, being a tiny round vesicle about the 1/120 of an inch in diameter; it can be seen under very favourable circumstances with the naked eye as a tiny particle, but is otherwise quite invisible. This particle is formed in the ovary inside a much larger globule, which takes the name of the Graafian follicle, from its discoverer, Graaf, and had previously been regarded as the true ovum. However, in 1827 Baer proved that it was not the real ovum, which is much smaller, and is contained within the follicle. (Compare the end of Chapter 2.29.)

Baer was also the first to observe what is known as the segmentation sphere of the vertebrate; that is to say, the round vesicle which first develops out of the impregnated ovum, and the thin wall of which is made up of a single layer of regular, polygonal (many-cornered) cells (see the illustration in Chapter 1.12). Another discovery of his

that was of great importance in constructing the vertebrate stem and the characteristic organisation of this extensive group (to which man belongs) was the detection of the axial rod, or the chorda dorsalis. There is a long, round, cylindrical rod of cartilage which runs down the longer axis of the vertebrate embryo; it appears at an early stage, and is the first sketch of the spinal column, the solid skeletal axis of the vertebrate. In the lowest of the vertebrates, the amphioxus, the internal skeleton consists only of this cord throughout life. But even in the case of man and all the higher vertebrates it is round this cord that the spinal column and the brain are afterwards formed.

However, important as these and many other discoveries of Baer's were in vertebrate embryology, his researches were even more influential, from the circumstance that he was the first to employ the comparative method in studying the development of the animal frame. Baer occupied himself chiefly with the embryology of vertebrates (especially the birds and fishes). But he by no means confined his attention to these, gradually taking the various groups of the invertebrates into his sphere of study. As the general result of his comparative embryological research, Baer distinguished four different modes of development and four corresponding groups in the animal world. These chief groups or types are: 1, the vertebrata; 2, the articulata; 3, the mollusca; and 4, all the lower groups which were then wrongly comprehended under the general name of the radiata. Georges Cuvier had been the first to formulate this distinction, in 1812. He showed that these groups present specific differences in their whole internal structure, and the connection and disposal of their systems of organs; and that, on the other hand, all the animals of the same type--say, the vertebrates--essentially agreed in their inner structure, in spite of the greatest superficial differences. But Baer proved that these four groups are also quite differently developed from the ovum; and that the series of embryonic forms is the same throughout for animals of the same type, but different in the case of other animals. Up to that time the chief aim in the classification of the animal kingdom was to arrange all the animals from lowest to highest, from the infusorium to man, in one long and continuous series. The erroneous idea prevailed nearly everywhere that there was one uninterrupted chain of evolution from the lowest animal to the highest. Cuvier and Baer proved that this view was false, and that we must distinguish four totally different types of animals, on the ground of anatomic structure and embryonic development.

Baer's epoch-making works aroused an extraordinary and widespread interest in embryological research. Immediately afterwards we find a great number of observers at work in the newly opened field, enlarging it in a very short time with great energy by their various discoveries in detail. Next to Baer's comes the admirable work of Heinrich Rathke, of Konigsberg (died 1860); he made an extensive study of the embryology, not only of the invertebrates (crustaceans, insects, molluscs), but also, and particularly, of the vertebrates (fishes, tortoises, serpents, crocodiles, etc.). We owe the first comprehensive studies of mammal embryology to the careful research of Wilhelm Bischoff, of Munich; his embryology of the rabbit (1840), the dog (1842), the guinea-pig (1852), and the doe (1854), still form classical studies. About the same time a great impetus was given to the embryology of the invertebrates. The way was opened through this obscure province by the studies of the famous Berlin zoologist, Johannes Muller, on the echinoderms. He was followed by Albert

Kolliker, of Wurtzburg, writing on the cuttlefish (or the cephalopods), Siebold and Huxley on worms and zoophytes, Fritz Muller (Desterro) on the crustacea, Weismann on insects, and so on. The number of workers in this field has greatly increased of late, and a quantity of new and astonishing discoveries have been made. One notices, in several of these recent works on embryology, that their authors are too little acquainted with comparative anatomy and classification. Palaeontology is, unfortunately, altogether neglected by many of these new workers, although this interesting science furnishes most important facts for phylogeny, and thus often proves of very great service in ontogeny.

A very important advance was made in our science in 1839, when the cellular theory was established, and a new field of inquiry bearing on embryology was suddenly opened. When the famous botanist, M. Schleiden, of Jena, showed in 1838, with the aid of the microscope, that every plant was made up of innumerable elementary parts, which we call cells, a pupil of Johannes Muller at Berlin, Theodor Schwann, applied the discovery at once to the animal organism. He showed that in the animal body as well, when we examine its tissues in the microscope, we find these cells everywhere to be the elementary units. All the different tissues of the organism, especially the very dissimilar tissues of the nerves, muscles, bones, external skin, mucous lining, etc., are originally formed out of cells; and this is also true of all the tissues of the plant. These cells are separate living beings; they are the citizens of the State which the entire multicellular organism seems to be. This important discovery was bound to be of service to embryology, as it raised a number of new questions. What is the relation of the cells to the germinal layers? Are the germinal layers composed of cells, and what is their relation to the cells of the tissues that form later? How does the ovum stand in the cellular theory? Is the ovum itself a cell, or is it composed of cells? These important questions were now imposed on the embryologist by the cellular theory.

The most notable effort to answer these questions--which were attacked on all sides by different students--is contained in the famous work, Inquiries into the Development of the Vertebrates (not translated) of Robert Remak, of Berlin (1851). This gifted scientist succeeded in mastering, by a complete reform of the science, the great difficulties which the cellular theory had at first put in the way of embryology. A Berlin anatomist, Carl Boguslaus Reichert, had already attempted to explain the origin of the tissues. But this attempt was bound to miscarry, since its not very clear-headed author lacked a sound acquaintance with embryology and the cell theory, and even with the structure and development of the tissue in particular. Remak at length brought order into the dreadful confusion that Reichert had caused; he gave a perfectly simple explanation of the origin of the tissues. In his opinion the animal ovum is always a simple cell: the germinal layers which develop out of it are always composed of cells; and these cells that constitute the germinal layers arise simply from the continuous and repeated cleaving (segmentation) of the original solitary cell. It first divides into two and then into four cells; out of these four cells are born eight, then sixteen, thirty-two, and so on. Thus, in the embryonic development of every animal and plant there is formed first of all out of the simple egg cell, by a repeated subdivision, a cluster of cells, as Kolliker had already stated in connection with the cephalopods in 1844. The cells of this group spread themselves out flat and form leaves or plates; each of these

leaves is formed exclusively out of cells. The cells of different layers assume different shapes, increase, and differentiate; and in the end there is a further cleavage (differentiation) and division of work of the cells within the layers, and from these all the different tissues of the body proceed.

These are the simple foundations of histogeny, or the science that treats of the development of the tissues (hista), as it was established by Remak and Kolliker. Remak, in determining more closely the part which the different germinal layers play in the formation of the various tissues and organs, and in applying the theory of evolution to the cells and the tissues they compose, raised the theory of germinal layers, at least as far as it regards the vertebrates, to a high degree of perfection.

Remak showed that three layers are formed out of the two germinal layers which compose the first simple leaf-shaped structure of the vertebrate body (or the "germinal disk"), as the lower layer splits into two plates. These three layers have a very definite relation to the various tissues. First of all, the cells which form the outer skin of the body (the epidermis), with its various dependencies (hairs, nails, etc.)--that is to say, the entire outer envelope of the body--are developed out of the outer or upper layer; but there are also developed in a curious way out of the same layer the cells which form the central nervous system, the brain and the spinal cord. In the second place, the inner or lower germinal layer gives rise only to the cells which form the epithelium (the whole inner lining) of the alimentary canal and all that depends on it (the lungs, liver, pancreas, etc.), or the tissues that receive and prepare the nourishment of the body. Finally, the middle layer gives rise to all the other tissues of the body, the muscles, blood, bones, cartilage, etc. Remak further proved that this middle layer, which he calls "the motor-germinative layer," proceeds to subdivide into two secondary layers. Thus we find once more the four layers which Baer had indicated. Remak calls the outer secondary leaf of the middle layer (Baer's "muscular layer") the "skin layer" (it would be better to say, skin-fibre layer); it forms the outer wall of the body (the true skin, the muscles, etc.). To the inner secondary leaf (Baer's "vascular layer") he gave the name of the "alimentary-fibre layer"; this forms the outer envelope of the alimentary canal, with the mesentery, the heart, the blood-vessels, etc.

On this firm foundation provided by Remak for histogeny, or the science of the formation of the tissues, our knowledge has been gradually built up and enlarged in detail. There have been several attempts to restrict and even destroy Remak's principles. The two anatomists, Reichert (of Berlin) and Wilhelm His (of Leipzic), especially, have endeavoured in their works to introduce a new conception of the embryonic development of the vertebrate, according to which the two primary germinal layers would not be the sole sources of formation. But these efforts were so seriously marred by ignorance of comparative anatomy, an imperfect acquaintance with ontogenesis, and a complete neglect of phylogenesis, that they could not have more than a passing success. We can only explain how these curious attacks of Reichert and His came to be regarded for a time as advances by the general lack of discrimination and of grasp of the true object of embryology.

Wilhelm His published, in 1868, his extensive Researches into the

Earliest Form of the Vertebrate Body,* (* None of His's works have been translated into English.) one of the curiosities of embryological literature. The author imagines that he can build a "mechanical theory of embryonic development" by merely giving an exact description of the embryology of the chick, without any regard to comparative anatomy and phylogeny, and thus falls into an error that is almost without parallel in the history of biological literature. As the final result of his laborious investigations, His tells us "that a comparatively simple law of growth is the one essential thing in the first development. Every formation, whether it consist in cleavage of layers, or folding, or complete division, is a consequence of this fundamental law." Unfortunately, he does not explain what this "law of growth" is; just as other opponents of the theory of selection, who would put in its place a great "law of evolution," omit to tell us anything about the nature of this. Nevertheless, it is quite clear from His's works that he imagines constructive Nature to be a sort of skilful tailor. The ingenious operator succeeds in bringing into existence, by "evolution," all the various forms of living things by cutting up in different ways the germinal layers, bending and folding, tugging and splitting, and so on.

His's embryological theories excited a good deal of interest at the time of publication, and have evoked a fair amount of literature in the last few decades. He professed to explain the most complicated parts of organic construction (such as the development of the brain) in the simplest way on mechanical principles, and to derive them immediately from simple physical processes (such as unequal distribution of strain in an elastic plate). It is quite true that a mechanical or monistic explanation (or a reduction of natural processes) is the ideal of modern science, and this ideal would be realised if we could succeed in expressing these formative processes in mathematical formulae. His has, therefore, inserted plenty of numbers and measurements in his embryological works, and given them an air of "exact" scholarship by putting in a quantity of mathematical tables. Unfortunately, they are of no value, and do not help us in the least in forming an "exact" acquaintance with the embryonic phenomena. Indeed, they wander from the true path altogether by neglecting the phylogenetic method; this, he thinks, is "a mere by-path," and is "not necessary at all for the explanation of the facts of embryology," which are the direct consequence of physiological principles. What His takes to be a simple physical process--for instance, the folding of the germinal layers (in the formation of the medullary tube, alimentary tube, etc.)--is, as a matter of fact, the direct result of the growth of the various cells which form those organic structures; but these growth-motions have themselves been transmitted by heredity from parents and ancestors, and are only the hereditary repetition of countless phylogenetic changes which have taken place for thousands of years in the race-history of the said ancestors. Each of these historical changes was, of course, originally due to adaptation; it was, in other words, physiological, and reducible to mechanical causes. But we have, naturally, no means of observing them now. It is only by the hypotheses of the science of evolution that we can form an approximate idea of the organic links in this historic chain.

All the best recent research in animal embryology has led to the confirmation and development of Baer and Remak's theory of the germinal layers. One of the most important advances in this direction of late was the discovery that the two primary layers out of which is built the body of all vertebrates (including man) are also present in

all the invertebrates, with the sole exception of the lowest group, the unicellular protozoa. Huxley had detected them in the medusa in 1849. He showed that the two layers of cells from which the body of this zoophyte is developed correspond, both morphologically and physiologically, to the two original germinal layers of the vertebrate. The outer layer, from which come the external skin and the muscles, was then called by Allman (1853) the "ectoderm" (outer layer, or skin); the inner layer, which forms the alimentary and reproductory organs, was called the "entoderm" (= inner layer). In 1867 and the following years the discovery of the germinal layers was extended to other groups of the invertebrates. In particular, the indefatigable Russian zoologist, Kowalevsky, found them in all the most diverse sections of the invertebrates--the worms, tunicates, echinoderms, molluscs, articulates, etc.

In my monograph on the sponges (1872) I proved that these two primary germinal layers are also found in that group, and that they may be traced from it right up to man, through all the various classes, in identical form. This "homology of the two primary germinal layers" extends through the whole of the metazoa, or tissue-forming animals; that is to say, through the whole animal kingdom, with the one exception of its lowest section, the unicellular beings, or protozoa. These lowly organised animals do not form germinal layers, and therefore do not succeed in forming true tissue. Their whole body consists of a single cell (as is the case with the amoebae and infusoria), or of a loose aggregation of only slightly differentiated cells, though it may not even reach the full structure of a single cell (as with the monera). But in all other animals the ovum first grows into two primary layers, the outer or animal layer (the ectoderm, epiblast, or ectoblast), and the inner or vegetal layer (the entoderm, hypoblast, or endoblast); and from these the tissues and organs are formed. The first and oldest organ of all these metazoa is the primitive gut (or progaster) and its opening, the primitive mouth (prostoma). The typical embryonic form of the metazoa, as it is presented for a time by this simple structure of the two-layered body, is called the gastrula; it is to be conceived as the hereditary reproduction of some primitive common ancestor of the metazoa, which we call the gastraea. This applies to the sponges and other zoophyta, and to the worms, the mollusca, echinoderma, articulata, and vertebrata. All these animals may be comprised under the general heading of "gut animals," or metazoa, in contradistinction to the gutless protozoa.

I have pointed out in my Study of the Gastraea Theory [not translated] (1873) the important consequences of this conception in the morphology and classification of the animal world. I also divided the realm of metazoa into two great groups, the lower and higher metazoa. In the first are comprised the coelenterata (also called zoophytes, or plant-animals). In the lower forms of this group the body consists throughout life merely of the primary germinal layers, with the cells sometimes more and sometimes less differentiated. But with the higher forms of the coelentarata (the corals, higher medusae, ctenophorae, and platodes) a middle layer, or mesoderm, often of considerable size, is developed between the other two layers; but blood and an internal cavity are still lacking.

To the second great group of the metazoa I gave the name of the coelomaria, or bilaterata (or the bilateral higher forms). They all have a cavity within the body (coeloma), and most of them have blood

and blood-vessels. In this are comprised the six higher stems of the animal kingdom, the annulata and their descendants, the mollusca, echinoderma, articulata, tunicata, and vertebrata. In all these bilateral organisms the two-sided body is formed out of four secondary germinal layers, of which the inner two construct the wall of the alimentary canal, and the outer two the wall of the body. Between the two pairs of layers lies the cavity (coeloma).

Although I laid special stress on the great morphological importance of this cavity in my Study of the Gastraea Theory, and endeavoured to prove the significance of the four secondary germinal layers in the organisation of the coelomaria, I was unable to deal satisfactorily with the difficult question of the mode of their origin. This was done eight years afterwards by the brothers Oscar and Richard Hertwig in their careful and extensive comparative studies. In their masterly Coelum Theory: An Attempt to Explain the Middle Germinal Layer [not translated] (1881) they showed that in most of the metazoa, especially in all the vertebrates, the body-cavity arises in the same way, by the outgrowth of two sacs from the inner layer. These two coelom-pouches proceed from the rudimentary mouth of the gastrula, between the two primary layers. The inner plate of the two-layered coelom-pouch (the visceral layer) joins itself to the entoderm; the outer plate (parietal layer) unites with the ectoderm. Thus are formed the double-layered gut-wall within and the double-layered body-wall without; and between the two is formed the cavity of the coelom, by the blending of the right and left coelom-sacs. We shall see this more fully in Chapter 1.10.

The many new points of view and fresh ideas suggested by my gastraea theory and Hertwig's coelom theory led to the publication of a number of writings on the theory of germinal layers. Most of them set out to oppose it at first, but in the end the majority supported it. Of late years both theories are accepted in their essential features by nearly every competent man of science, and light and order have been introduced into this once dark and contradictory field of research. A further cause of congratulation for this solution of the great embryological controversy is that it brought with it a recognition of the need for phylogenetic study and explanation.

Interest and practice in embryological research have been remarkably stimulated during the past thirty years by this appreciation of phylogenetic methods. Hundreds of assiduous and able observers are now engaged in the development of comparative embryology and its establishment on a basis of evolution, whereas they numbered only a few dozen not many decades ago. It would take too long to enumerate even the most important of the countless valuable works which have enriched embryological literature since that time. References to them will be found in the latest manuals of embryology of Kolliker, Balfour, Hertwig, Kollman, Korschelt, and Heider.

Kolliker's Entwickelungsgeschichte des Menschen und der hoherer Thiere, the first edition of which appeared forty-two years ago, had the rare merit at that time of gathering into presentable form the scattered attainments of the science, and expounding them in some sort of unity on the basis of the cellular theory and the theory of germinal layers. Unfortunately, the distinguished Wurtzburg anatomist, to whom comparative anatomy, histology, and ontogeny owe so much, is opposed to the theory of descent generally and to Darwinism in particular. All the other manuals I have mentioned take a decided

stand on evolution. Francis Balfour has carefully collected and presented with discrimination, in his Manual of Comparative Embryology (1880), the very scattered and extensive literature of the subject; he has also widened the basis of the gastraea theory by a comparative description of the rise of the organs from the germinal layers in all the chief groups of the animal kingdom, and has given a most thorough empirical support to the principles I have formulated. A comparison of his work with the excellent Text-book of the Embryology of the Vertebrates (1890) [translation 1895] of Korschelt and Heider shows what astonishing progress has been made in the science in the course of ten years. I would especially recommend the manuals of Julius Kollmann and Oscar Hertwig to those readers who are stimulated to further study by these chapters on human embryology. Kollmann's work is commendable for its clear treatment of the subject and very fine original illustrations; its author adheres firmly to the biogenetic law, and uses it throughout with considerable profit. That is not the case in Oscar Hertwig's recent Text-book of the Embryology of Man and the Mammals [translations 1892 and 1899] (seventh edition 1902). This able anatomist has of late often been quoted as an opponent of the biogenetic law, although he himself had demonstrated its great value thirty years ago. His recent vacillation is partly due to the timidity which our "exact" scientists have with regard to hypotheses; though it is impossible to make any headway in the explanation of facts without them. However, the purely descriptive part of embryology in Hertwig's Text-book is very thorough and reliable.

A new branch of embryological research has been studied very assiduously in the last decade of the nineteenth century--namely, "experimental embryology." The great importance which has been attached to the application of physical experiments to the living organism for the last hundred years, and the valuable results that it has given to physiology in the study of the vital phenomena, have led to its extension to embryology. I was the first to make experiments of this kind during a stay of four months on the Canary Island, Lanzerote, in 1866. I there made a thorough investigation of the almost unknown embryology of the siphonophorae. I cut a number of the embryos of these animals (which develop freely in the water, and pass through a very curious transformation), at an early stage, into several pieces, and found that a fresh organism (more or less complete, according to the size of the piece) was developed from each particle. More recently some of my pupils have made similar experiments with the embryos of vertebrates (especially the frog) and some of the invertebrates. Wilhelm Roux, in particular, has made extensive experiments, and based on them a special "mechanical embryology," which has given rise to a good deal of discussion and controversy. Roux has published a special journal for these subjects since 1895, the Archiv fur Entwickelungsmechanik. The contributions to it are very varied in value. Many of them are valuable papers on the physiology and pathology of the embryo. Pathological experiments--the placing of the embryo in abnormal conditions--have yielded many interesting results; just as the physiology of the normal body has for a long time derived assistance from the pathology of the diseased organism. Other of these mechanical-embryological articles return to the erroneous methods of His, and are only misleading. This must be said of the many contributions of mechanical embryology which take up a position of hostility to the theory of descent and its chief embryological foundation--the biogenetic law. This law, however, when rightly understood, is not opposed to, but is the best and most solid support of, a sound mechanical embryology. Impartial reflection and a

due attention to paleontology and comparative anatomy should convince these one-sided mechanicists that the facts they have discovered--and, indeed, the whole embryological process--cannot be fully understood without the theory of descent and the biogenetic law.

CHAPTER 1.4. THE OLDER PHYLOGENY.

The embryology of man and the animals, the history of which we have reviewed in the last two chapters, was mainly a descriptive science forty years ago. The earlier investigations in this province were chiefly directed to the discovery, by careful observation, of the wonderful facts of the embryonic development of the animal body from the ovum. Forty years ago no one dared attack the question of the CAUSES of these phenomena. For fully a century, from the year 1759, when Wolff's solid Theoria generationis appeared, until 1859, when Darwin published his famous Origin of Species, the real causes of the embryonic processes were quite unknown. No one thought of seeking the agencies that effected this marvellous succession of structures. The task was thought to be so difficult as almost to pass beyond the limits of human thought. It was reserved for Charles Darwin to initiate us into the knowledge of these causes. This compels us to recognise in this great genius, who wrought a complete revolution in the whole field of biology, a founder at the same time of a new period in embryology. It is true that Darwin occupied himself very little with direct embryological research, and even in his chief work he only touches incidentally on the embryonic phenomena; but by his reform of the theory of descent and the founding of the theory of selection he has given us the means of attaining to a real knowledge of the causes of embryonic formation. That is, in my opinion, the chief feature in Darwin's incalculable influence on the whole science of evolution.

When we turn our attention to this latest period of embryological research, we pass into the second division of organic evolution--stem-evolution, or phylogeny. I have already indicated in Chapter 1.1 the important and intimate causal connection between these two sections of the science of evolution--between the evolution of the individual and that of his ancestors. We have formulated this connection in the biogenetic law; the shorter evolution, that of the individual, or ontogenesis, is a rapid and summary repetition, a condensed recapitulation, of the larger evolution, or that of the species. In this principle we express all the essential points relating to the causes of evolution; and we shall seek throughout this work to confirm this principle and lend it the support of facts. When we look to its CAUSAL significance, perhaps it would be better to formulate the biogenetic law thus: "The evolution of the species and the stem (phylon) shows us, in the physiological functions of heredity and adaptation, the conditioning causes on which the evolution of the individual depends"; or, more briefly: "Phylogenesis is the mechanical cause of ontogenesis."

But before we examine the great achievement by which Darwin revealed the causes of evolution to us, we must glance at the efforts of earlier scientists to attain this object. Our historical inquiry into these will be even shorter than that into the work done in the field of ontogeny. We have very few names to consider here. At the head of them we find the great French naturalist, Jean Lamarck, who first established evolution as a scientific theory in 1809. Even before his time, however, the chief philosopher, Kant, and the chief poet,

Goethe, of Germany had occupied themselves with the subject. But their efforts passed almost without recognition in the eighteenth century. A "philosophy of nature" did not arise until the beginning of the nineteenth century. In the whole of the time before this no one had ventured to raise seriously the question of the origin of species, which is the culminating point of phylogeny. On all sides it was regarded as an insoluble enigma.

The whole science of the evolution of man and the other animals is intimately connected with the question of the nature of species, or with the problem of the origin of the various animals which we group together under the name of species. Thus the definition of the species becomes important. It is well known that this definition was given by Linne, who, in his famous Systema Naturae (1735), was the first to classify and name the various groups of animals and plants, and drew up an orderly scheme of the species then known. Since that time "species" has been the most important and indispensable idea in descriptive natural history, in zoological and botanical classification; although there have been endless controversies as to its real meaning.

What, then, is this "organic species"? Linne himself appealed directly to the Mosaic narrative; he believed that, as it is stated in Genesis, one pair of each species of animals and plants was created in the beginning, and that all the individuals of each species are the descendants of these created couples. As for the hermaphrodites (organisms that have male and female organs in one being), he thought it sufficed to assume the creation of one sole individual, since this would be fully competent to propagate its species. Further developing these mystic ideas, Linne went on to borrow from Genesis the account of the deluge and of Noah's ark as a ground for a science of the geographical and topographical distribution of organisms. He accepted the story that all the plants, animals, and men on the earth were swept away in a universal deluge, except the couples preserved with Noah in the ark, and ultimately landed on Mount Ararat. This mountain seemed to Linne particularly suitable for the landing, as it reaches a height of more than 16,000 feet, and thus provides in its higher zones the several climates demanded by the various species of animals and plants: the animals that were accustomed to a cold climate could remain at the summit; those used to a warm climate could descend to the foot; and those requiring a temperate climate could remain half-way down. From this point the re-population of the earth with animals and plants could proceed.

It was impossible to have any scientific notion of the method of evolution in Linne's time, as one of the chief sources of information, paleontology, was still wholly unknown. This science of the fossil remains of extinct animals and plants is very closely bound up with the whole question of evolution. It is impossible to explain the origin of living organisms without appealing to it. But this science did not rise until a much later date. The real founder of scientific paleontology was Georges Cuvier, the most distinguished zoologist who, after Linne, worked at the classification of the animal world, and effected a complete revolution in systematic zoology at the beginning of the nineteenth century. In regard to the nature of the species he associated himself with Linne and the Mosaic story of creation, though this was more difficult for him with his acquaintance with fossil remains. He clearly showed that a number of quite different animal populations have lived on the earth; and he claimed that we must

distinguish a number of stages in the history of our planet, each of which was characterised by a special population of animals and plants. These successive populations were, he said, quite independent of each other, and therefore the supernatural creative act, which was demanded as the origin of the animals and plants by the dominant creed, must have been repeated several times. In this way a whole series of different creative periods must have succeeded each other; and in connection with these he had to assume that stupendous revolutions or cataclysms--something like the legendary deluge--must have taken place repeatedly. Cuvier was all the more interested in these catastrophes or cataclysms as geology was just beginning to assert itself, and great progress was being made in our knowledge of the structure and formation of the earth's crust. The various strata of the crust were being carefully examined, especially by the famous geologist Werner and his school, and the fossils found in them were being classified; and these researches also seemed to point to a variety of creative periods. In each period the earth's crust, composed of the various strata, seemed to be differently constituted, just like the population of animals and plants that then lived on it. Cuvier combined this notion with the results of his own paleontological and zoological research; and in his effort to get a consistent view of the whole process of the earth's history he came to form the theory which is known as "the catastrophic theory," or the theory of terrestrial revolutions. According to this theory, there have been a series of mighty cataclysms on the earth, and these have suddenly destroyed the whole animal and plant population then living on it; after each cataclysm there was a fresh creation of living things throughout the earth. As this creation could not be explained by natural laws, it was necessary to appeal to an intervention on the part of the Creator. This catastrophic theory, which Cuvier described in a special work, was soon generally accepted, and retained its position in biology for half a century.

However, Cuvier's theory was completely overthrown sixty years ago by the geologists, led by Charles Lyell, the most distinguished worker in this field of science. Lyell proved in his famous Principles of Geology (1830) that the theory was false, in so far as it concerned the crust of the earth; that it was totally unnecessary to bring in supernatural agencies or general catastrophes in order to explain the structure and formation of the mountains; and that we can explain them by the familiar agencies which are at work to-day in altering and reconstructing the surface of the earth. These causes are--the action of the atmosphere and water in its various forms (snow, ice, fog, rain, the wear of the river, and the stormy ocean), and the volcanic action which is exerted by the molten central mass. Lyell convincingly proved that these natural causes are quite adequate to explain every feature in the build and formation of the crust. Hence Cuvier's theory of cataclysms was very soon driven out of the province of geology, though it remained for another thirty years in undisputed authority in biology. All the zoologists and botanists who gave any thought to the question of the origin of organisms adhered to Cuvier's erroneous idea of revolutions and new creations.

In order to illustrate the complete stagnancy of biology from 1830 to 1859 on the question of the origin of the various species of animals and plants, I may say, from my own experience, that during the whole of my university studies I never heard a single word said about this most important problem of the science. I was fortunate enough at that time (1852 to 1857) to have the most distinguished masters for every

branch of biological science. Not one of them ever mentioned this question of the origin of species. Not a word was ever said about the earlier efforts to understand the formation of living things, nor about Lamarck's Philosophie Zoologique which had made a fresh attack on the problem in 1809. Hence it is easy to understand the enormous opposition that Darwin encountered when he took up the question for the first time. His views seemed to float in the air, without a single previous effort to support them. The whole question of the formation of living things was considered by biologists, until 1859, as pertaining to the province of religion and transcendentalism; even in speculative philosophy, in which the question had been approached from various sides, no one had ventured to give it serious treatment. This was due to the dualistic system of Immanuel Kant, who taught a natural system of evolution as far as the inorganic world was concerned; but, on the whole, adopted a supernaturalist system as regards the origin of living things. He even went so far as to say: "It is quite certain that we cannot even satisfactorily understand, much less explain, the nature of an organism and its internal forces on purely mechanical principles; it is so certain, indeed, that we may confidently say: 'It is absurd for a man to imagine even that some day a Newton will arise who will explain the origin of a single blade of grass by natural laws not controlled by design'--such a hope is entirely forbidden us." In these words Kant definitely adopts the dualistic and teleological point of view for biological science.

Nevertheless, Kant deserted this point of view at times, particularly in several remarkable passages which I have dealt with at length in my Natural History of Creation (chapter 5), where he expresses himself in the opposite, or monistic, sense. In fact, these passages would justify one, as I showed, in claiming his support for the theory of evolution. However, these monistic passages are only stray gleams of light; as a rule, Kant adheres in biology to the obscure dualistic ideas, according to which the forces at work in inorganic nature are quite different from those of the organic world. This dualistic system prevails in academic philosophy to-day--most of our philosophers still regarding these two provinces as totally distinct. They put, on the one side, the inorganic or "lifeless" world, in which there are at work only mechanical laws, acting necessarily and without design; and, on the other, the province of organic nature, in which none of the phenomena can be properly understood, either as regards their inner nature or their origin, except in the light of preconceived design, carried out by final or purposive causes.

The prevalence of this unfortunate dualistic prejudice prevented the problem of the origin of species, and the connected question of the origin of man, from being regarded by the bulk of people as a scientific question at all until 1859. Nevertheless, a few distinguished students, free from the current prejudice, began, at the commencement of the nineteenth century, to make a serious attack on the problem. The merit of this attaches particularly to what is known as "the older school of natural philosophy," which has been so much misrepresented, and which included Jean Lamarck, Buffon, Geoffroy St. Hilaire, and Blainville in France; Wolfgang Goethe, Reinhold Treviranus, Schelling, and Lorentz Oken in Germany [and Erasmus Darwin in England].

The gifted natural philosopher who treated this difficult question with the greatest sagacity and comprehensiveness was Jean Lamarck. He was born at Bazentin, in Picardy, on August 1st, 1744; he was the son

of a clergyman, and was destined for the Church. But he turned to seek glory in the army, and eventually devoted himself to science.

His Philosophie Zoologique was the first scientific attempt to sketch the real course of the origin of species, the first "natural history of creation" of plants, animals, and men. But, as in the case of Wolff's book, this remarkably able work had no influence whatever; neither one nor the other could obtain any recognition from their prejudiced contemporaries. No man of science was stimulated to take an interest in the work, and to develop the germs it contained of the most important biological truths. The most distinguished botanists and zoologists entirely rejected it, and did not even deign to reply to it. Cuvier, who lived and worked in the same city, has not thought fit to devote a single syllable to this great achievement in his memoir on progress in the sciences, in which the pettiest observations found a place. In short, Lamarck's Philosophie Zoologique shared the fate of Wolff's theory of development, and was for half a century ignored and neglected. The German scientists, especially Oken and Goethe, who were occupied with similar speculations at the same time, seem to have known nothing about Lamarck's work. If they had known it, they would have been greatly helped by it, and might have carried the theory of evolution much farther than they found it possible to do.

To give an idea of the great importance of the Philosophie Zoologique, I will briefly explain Lamarck's leading thought. He held that there was no essential difference between living and lifeless beings. Nature is one united and connected system of phenomena; and the forces which fashion the lifeless bodies are the only ones at work in the kingdom of living things. We have, therefore, to use the same method of investigation and explanation in both provinces. Life is only a physical phenomenon. All the plants and animals, with man at their head, are to be explained, in structure and life, by mechanical or efficient causes, without any appeal to final causes, just as in the case of minerals and other inorganic bodies. This applies equally to the origin of the various species. We must not assume any original creation, or repeated creations (as in Cuvier's theory), to explain this, but a natural, continuous, and necessary evolution. The whole evolutionary process has been uninterrupted. All the different kinds of animals and plants which we see to-day, or that have ever lived, have descended in a natural way from earlier and different species; all come from one common stock, or from a few common ancestors. These remote ancestors must have been quite simple organisms of the lowest type, arising by spontaneous generation from inorganic matter. The succeeding species have been constantly modified by adaptation to their varying environment (especially by use and habit), and have transmitted their modifications to their successors by heredity.

Lamarck was the first to formulate as a scientific theory the natural origin of living things, including man, and to push the theory to its extreme conclusions--the rise of the earliest organisms by spontaneous generation (or abiogenesis) and the descent of man from the nearest related mammal, the ape. He sought to explain this last point, which is of especial interest to us here, by the same agencies which he found at work in the natural origin of the plant and animal species. He considered use and habit (adaptation) on the one hand, and heredity on the other, to be the chief of these agencies. The most important modifications of the organs of plants and animals are due, in his opinion, to the function of these very organs, or to the use or disuse of them. To give a few examples, the woodpecker and the humming-bird

have got their peculiarly long tongues from the habit of extracting their food with their tongues from deep and narrow folds or canals; the frog has developed the web between his toes by his own swimming; the giraffe has lengthened his neck by stretching up to the higher branches of trees, and so on. It is quite certain that this use or disuse of organs is a most important factor in organic development, but it is not sufficient to explain the origin of species.

To adaptation we must add heredity as the second and not less important agency, as Lamarck perfectly recognised. He said that the modification of the organs in any one individual by use or disuse was slight, but that it was increased by accumulation in passing by heredity from generation to generation. But he missed altogether the principle which Darwin afterwards found to be the chief factor in the theory of transformation--namely, the principle of natural selection in the struggle for existence. It was partly owing to his failure to detect this supremely important element, and partly to the poor condition of all biological science at the time, that Lamarck did not succeed in establishing more firmly his theory of the common descent of man and the other animals.

Independently of Lamarck, the older German school of natural philosophy, especially Reinhold Treviranus, in his Biologie (1802), and Lorentz Oken, in his Naturphilosophie (1809), turned its attention to the problem of evolution about the end of the eighteenth and beginning of the nineteenth century. I have described its work in my History of Creation (chapter 4). Here I can only deal with the brilliant genius whose evolutionary ideas are of special interest--the greatest of German poets, Wolfgang Goethe. With his keen eye for the beauties of nature, and his profound insight into its life, Goethe was early attracted to the study of various natural sciences. It was the favourite occupation of his leisure hours throughout life. He gave particular and protracted attention to the theory of colours. But the most valuable of his scientific studies are those which relate to that "living, glorious, precious thing," the organism. He made profound research into the science of structures or morphology (morphae = forms). Here, with the aid of comparative anatomy, he obtained the most brilliant results, and went far in advance of his time. I may mention, in particular, his vertebral theory of the skull, his discovery of the pineal gland in man, his system of the metamorphosis of plants, etc. These morphological studies led Goethe on to research into the formation and modification of organic structures which we must count as the first germ of the science of evolution. He approaches so near to the theory of descent that we must regard him, after Lamarck, as one of its earliest founders. It is true that he never formulated a complete scientific theory of evolution, but we find a number of remarkable suggestions of it in his splendid miscellaneous essays on morphology. Some of them are really among the very basic ideas of the science of evolution. He says, for instance (1807): "When we compare plants and animals in their most rudimentary forms, it is almost impossible to distinguish between them. But we may say that the plants and animals, beginning with an almost inseparable closeness, gradually advance along two divergent lines, until the plant at last grows in the solid, enduring tree and the animal attains in man to the highest degree of mobility and freedom." That Goethe was not merely speaking in a poetical, but in a literal genealogical, sense of this close affinity of organic forms is clear from other remarkable passages in which he treats of their variety in outward form and unity in internal structure. He believes that every living

thing has arisen by the interaction of two opposing formative forces or impulses. The internal or "centripetal" force, the type or "impulse to specification," seeks to maintain the constancy of the specific forms in the succession of generations: this is heredity. The external or "centrifugal" force, the element of variation or "impulse to metamorphosis," is continually modifying the species by changing their environment: this is adaptation. In these significant conceptions Goethe approaches very close to a recognition of the two great mechanical factors which we now assign as the chief causes of the formation of species.

However, in order to appreciate Goethe's views on morphology, one must associate his decidedly monistic conception of nature with his pantheistic philosophy. The warm and keen interest with which he followed, in his last years, the controversies of contemporary French scientists, and especially the struggle between Cuvier and Geoffroy St. Hilaire (see chapter 4 of The History of Creation), is very characteristic. It is also necessary to be familiar with his style and general tenour of thought in order to appreciate rightly the many allusions to evolution found in his writings. Otherwise, one is apt to make serious errors.

He approached so close, at the end of the eighteenth century, to the principles of the science of evolution that he may well be described as the first forerunner of Darwin, although he did not go so far as to formulate evolution as a scientific system, as Lamarck did.

CHAPTER 1.5. THE MODERN SCIENCE OF EVOLUTION.

We owe so much of the progress of scientific knowledge to Darwin's Origin of Species that its influence is almost without parallel in the history of science. The literature of Darwinism grows from day to day, not only on the side of academic zoology and botany, the sciences which were chiefly affected by Darwin's theory, but in a far wider circle, so that we find Darwinism discussed in popular literature with a vigour and zest that are given to no other scientific conception. This remarkable success is due chiefly to two circumstances. In the first place, all the sciences, and especially biology, have made astounding progress in the last half-century, and have furnished a very vast quantity of proofs of the theory of evolution. In striking contrast to the failure of Lamarck and the older scientists to attract attention to their effort to explain the origin of living things and of man, we have this second and successful effort of Darwin, which was able to gather to its support a large number of established facts. Availing himself of the progress already made, he had very different scientific proofs to allege than Lamarck, or St. Hilaire, or Goethe, or Treviranus had had. But, in the second place, we must acknowledge that Darwin had the special distinction of approaching the subject from an entirely new side, and of basing the theory of descent on a consistent system, which now goes by the name of Darwinism.

Lamarck had unsuccessfully attempted to explain the modification of organisms that descend from a common form chiefly by the action of habit and the use of organs, though with the aid of heredity. But Darwin's success was complete when he independently sought to give a mechanical explanation, on a quite new ground, of this modification of plant and animal structures by adaptation and heredity. He was impelled to his theory of selection on the following grounds. He

compared the origin of the various kinds of animals and plants which we modify artificially--by the action of artificial selection in horticulture and among domestic animals--with the origin of the species of animals and plants in their natural state. He then found that the agencies which we employ in the modification of forms by artificial selection are also at work in Nature. The chief of these agencies he held to be "the struggle for life." The gist of this peculiarly Darwinian idea is given in this formula: The struggle for existence produces new species without premeditated design in the life of Nature, in the same way that the will of man consciously selects new races in artificial conditions. The gardener or the farmer selects new forms as he wills for his own profit, by ingeniously using the agency of heredity and adaptation for the modification of structures; so, in the natural state, the struggle for life is always unconsciously modifying the various species of living things. This struggle for life, or competition of organisms in securing the means of subsistence, acts without any conscious design, but it is none the less effective in modifying structures. As heredity and adaptation enter into the closest reciprocal action under its influence, new structures, or alterations of structure, are produced; and these are purposive in the sense that they serve the organism when formed, but they were produced without any pre-conceived aim.

This simple idea is the central thought of Darwinism, or the theory of selection. Darwin conceived this idea at an early date, and then, for more than twenty years, worked at the collection of empirical evidence in support of it before he published his theory. His grandfather, Erasmus Darwin, was an able scientist of the older school of natural philosophy, who published a number of natural-philosophic works about the end of the eighteenth century. The most important of them is his Zoonomia, published in 1794, in which he expounds views similar to those of Goethe and Lamarck, without really knowing anything of the work of these contemporaries. However, in the writings of the grandfather the plastic imagination rather outran the judgment, while in Charles Darwin the two were better balanced.

Darwin did not publish any account of his theory until 1858, when Alfred Russel Wallace, who had independently reached the same theory of selection, published his own work. In the following year appeared the Origin of Species, in which he develops it at length and supports it with a mass of proof. Wallace had reached the same conclusion, but he had not so clear a perception as Darwin of the effectiveness of natural selection in forming species, and did not develop the theory so fully. Nevertheless, Wallace's writings, especially those on mimicry, etc., and an admirable work on The Geographical Distribution of Animals, contain many fine original contributions to the theory of selection. Unfortunately, this gifted scientist has since devoted himself to spiritism.* (* Darwin and Wallace arrived at the theory quite independently. Vide Wallace's Contributions to the Theory of Natural Selection (1870) and Darwinism (1891).)

Darwin's Origin of Species had an extraordinary influence, though not at first on the experts of the science. It took zoologists and botanists several years to recover from the astonishment into which they had been thrown through the revolutionary idea of the work. But its influence on the special sciences with which we zoologists and botanists are concerned has increased from year to year; it has introduced a most healthy fermentation in every branch of biology, especially in comparative anatomy and ontogeny, and in zoological and

botanical classification. In this way it has brought about almost a revolution in the prevailing views.

However, the point which chiefly concerns us here--the extension of the theory to man--was not touched at all in Darwin's first work in 1859. It was believed for several years that he had no thought of applying his principles to man, but that he shared the current idea of man holding a special position in the universe. Not only ignorant laymen (especially several theologians), but also a number of men of science, said very naively that Darwinism in itself was not to be opposed; that it was quite right to use it to explain the origin of the various species of plants and animals, but that it was totally inapplicable to man.

In the meantime, however, it seemed to a good many thoughtful people, laymen as well as scientists, that this was wrong; that the descent of man from some other animal species, and immediately from some ape-like mammal, followed logically and necessarily from Darwin's reformed theory of evolution. Many of the acuter opponents of the theory saw at once the justice of this position, and, as this consequence was intolerable, they wanted to get rid of the whole theory.

The first scientific application of the Darwinian theory to man was made by Huxley, the greatest zoologist in England. This able and learned scientist, to whom zoology owes much of its progress, published in 1863 a small work entitled Evidence as to Man's Place in Nature. In the extremely important and interesting lectures which made up this work he proved clearly that the descent of man from the ape followed necessarily from the theory of descent. If that theory is true, we are bound to conceive the animals which most closely resemble man as those from which humanity has been gradually evolved. About the same time Carl Vogt published a larger work on the same subject. We must also mention Gustav Jaeger and Friedrich Rolle among the zoologists who accepted and taught the theory of evolution immediately after the publication of Darwin's book, and maintained that the descent of man from the lower animals logically followed from it. The latter published, in 1866, a work on the origin and position of man.

About the same time I attempted, in the second volume of my General Morphology (1866), to apply the theory of evolution to the whole organic kingdom, including man.* (* Huxley spoke of this "as one of the greatest scientific works ever published."--Translator.) I endeavoured to sketch the probable ancestral trees of the various classes of the animal world, the protists, and the plants, as it seemed necessary to do on Darwinian principles, and as we can actually do now with a high degree of confidence. If the theory of descent, which Lamarck first clearly formulated and Darwin thoroughly established, is true, we should be able to draw up a natural classification of plants and animals in the light of their genealogy, and to conceive the large and small divisions of the system as the branches and twigs of an ancestral tree. The eight genealogical tables which I inserted in the second volume of the General Morphology are the first sketches of their kind. In Chapter 2.27, particularly, I trace the chief stages in man's ancestry, as far as it is possible to follow it through the vertebrate stem. I tried especially to determine, as well as one could at that time, the position of man in the classification of the mammals and its genealogical significance. I have greatly improved this attempt, and treated it in a more popular form, in chapters 26 to 28 of my History of Creation (1868).* (* Of

which Darwin said that the Descent of Man would probably never have been written if he had seen it earlier.--Translator.)

It was not until 1871, twelve years after the appearance of The Origin of Species, that Darwin published the famous work which made the much-contested application of his theory to man, and crowned the splendid structure of his system. This important work was The Descent of Man, and Selection in Relation to Sex. In this Darwin expressly drew the conclusion, with rigorous logic, that man also must have been developed out of lower species, and described the important part played by sexual selection in the elevation of man and the other higher animals. He showed that the careful selection which the sexes exercise on each other in regard to sexual relations and procreation, and the aesthetic feeling which the higher animals develop through this, are of the utmost importance in the progressive development of forms and the differentiation of the sexes. The males choosing the handsomest females in one class of animals, and the females choosing only the finest-looking males in another, the special features and the sexual characteristics are increasingly accentuated. In fact, some of the higher animals develop in this connection a finer taste and judgment than man himself. But, even as regards man, it is to this sexual selection that we owe the family-life, which is the chief foundation of civilisation. The rise of the human race is due for the most part to the advanced sexual selection which our ancestors exercised in choosing their mates.

Darwin accepted in the main the general outlines of man's ancestral tree, as I gave it in the General Morphology and the History of Creation, and admitted that his studies led him to the same conclusion. That he did not at once apply the theory to man in his first work was a commendable piece of discretion; such a sequel was bound to excite the strongest opposition to the whole theory. The first thing to do was to establish it as regards the animal and plant worlds. The subsequent extension to man was bound to be made sooner or later.

It is important to understand this very clearly. If all living things come from a common root, man must be included in the general scheme of evolution. On the other hand, if the various species were separately created, man, too, must have been created, and not evolved. We have to choose between these two alternatives. This cannot be too frequently or too strongly emphasised. EITHER all the species of animals and plants are of supernatural origin--created, not evolved--and in that case man also is the outcome of a creative act, as religion teaches, OR the different species have been evolved from a few common, simple ancestral forms, and in that case man is the highest fruit of the tree of evolution.

We may state this briefly in the following principle--The descent of man from the lower animals is a special deduction which inevitably follows from the general inductive law of the whole theory of evolution. In this principle we have a clear and plain statement of the matter. Evolution is in reality nothing but a great induction, which we are compelled to make by the comparative study of the most important facts of morphology and physiology. But we must draw our conclusion according to the laws of induction, and not attempt to determine scientific truths by direct measurement and mathematical calculation. In the study of living things we can scarcely ever directly and fully, and with mathematical accuracy, determine the

nature of phenomena, as is done in the simpler study of the inorganic world--in chemistry, physics, mineralogy, and astronomy. In the latter, especially, we can always use the simplest and absolutely safest method--that of mathematical determination. But in biology this is quite impossible for various reasons; one very obvious reason being that most of the facts of the science are very complicated and much too intricate to allow a direct mathematical analysis. The greater part of the phenomena that biology deals with are complicated HISTORICAL PROCESSES, which are related to a far-reaching past, and as a rule can only be approximately estimated. Hence we have to proceed by INDUCTION--that is to say, to draw general conclusions, stage by stage, and with proportionate confidence, from the accumulation of detailed observations. These inductive conclusions cannot command absolute confidence, like mathematical axioms; but they approach the truth, and gain increasing probability, in proportion as we extend the basis of observed facts on which we build. The importance of these inductive laws is not diminished from the circumstance that they are looked upon merely as temporary acquisitions of science, and may be improved to any extent in the progress of scientific knowledge. The same may be said of the attainments of many other sciences, such as geology or archeology. However much they may be altered and improved in detail in the course of time, these inductive truths may retain their substance unchanged.

Now, when we say that the theory of evolution in the sense of Lamarck and Darwin is an inductive law--in fact, the greatest of all biological inductions--we rely, in the first place, on the facts of paleontology. This science gives us some direct acquaintance with the historical phenomena of the changes of species. From the situations in which we find the fossils in the various strata of the earth we gather confidently, in the first place, that the living population of the earth has been gradually developed, as clearly as the earth's crust itself; and that, in the second place, several different populations have succeeded each other in the various geological periods. Modern geology teaches that the formation of the earth has been gradual, and unbroken by any violent revolutions. And when we compare together the various kinds of animals and plants which succeed each other in the history of our planet, we find, in the first place, a constant and gradual increase in the number of species from the earliest times until the present day; and, in the second place, we notice that the forms in each great group of animals and plants also constantly improve as the ages advance. Thus, of the vertebrates there are at first only the lower fishes; then come the higher fishes, and later the amphibia. Still later appear the three higher classes of vertebrates--the reptiles, birds, and mammals, for the first time; only the lowest and least perfect forms of the mammals are found at first; and it is only at a very late period that placental mammals appear, and man belongs to the latest and youngest branch of these. Thus perfection of form increases as well as variety from the earliest to the latest stage. That is a fact of the greatest importance. It can only be explained by the theory of evolution, with which it is in perfect harmony. If the different groups of plants and animals do really descend from each other, we must expect to find this increase in their number and perfection under the influence of natural selection, just as the succession of fossils actually discloses it to us.

Comparative anatomy furnishes a second series of facts which are of great importance for the forming of our inductive law. This branch of

morphology compares the adult structures of living things, and seeks in the great variety of organic forms the stable and simple law of organisation, or the common type or structure. Since Cuvier founded this science at the beginning of the nineteenth century it has been a favourite study of the most distinguished scientists. Even before Cuvier's time Goethe had been greatly stimulated by it, and induced to take up the study of morphology. Comparative osteology, or the philosophic study and comparison of the bony skeleton of the vertebrates--one of its most interesting sections--especially fascinated him, and led him to form the theory of the skull which I mentioned before. Comparative anatomy shows that the internal structure of the animals of each stem and the plants of each class is the same in its essential features, however much they differ in external appearance. Thus man has so great a resemblance in the chief features of his internal organisation to the other mammals that no comparative anatomist has ever doubted that he belongs to this class. The whole internal structure of the human body, the arrangement of its various systems of organs, the distribution of the bones, muscles, blood-vessels, etc., and the whole structure of these organs in the larger and the finer scale, agree so closely with those of the other mammals (such as the apes, rodents, ungulates, cetacea, marsupials, etc.) that their external differences are of no account whatever. We learn further from comparative anatomy that the chief features of animal structure are so similar in the various classes (fifty to sixty in number altogether) that they may all be comprised in from eight to twelve great groups. But even in these groups, the stem-forms or animal types, certain organs (especially the alimentary canal) can be proved to have been originally the same for all. We can only explain by the theory of evolution this essential unity in internal structure of all these animal forms that differ so much in outward appearance. This wonderful fact can only be really understood and explained when we regard the internal resemblance as an inheritance from common-stem forms, and the external differences as the effect of adaptation to different environments.

In recognising this, comparative anatomy has itself advanced to a higher stage. Gegenbaur, the most distinguished of recent students of this science, says that with the theory of evolution a new period began in comparative anatomy, and that the theory in turn found a touch stone in the science. "Up to now there is no fact in comparative anatomy that is inconsistent with the theory of evolution; indeed, they all lead to it. In this way the theory receives back from the science all the service it rendered to its method." Until then students had marvelled at the wonderful resemblance of living things in their inner structure without being able to explain it. We are now in a position to explain the causes of this, by showing that this remarkable agreement is the necessary consequence of the inheriting of common stem-forms; while the striking difference in outward appearance is a result of adaptation to changes of environment. Heredity and adaptation alone furnish the true explanation.

But one special part of comparative anatomy is of supreme interest and of the utmost philosophic importance in this connection. This is the science of rudimentary or useless organs; I have given it the name of "dysteleology" in view of its philosophic consequences. Nearly every organism (apart from the very lowest), and especially every highly-developed animal or plant, including man, has one or more organs which are of no use to the body itself, and have no share in its functions or vital aims. Thus we all have, in various parts of our

frame, muscles which we never use, as, for instance, in the shell of the ear and adjoining parts. In most of the mammals, especially those with pointed ears, these internal and external ear-muscles are of great service in altering the shell of the ear, so as to catch the waves of sound as much as possible. But in the case of man and other short-eared mammals these muscles are useless, though they are still present. Our ancestors having long abandoned the use of them, we cannot work them at all to-day. In the inner corner of the eye we have a small crescent-shaped fold of skin; this is the last relic of a third inner eye-lid, called the nictitating (winking) membrane. This membrane is highly developed and of great service in some of our distant relations, such as fishes of the shark type and several other vertebrates; in us it is shrunken and useless. In the intestines we have a process that is not only quite useless, but may be very harmful--the vermiform appendage. This small intestinal appendage is often the cause of a fatal illness. If a cherry-stone or other hard body is unfortunately squeezed through its narrow aperture during digestion, a violent inflammation is set up, and often proves fatal. This appendix has no use whatever now in our frame; it is a dangerous relic of an organ that was much larger and was of great service in our vegetarian ancestors. It is still large and important in many vegetarian animals, such as apes and rodents.

There are similar rudimentary organs in all parts of our body, and in all the higher animals. They are among the most interesting phenomena to which comparative anatomy introduces us; partly because they furnish one of the clearest proofs of evolution, and partly because they most strikingly refute the teleology of certain philosophers. The theory of evolution enables us to give a very simple explanation of these phenomena.

We have to look on them as organs which have fallen into disuse in the course of many generations. With the decrease in the use of its function, the organ itself shrivels up gradually, and finally disappears. There is no other way of explaining rudimentary organs. Hence they are also of great interest in philosophy; they show clearly that the monistic or mechanical view of the organism is the only correct one, and that the dualistic or teleological conception is wrong. The ancient legend of the direct creation of man according to a pre-conceived plan and the empty phrases about "design" in the organism are completely shattered by them. It would be difficult to conceive a more thorough refutation of teleology than is furnished by the fact that all the higher animals have these rudimentary organs.

The theory of evolution finds its broadest inductive foundation in the natural classification of living things, which arranges all the various forms in larger and smaller groups, according to their degree of affinity. These groupings or categories of classification--the varieties, species, genera, families, orders, classes, etc.--show such constant features of coordination and subordination that we are bound to look on them as genealogical, and represent the whole system in the form of a branching tree. This is the genealogical tree of the variously related groups; their likeness in form is the expression of a real affinity. As it is impossible to explain in any other way the natural tree-like form of the system of organisms, we must regard it at once as a weighty proof of the truth of evolution. The careful construction of these genealogical trees is, therefore, not an amusement, but the chief task of modern classification.

Among the chief phenomena that bear witness to the inductive law of evolution we have the geographical distribution of the various species of animals and plants over the surface of the earth, and their topographical distribution on the summits of mountains and in the depths of the ocean. The scientific study of these features--the "science of distribution," or chorology (chora = a place)--has been pursued with lively interest since the discoveries made by Alexander von Humboldt. Until Darwin's time the work was confined to the determination of the facts of the science, and chiefly aimed at settling the spheres of distribution of the existing large and small groups of living things. It was impossible at that time to explain the causes of this remarkable distribution, or the reasons why one group is found only in one locality and another in a different place, and why there is this manifold distribution at all. Here, again, the theory of evolution has given us the solution of the problem. It furnishes the only possible explanation when it teaches that the various species and groups of species descend from common stem-forms, whose ever-branching offspring have gradually spread themselves by migration over the earth. For each group of species we must admit a "centre of production," or common home; this is the original habitat in which the ancestral form was developed, and from which its descendants spread out in every direction. Several of these descendants became in their turn the stem-forms for new groups of species, and these also scattered themselves by active and passive migration, and so on. As each migrating organism found a different environment in its new home, and adapted itself to it, it was modified, and gave rise to new forms.

This very important branch of science that deals with active and passive migration was founded by Darwin, with the aid of the theory of evolution; and at the same time he advanced the true explanation of the remarkable relation or similarity of the living population in any locality to the fossil forms found in it. Moritz Wagner very ably developed his idea under the title of "the theory of migration." In my opinion, this famous traveller has rather over-estimated the value of his theory of migration when he takes it to be an indispensable condition of the formation of new species and opposes the theory of selection. The two theories are not opposed in their main features. Migration (by which the stem-form of a new species is isolated) is really only a special case of selection. The striking and interesting facts of chorology can be explained only by the theory of evolution, and therefore we must count them among the most important of its inductive bases.

The same must be said of all the remarkable phenomena which we perceive in the economy of the living organism. The many and various relations of plants and animals to each other and to their environment, which are treated in bionomy (from nomos, law or norm, and bios, life), the interesting facts of parasitism, domesticity, care of the young, social habits, etc., can only be explained by the action of heredity and adaptation. Formerly people saw only the guidance of a beneficent Providence in these phenomena; to-day we discover in them admirable proofs of the theory of evolution. It is impossible to understand them except in the light of this theory and the struggle for life.

Finally, we must, in my opinion, count among the chief inductive bases of the theory of evolution the foetal development of the individual organism, the whole science of embryology or ontogeny. But as the

later chapters will deal with this in detail, I need say nothing further here. I shall endeavour in the following pages to show, step by step, how the whole of the embryonic phenomena form a massive chain of proof for the theory of evolution; for they can be explained in no other way. In thus appealing to the close causal connection between ontogenesis and phylogenesis, and taking our stand throughout on the biogenetic law, we shall be able to prove, stage by stage, from the facts of embryology, the evolution of man from the lower animals.

The general adoption of the theory of evolution has definitely closed the controversy as to the nature or definition of the species. The word has no ABSOLUTE meaning whatever, but is only a group-name, or category of classification, with a purely relative value. In 1857, it is true, a famous and gifted, but inaccurate and dogmatic, scientist, Louis Agassiz, attempted to give an absolute value to these "categories of classification." He did this in his Essay on Classification, in which he turns upside down the phenomena of organic nature, and, instead of tracing them to their natural causes, examines them through a theological prism. The true species (bona species) was, he said, an "incarnate idea of the Creator." Unfortunately, this pretty phrase has no more scientific value than all the other attempts to save the absolute or intrinsic value of the species.

The dogma of the fixity and creation of species lost its last great champion when Agassiz died in 1873. The opposite theory, that all the different species descend from common stem-forms, encounters no serious difficulty to-day. All the endless research into the nature of the species, and the possibility of several species descending from a common ancestor, has been closed to-day by the removal of the sharp limits that had been set up between species and varieties on the one hand, and species and genera on the other. I gave an analytic proof of this in my monograph on the sponges (1872), having made a very close study of variability in this small but highly instructive group, and shown the impossibility of making any dogmatic distinction of species. According as the classifier takes his ideas of genus, species, and variety in a broader or in a narrower sense, he will find in the small group of the sponges either one genus with three species, or three genera with 238 species, or 113 genera with 591 species. Moreover, all these forms are so connected by intermediate forms that we can convincingly prove the descent of all the sponges from a common stem-form, the olynthus.

Here, I think, I have given an analytic solution of the problem of the origin of species, and so met the demand of certain opponents of evolution for an actual instance of descent from a stem-form. Those who are not satisfied with the synthetic proofs of the theory of evolution which are provided by comparative anatomy, embryology, paleontology, dysteleology, chorology, and classification, may try to refute the analytic proof given in my treatise on the sponge, the outcome of five years of assiduous study. I repeat: It is now impossible to oppose evolution on the ground that we have no convincing example of the descent of all the species of a group from a common ancestor. The monograph on the sponges furnishes such a proof, and, in my opinion, an indisputable proof. Any man of science who will follow the protracted steps of my inquiry and test my assertions will find that in the case of the sponges we can follow the actual evolution of species in a concrete case. And if this is so, if we can show the origin of all the species from a common form in one single class, we have the solution of the problem of man's origin, because we

are in a position to prove clearly his descent from the lower animals.

At the same time, we can now reply to the often-repeated assertion, even heard from scientists of our own day, that the descent of man from the lower animals, and proximately from the apes, still needs to be "proved with certainty." These "certain proofs" have been available for a long time; one has only to open one's eyes to see them. It is a mistake to seek them in the discovery of intermediate forms between man and the ape, or the conversion of an ape into a human being by skilful education. The proofs lie in the great mass of empirical material we have already collected. They are furnished in the strongest form by the data of comparative anatomy and embryology, completed by paleontology. It is not a question now of detecting new proofs of the evolution of man, but of examining and understanding the proofs we already have.

I was almost alone thirty-six years ago when I made the first attempt, in my General Morphology, to put organic science on a mechanical foundation through Darwin's theory of descent. The association of ontogeny and phylogeny and the proof of the intimate causal connection between these two sections of the science of evolution, which I expounded in my work, met with the most spirited opposition on nearly all sides. The next ten years were a terrible "struggle for life" for the new theory. But for the last twenty-five years the tables have been turned. The phylogenetic method has met with so general a reception, and found so prolific a use in every branch of biology, that it seems superfluous to treat any further here of its validity and results. The proof of it lies in the whole morphological literature of the last three decades. But no other science has been so profoundly modified in its leading thoughts by this adoption, and been forced to yield such far-reaching consequences, as that science which I am now seeking to establish--monistic anthropogeny.

This statement may seem to be rather audacious, since the very next branch of biology, anthropology in the stricter sense, makes very little use of these results of anthropogeny, and sometimes expressly opposes them.* (*This does not apply to English anthropologists, who are almost all evolutionists.) This applies especially to the attitude which has characterised the German Anthropological Society (the Deutsche Gesellschaft fur Anthropologie) for some thirty years. Its powerful president, the famous pathologist, Rudolph Virchow, is chiefly responsible for this. Until his death (September 5th, 1902) he never ceased to reject the theory of descent as unproven, and to ridicule its chief consequence--the descent of man from a series of mammal ancestors--as a fantastic dream. I need only recall his well-known expression at the Anthropological Congress at Vienna in 1894, that "it would be just as well to say man came from the sheep or the elephant as from the ape."

Virchow's assistant, the secretary of the German Anthropological Society, Professor Johannes Ranke of Munich, has also indefatigably opposed transformism: he has succeeded in writing a work in two volumes (Der Mensch), in which all the facts relating to his organisation are explained in a sense hostile to evolution. This work has had a wide circulation, owing to its admirable illustrations and its able treatment of the most interesting facts of anatomy and physiology--exclusive of the sexual organs! But, as it has done a great deal to spread erroneous views among the general public, I have included a criticism of it in my History of Creation, as well as met

Virchow's attacks on anthropogeny.

Neither Virchow, nor Ranke, nor any other "exact" anthropologist, has attempted to give any other natural explanation of the origin of man. They have either set completely aside this "question of questions" as a transcendental problem, or they have appealed to religion for its solution. We have to show that this rejection of the rational explanation is totally without justification. The fund of knowledge which has accumulated in the progress of biology in the nineteenth century is quite adequate to furnish a rational explanation, and to establish the theory of the evolution of man on the solid facts of his embryology.

CHAPTER 1.6. THE OVUM AND THE AMOEBA.

In order to understand clearly the course of human embryology, we must select the more important of its wonderful and manifold processes for fuller explanation, and then proceed from these to the innumerable features of less importance. The most important feature in this sense, and the best starting-point for ontogenetic study, is the fact that man is developed from an ovum, and that this ovum is a simple cell. The human ovum does not materially differ in form and composition from that of the other mammals, whereas there is a distinct difference between the fertilised ovum of the mammal and that of any other animal.

(FIGURE 1.1. The human ovum, magnified 100 times. The globular mass of yelk (b) is enclosed by a transparent membrane (the ovolemma or zona pellucida [a]), and contains a noncentral nucleus (the germinal vesicle, c). Cf. Figure 1.14.)

This fact is so important that few should be unaware of its extreme significance; yet it was quite unknown in the first quarter of the nineteenth century. As we have seen, the human and mammal ovum was not discovered until 1827, when Carl Ernst von Baer detected it. Up to that time the larger vesicles, in which the real and much smaller ovum is contained, had been wrongly regarded as ova. The important circumstance that this mammal ovum is a simple cell, like the ovum of other animals, could not, of course, be recognised until the cell theory was established. This was not done, by Schleiden for the plant and Schwann for the animal, until 1838. As we have seen, this cell theory is of the greatest service in explaining the human frame and its embryonic development. Hence we must say a few words about the actual condition of the theory and the significance of the views it has suggested.

In order properly to appreciate the cellular theory, the most important element in our science, it is necessary to understand in the first place that the cell is a UNIFIED ORGANISM, a self-contained living being. When we anatomically dissect the fully-formed animal or plant into its various organs, and then examine the finer structure of these organs with the microscope, we are surprised to find that all these different parts are ultimately made up of the same structural element or unit. This common unit of structure is the cell. It does not matter whether we thus dissect a leaf, flower, or fruit, or a bone, muscle, gland, or bit of skin, etc.; we find in every case the same ultimate constituent, which has been called the cell since Schleiden's discovery. There are many opinions as to its real nature,

but the essential point in our view of the cell is to look upon it as a self-contained or independent living unit. It is, in the words of Brucke, "an elementary organism." We may define it most precisely as the ultimate organic unit, and, as the cells are the sole active principles in every vital function, we may call them the "plastids," or "formative elements." This unity is found in both the anatomic structure and the physiological function. In the case of the protists, the entire organism usually consists of a single independent cell throughout life. But in the tissue-forming animals and plants, which are the great majority, the organism begins its career as a simple cell, and then grows into a cell-community, or, more correctly, an organised cell-state. Our own body is not really the simple unity that it is generally supposed to be. On the contrary, it is a very elaborate social system of countless microscopic organisms, a colony or commonwealth, made up of innumerable independent units, or very different tissue-cells.

In reality, the term "cell," which existed long before the cell theory was formulated, is not happily chosen. Schleiden, who first brought it into scientific use in the sense of the cell theory, gave this name to the elementary organisms because, when you find them in the dissected plant, they generally have the appearance of chambers, like the cells in a bee-hive, with firm walls and a fluid or pulpy content. But some cells, especially young ones, are entirely without the enveloping membrane, or stiff wall. Hence we now generally describe the cell as a living, viscous particle of protoplasm, enclosing a firmer nucleus in its albuminoid body. There may be an enclosing membrane, as there actually is in the case of most of the plants; but it may be wholly lacking, as is the case with most of the animals. There is no membrane at all in the first stage. The young cells are usually round, but they vary much in shape later on. Illustrations of this will be found in the cells of the various parts of the body shown in Figures 1.3 to 1.7.

Hence the essential point in the modern idea of the cell is that it is made up of two different active constituents--an inner and an outer part. The smaller and inner part is the nucleus (or caryon or cytoblastus, Figure 1.1 c and Figure 1.2 k). The outer and larger part, which encloses the other, is the body of the cell (celleus, cytos, or cytosoma). The soft living substance of which the two are composed has a peculiar chemical composition, and belongs to the group of the albuminoid plasma-substances ("formative matter"), or protoplasm. The essential and indispensable element of the nucleus is called nuclein (or caryoplasm); that of the cell body is called plastin (or cytoplasm). In the most rudimentary cases both substances seem to be quite simple and homogeneous, without any visible structure. But, as a rule, when we examine them under a high power of the microscope, we find a certain structure in the protoplasm. The chief and most common form of this is the fibrous or net-like "thready structure" (Frommann) and the frothy "honeycomb structure" (Butschli).

(FIGURE 1.2. Stem-cell of one of the echinoderms (cytula, or "first segmentation-cell" = fertilised ovum), after Hertwig. k is the nucleus or caryon.)

The shape or outer form of the cell is infinitely varied, in accordance with its endless power of adapting itself to the most diverse activities or environments. In its simplest form the cell is globular (Figure 1.2). This normal round form is especially found in

cells of the simplest construction, and those that are developed in a free fluid without any external pressure. In such cases the nucleus also is not infrequently round, and located in the centre of the cell-body (Figure 1.2 k). In other cases, the cells have no definite shape; they are constantly changing their form owing to their automatic movements. This is the case with the amoebae (Figures 1.15 and 1.16) and the amoeboid travelling cells (Figure 1.11), and also with very young ova (Figure 1.13). However, as a rule, the cell assumes a definite form in the course of its career. In the tissues of the multicellular organism, in which a number of similar cells are bound together in virtue of certain laws of heredity, the shape is determined partly by the form of their connection and partly by their special functions. Thus, for instance, we find in the mucous lining of our tongue very thin and delicate flat cells of roundish shape (Figure 1.3). In the outer skin we find similar, but harder, covering cells, joined together by saw-like edges (Figure 1.4). In the liver and other glands there are thicker and softer cells, linked together in rows (Figure 1.5).

The last-named tissues (Figures 1.3 to 1.5) belong to the simplest and most primitive type, the group of the "covering-tissues," or epithelia. In these "primary tissues" (to which the germinal layers belong) simple cells of the same kind are arranged in layers. The arrangement and shape are more complicated in the "secondary tissues," which are gradually developed out of the primary, as in the tissues of the muscles, nerves, bones, etc. In the bones, for instance, which belong to the group of supporting or connecting organs, the cells (Figure 1.6) are star-shaped, and are joined together by numbers of net-like interlacing processes; so, also, in the tissues of the teeth (Figure 1.7), and in other forms of supporting-tissue, in which a soft or hard substance (intercellular matter, or base) is inserted between the cells.

(FIGURE 1.3. Three epithelial cells from the mucous lining of the tongue.

FIGURE 1.4. Five spiny or grooved cells, with edges joined, from the outer skin (epidermis): one of them (b) is isolated.

FIGURE 1.5. Ten liver-cells: one of them (b) has two nuclei.)

The cells also differ very much in size. The great majority of them are invisible to the naked eye, and can be seen only through the microscope (being as a rule between 1/2500 and 1/250 inch in diameter). There are many of the smaller plastids--such as the famous bacteria--which only come into view with a very high magnifying power. On the other hand, many cells attain a considerable size, and run occasionally to several inches in diameter, as do certain kinds of rhizopods among the unicellular protists (such as the radiolaria and thalamophora). Among the tissue-cells of the animal body many of the muscular fibres and nerve fibres are more than four inches, and sometimes more than a yard, in length. Among the largest cells are the yelk-filled ova; as, for instance, the yellow "yolk" in the hen's egg, which we shall describe later (Figure 1.15).

Cells also vary considerably in structure. In this connection we must first distinguish between the active and passive components of the cell. It is only the former, or active parts of the cell, that really live, and effect that marvellous world of phenomena to which we give

the name of "organic life." The first of these is the inner nucleus (caryoplasm), and the second the body of the cell (cytoplasm). The passive portions come third; these are subsequently formed from the others, and I have given them the name of "plasma-products." They are partly external (cell-membranes and intercellular matter) and partly internal (cell-sap and cell-contents).

The nucleus (or caryon), which is usually of a simple roundish form, is quite structureless at first (especially in very young cells), and composed of homogeneous nuclear matter or caryoplasm (Figure 1.2 k). But, as a rule, it forms a sort of vesicle later on, in which we can distinguish a more solid nuclear base (caryobasis) and a softer or fluid nuclear sap (caryolymph). In a mesh of the nuclear network (or it may be on the inner side of the nuclear envelope) there is, as a rule, a dark, very opaque, solid body, called the nucleolus. Many of the nuclei contain several of these nucleoli (as, for instance, the germinal vesicle of the ova of fishes and amphibia). Recently a very small, but particularly important, part of the nucleus has been distinguished as the central body (centrosoma)--a tiny particle that is originally found in the nucleus itself, but is usually outside it, in the cytoplasm; as a rule, fine threads stream out from it in the cytoplasm. From the position of the central body with regard to the other parts it seems probable that it has a high physiological importance as a centre of movement; but it is lacking in many cells.

The cell-body also consists originally, and in its simplest form, of a homogeneous viscid plasmic matter. But, as a rule, only the smaller part of it is formed of the living active cell-substance (protoplasm); the greater part consists of dead, passive plasma-products (metaplasm). It is useful to distinguish between the inner and outer of these. External plasma-products (which are thrust out from the protoplasm as solid "structural matter") are the cell-membranes and the intercellular matter. The internal plasma-products are either the fluid cell-sap or hard structures. As a rule, in mature and differentiated cells these various parts are so arranged that the protoplasm (like the caryoplasm in the round nucleus) forms a sort of skeleton or framework. The spaces of this network are filled partly with the fluid cell-sap and partly by hard structural products.

(FIGURE 1.6. Nine star-shaped bone-cells, with interlaced branches.

FIGURE 1.7. Eleven star-shaped cells from the enamel of a tooth, joined together by their branchlets.)

The simple round ovum, which we take as the starting-point of our study (Figures 1.1 and 1.2), has in many cases the vague, indifferent features of the typical primitive cell. As a contrast to it, and as an instance of a very highly differentiated plastid, we may consider for a moment a large nerve-cell, or ganglionic cell, from the brain. The ovum stands potentially for the entire organism--in other words, it has the faculty of building up out of itself the whole multicellular body. It is the common parent of all the countless generations of cells which form the different tissues of the body; it unites all their powers in itself, though only potentially or in germ. In complete contrast to this, the neural cell in the brain (Figure 1.9) develops along one rigid line. It cannot, like the ovum, beget endless generations of cells, of which some will become skin-cells, others muscle-cells, and others again bone-cells. But, on the other hand, the nerve-cell has become fitted to discharge the highest functions of

life; it has the powers of sensation, will, and thought. It is a real soul-cell, or an elementary organ of the psychic activity. It has, therefore, a most elaborate and delicate structure. Numbers of extremely fine threads, like the electric wires at a large telegraphic centre, cross and recross in the delicate protoplasm of the nerve cell, and pass out in the branching processes which proceed from it and put it in communication with other nerve-cells or nerve-fibres (a, b). We can only partly follow their intricate paths in the fine matter of the body of the cell.

Here we have a most elaborate apparatus, the delicate structure of which we are just beginning to appreciate through our most powerful microscopes, but whose significance is rather a matter of conjecture than knowledge. Its intricate structure corresponds to the very complicated functions of the mind. Nevertheless, this elementary organ of psychic activity--of which there are thousands in our brain--is nothing but a single cell. Our whole mental life is only the joint result of the combined activity of all these nerve-cells, or soul-cells. In the centre of each cell there is a large transparent nucleus, containing a small and dark nuclear body. Here, as elsewhere, it is the nucleus that determines the individuality of the cell; it proves that the whole structure, in spite of its intricate composition, amounts to only a single cell.

(FIGURE 1.8. Unfertilised ovum of an echinoderm (from Hertwig). The vesicular nucleus (or "germinal vesicle") is globular, half the size of the round ovum, and encloses a nuclear framework, in the central knot of which there is a dark nucleolus (the "germinal spot").

FIGURE 1.9. A large branching nerve-cell, or "soul-cell," from the brain of an electric fish (Torpedo), magnified 600 times. In the middle of the cell is the large transparent round nucleus, one nucleolus, and, within the latter again, a nucleolinus. The protoplasm of the cell is split into innumerable fine threads (or fibrils), which are embedded in intercellular matter, and are prolonged into the branching processes of the cell (b). One branch (a) passes into a nerve-fibre. (From Max Schultze.))

In contrast with this very elaborate and very strictly differentiated psychic cell (Figure 1.9), we have our ovum (Figures 1.1 and 1.2), which has hardly any structure at all. But even in the case of the ovum we must infer from its properties that its protoplasmic body has a very complicated chemical composition and a fine molecular structure which escapes our observation. This presumed molecular structure of the plasm is now generally admitted; but it has never been seen, and, indeed, lies far beyond the range of microscopic vision. It must not be confused--as is often done--with the structure of the plasm (the fibrous network, groups of granules, honey-comb, etc.) which does come within the range of the microscope.

But when we speak of the cells as the elementary organisms, or structural units, or "ultimate individualities," we must bear in mind a certain restriction of the phrases. I mean, that the cells are not, as is often supposed, the very lowest stage of organic individuality. There are yet more elementary organisms to which I must refer occasionally. These are what we call the "cytodes" (cytos = cell), certain living, independent beings, consisting only of a particle of plasson--an albuminoid substance, which is not yet differentiated into caryoplasm and cytoplasm, but combines the properties of both. Those

remarkable beings called the monera--especially the chromacea and bacteria--are specimens of these simple cytodes. (Compare Chapter 2.19.) To be quite accurate, then, we must say: the elementary organism, or the ultimate individual, is found in two different stages. The first and lower stage is the cytode, which consists merely of a particle of plasson, or quite simple plasm. The second and higher stage is the cell, which is already divided or differentiated into nuclear matter and cellular matter. We comprise both kinds--the cytodes and the cells--under the name of plastids ("formative particles"), because they are the real builders of the organism. However, these cytodes are not found, as a rule, in the higher animals and plants; here we have only real cells with a nucleus. Hence, in these tissue-forming organisms (both plant and animal) the organic unit always consists of two chemically and anatomically different parts--the outer cell-body and the inner nucleus.

In order to convince oneself that this cell is really an independent organism, we have only to observe the development and vital phenomena of one of them. We see then that it performs all the essential functions of life--both vegetal and animal--which we find in the entire organism. Each of these tiny beings grows and nourishes itself independently. It takes its food from the surrounding fluid; sometimes, even, the naked cells take in solid particles at certain points of their surface--in other words, "eat" them--without needing any special mouth and stomach for the purpose (cf. Figure 1.19).

Further, each cell is able to reproduce itself. This multiplication, in most cases, takes the form of a simple cleavage, sometimes direct, sometimes indirect; the simple direct (or "amitotic") division is less common, and is found, for instance, in the blood cells (Figure 1.10). In these the nucleus first divides into two equal parts by constriction. The indirect (or "mitotic") cleavage is much more frequent; in this the caryoplasm of the nucleus and the cytoplasm of the cell-body act upon each other in a peculiar way, with a partial dissolution (caryolysis), the formation of knots and loops (mitosis), and a movement of the halved plasma-particles towards two mutually repulsive poles of attraction (caryokinesis, Figure 1.11.)

(FIGURE 1.10. Blood-cells, multiplying by direct division, from the blood of the embryo of a stag. Originally, each blood-cell has a nucleus and is round (a). When it is going to multiply, the nucleus divides into two (b, c, d). Then the protoplasmic body is constricted between the two nuclei, and these move away from each other (e). Finally, the constriction is complete, and the cell splits into two daughter-cells (f). (From Frey.))

FIGURE 1.11. Indirect or mitotic cell-division (with caryolysis and caryokinesis) from the skin of the larva of a salamander. (From Rabl.).

A. Mother-cell (Knot, spirema), with Nuclear threads (chromosomata) (coloured nuclear matter, chromatin), Cytosoma, Nuclear membrane, Protoplasm of the cell-body and Nuclear sap.

B. Mother-star, the loops beginning to split lengthways (nuclear membrane gone), with Star-like appearance in cytoplasm, Centrosoma (sphere of attraction), Nuclear spindle (achromin, colourless matter) and Nuclear loops (chromatin, coloured matter).

C. The two daughter-stars, produced by the breaking of the loops of the mother-star (moving away), with Upper daughter-crown, Connecting threads of the two crowns (achromin), Lower daughter-crown and

Double-star (amphiaster).
D. The two daughter-cells, produced by the complete division of the two nuclear halves (cytosomata still connected at the equator) (Double-knot, Dispirema), with Upper daughter-nucleus, Equatorial constriction of the cell-body and Lower daughter-nucleus.)

The intricate physiological processes which accompany this "mitosis" have been very closely studied of late years. The inquiry has led to the detection of certain laws of evolution which are of extreme importance in connection with heredity. As a rule, two very different parts of the nucleus play an important part in these changes. They are: the chromatin, or coloured nuclear substance, which has a peculiar property of tingeing itself deeply with certain colouring matters (carmine, haematoxylin, etc.), and the achromin (or linin, or achromatin), a colourless nuclear substance that lacks this property. The latter generally forms in the dividing cell a sort of spindle, at the poles of which there is a very small particle, also colourless, called the "central body" (centrosoma). This acts as the centre or focus in a "sphere of attraction" for the granules of protoplasm in the surrounding cell-body, and assumes a star-like appearance (the cell-star, or monaster). The two central bodies, standing opposed to each other at the poles of the nuclear spindle, form "the double-star" (or amphiaster, Figure 1.11, BC). The chromatin often forms a long, irregularly-wound thread--"the coil" (spirema, Figure A). At the commencement of the cleavage it gathers at the equator of the cell, between the stellar poles, and forms a crown of U-shaped loops (generally four or eight, or some other definite number). The loops split lengthwise into two halves (B), and these back away from each other towards the poles of the spindle (C). Here each group forms a crown once more, and this, with the corresponding half of the divided spindle, forms a fresh nucleus (D). Then the protoplasm of the cell-body begins to contract in the middle, and gather about the new daughter-nuclei, and at last the two daughter-cells become independent beings.

Between this common mitosis, or indirect cell-division--which is the normal cleavage-process in most cells of the higher animals and plants--and the simple direct division (Figure 1.10) we find every grade of segmentation; in some circumstances even one kind of division may be converted into another.

The plastid is also endowed with the functions of movement and sensation. The single cell can move and creep about, when it has space for free movement and is not prevented by a hard envelope; it then thrusts out at its surface processes like fingers, and quickly withdraws them again, and thus changes its shape (Figure 1.12). Finally, the young cell is sensitive, or more or less responsive to stimuli; it makes certain movements on the application of chemical and mechanical irritation. Hence we can ascribe to the individual cell all the chief functions which we comprehend under the general heading of "life"--sensation, movement, nutrition, and reproduction. All these properties of the multicellular and highly developed animal are also found in the single animal-cell, at least in its younger stages. There is no longer any doubt about this, and so we may regard it as a solid and important base of our physiological conception of the elementary organism.

Without going any further here into these very interesting phenomena of the life of the cell, we will pass on to consider the application

of the cell theory to the ovum. Here comparative research yields the important result that EVERY OVUM IS AT FIRST A SIMPLE CELL. I say this is very important, because our whole science of embryology now resolves itself into the problem: "How does the multicellular organism arise from the unicellular?" Every organic individual is at first a simple cell, and as such an elementary organism, or a unit of individuality. This cell produces a cluster of cells by segmentation, and from these develops the multicellular organism, or individual of higher rank.

When we examine a little closer the original features of the ovum, we notice the extremely significant fact that in its first stage the ovum is just the same simple and indefinite structure in the case of man and all the animals (Figure 1.13). We are unable to detect any material difference between them, either in outer shape or internal constitution. Later, though the ova remain unicellular, they differ in size and shape, enclose various kinds of yelk-particles, have different envelopes, and so on. But when we examine them at their birth, in the ovary of the female animal, we find them to be always of the same form in the first stages of their life. In the beginning each ovum is a very simple, roundish, naked, mobile cell, without a membrane; it consists merely of a particle of cytoplasm enclosing a nucleus (Figure 1.13). Special names have been given to these parts of the ovum; the cell-body is called the yelk (vitellus), and the cell-nucleus the germinal vesicle. As a rule, the nucleus of the ovum is soft, and looks like a small pimple or vesicle. Inside it, as in many other cells, there is a nuclear skeleton or frame and a third, hard nuclear body (the nucleolus). In the ovum this is called the germinal spot. Finally, we find in many ova (but not in all) a still further point within the germinal spot, a "nucleolin," which goes by the name of the germinal point. The latter parts (germinal spot and germinal point) have, apparently, a minor importance, in comparison with the other two (the yelk and germinal vesicle). In the yelk we must distinguish the active formative yelk (or protoplasm = first plasm) from the passive nutritive yelk (or deutoplasm = second plasm).

(FIGURE 1.12. Mobile cells from the inflamed eye of a frog (from the watery fluid of the eye, the humor aqueus). The naked cells creep freely about, by (like the amoeba or rhizopods) protruding fine processes from the uncovered protoplasmic body. These bodies vary continually in number, shape, and size. The nucleus of these amoeboid lymph-cells ("travelling cells," or planocytes) is invisible, because concealed by the numbers of fine gra

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