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By Joseph McCabe

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PREFACE

An ingenious student of science once entertained his generation with a theory of how one might behold again all the stirring chapters that make up the story of the earth. The living scene of our time is lit by the light of the sun, and for every few rays that enter the human eye, and convey the image of it to the human mind, great floods of the reflected light pour out, swiftly and indefinitely, into space. Imagine, then, a man moving out into space more rapidly than light, his face turned toward the earth. Flashing through the void at, let us say, a million miles a second, he would (if we can overlook the dispersion of the rays of light) overtake in succession the light that fell on the French Revolution, the Reformation, the Norman Conquest, and the faces of the ancient empires. He would read, in reverse order, the living history of man and whatever lay before the coming of man.

Few thought, as they smiled over this fairy tale of science, that some such panoramic survey of the story of the earth, and even of the heavens, might one day be made in a leisure hour by ordinary mortals; that in the soil on which they trod were surer records of the past than in its doubtful literary remains, and in the deeper rocks were records that dimly lit a vast abyss of time of which they never dreamed. It is the supreme achievement of modern science to have discovered and deciphered these records. The picture of the past which they afford is, on the whole, an outline sketch. Here and there the details, the colour, the light and shade, may be added; but the greater part of the canvas is left to the more skilful hand of a future generation, and even the broad lines are at times uncertain. Yet each age would know how far its scientific men have advanced in constructing that picture of the growth of the heavens and the earth, and the aim of the present volume is to give, in clear and plain language, as full an account of the story as the present condition of our knowledge and the limits of the volume will allow. The author has been for many years interested in the evolution of things, or the way in which suns and atoms, fishes and flowers, hills and elephants, even man and his institutions, came to be what they are. Lecturing and writing on one or other phase of the subject have, moreover, taught him a language which the inexpert seem to understand, although he is not content merely to give a superficial description of the past inhabitants of the earth.

The particular features which, it is hoped, may give the book a distinctive place in the large literature of evolution are, first, that it includes the many evolutionary discoveries of the last few years, gathers its material from the score of sciences which confine themselves to separate aspects of the universe, and blends all these facts and discoveries in a more or less continuous chronicle of the life of the heavens and the earth. Then the author has endeavoured to show, not merely how, but why, scene succeeds scene in the chronicle of the earth, and life slowly climbs from level to level. He has taken nature in the past as we find it to-day: an interconnected whole, in which the changes of land and sea, of heat and cold, of swamp and hill, are faithfully reflected in the forms of its living population. And, finally, he has written for those who are not students of science, or whose knowledge may be confined to one branch of science, and used a plain speech which assumes no previous knowledge on the reader's part.

For the rest, it will be found that no strained effort is made to trace pedigrees of animals and plants when the material is scanty; that, if on account of some especial interest disputable or conjectural speculations are admitted, they are frankly described as such; and that the more important differences of opinion which actually divide astronomers, geologists, biologists, and anthropologists are carefully taken into account and briefly explained. A few English and American works are recommended for the convenience of those who would study particular chapters more closely, but it has seemed useless, in such a work, to give a bibliography of the hundreds of English, American, French, German, and Italian works which have been consulted.

CONTENTS

THE STORY OF EVOLUTION

THE STORY OF EVOLUTION

CHAPTER I. THE DISCOVERY OF THE UNIVERSE

The beginning of the victorious career of modern science was very largely due to the making of two stimulating discoveries at the close of the Middle Ages. One was the discovery of the earth: the other the discovery of the universe. Men were confined, like molluscs in their shells, by a belief that they occupied the centre of a comparatively small disk—some ventured to say a globe—which was poised in a mysterious way in the middle of a small system of heavenly bodies. The general feeling was that these heavenly bodies were lamps hung on a not too remote ceiling for the purpose of lighting their ways. Then certain enterprising sailors—Vasco da Gama, Maghalaes, Columbus—brought home the news that the known world was only one side of an enormous globe, and that there were vast lands and great peoples thousands of miles across the ocean. The minds of men in Europe had hardly strained their shells sufficiently to embrace this larger earth when the second discovery was reported. The roof of the world, with its useful little system of heavenly bodies, began to crack and disclose a profound and mysterious universe surrounding them on every side. One cannot understand the solidity of the modern doctrine of the formation of the heavens and the earth until one appreciates this revolution.

Before the law of gravitation had been discovered it was almost impossible to regard the universe as other than a small and compact system. We shall see that a few daring minds pierced the veil, and peered out wonderingly into the real universe beyond, but for the great mass of men it was quite impossible. To them the modern idea of a universe consisting of hundreds of millions of bodies, each weighing billions of tons, strewn over billions of miles of space, would have seemed the dream of a child or a savage. Material bodies were "heavy," and would "fall down" if they were not supported. The universe, they said, was a sensible scientific structure; things were supported in their respective places. A great dome, of some unknown but compact material, spanned the earth, and sustained the heavenly bodies. It might rest on the distant mountains, or be borne on the shoulders of an Atlas; or the whole cosmic scheme might be laid on the back of a gigantic elephant, and—if you pressed—the elephant might stand on the hard shell of a tortoise. But you were not encouraged to press.

The idea of the vault had come from Babylon, the first home of science. No furnaces thickened that clear atmosphere, and the heavy-robed priests at the summit of each of the seven-staged temples were astronomers. Night by night for thousands of years they watched the stars and planets tracing their undeviating paths across the sky. To explain their movements the priest-astronomers invented the solid firmament. Beyond the known land, encircling it, was the sea, and beyond the sea was a range of high mountains, forming another girdle round the earth. On these mountains the dome of the heavens rested, much as the dome of St. Paul's rests on its lofty masonry. The sun travelled across its under-surface by day, and went back to the east during the night through a tunnel in the lower portion of the vault. To the common folk the priests explained that this framework of the world was the body of an ancient and disreputable goddess. The god of light had slit her in two, "as you do a dried fish," they said, and made the plain of the earth with one half and the blue arch of the heavens with the other.

So Chaldaea lived out its 5000 years without discovering the universe. Egypt adopted the idea from more scientific Babylon. Amongst the fragments of its civilisation we find representations of the firmament as a goddess, arching over the earth on her hands and feet, condemned to that eternal posture by some victorious god. The idea spread amongst the smaller nations which were lit by the civilisation of Babylon and Egypt. Some blended it with coarse old legends; some, like the Persians and Hebrews, refined it. The Persians made fire a purer and lighter spirit, so that the stars would need no support. But everywhere the blue vault hemmed in the world and the ideas of men. It was so close, some said, that the birds could reach it. At last the genius of Greece brooded over the whole chaos of cosmical speculations.

The native tradition of Greece was a little more helpful than the Babylonian teaching. First was chaos; then the heavier matter sank to the bottom, forming the disk of the earth, with the ocean poured round it, and the less coarse matter floated as an atmosphere above it, and the still finer matter formed an "aether" above the atmosphere. A remarkably good guess, in its very broad outline; but the solid firmament still arched the earth, and the stars were little undying fires in the vault. The earth itself was small and flat. It stretched (on the modern map) from about Gibraltar to the Caspian, and from Central Germany—where the entrance to the lower world was located—to the Atlas mountains. But all the varied and conflicting culture of the older empires was now passing into Greece, lighting up in succession the civilisations of Asia Minor, the Greek islands, and then Athens and its sister states. Men began to think.

The first genius to have a glimpse of the truth seems to have been the grave and mystical Pythagorus (born about 582 B.C.). He taught his little school that the earth was a globe, not a disk, and that it turned on its axis in twenty-four hours. The earth and the other planets were revolving round the central fire of the system; but the sun was a reflection of this central fire, not the fire itself. Even Pythagoras, moreover, made the heavens a solid sphere revolving, with its stars, round the central fire; and the truth he discovered was mingled with so much mysticism, and confined to so small and retired a school, that it was quickly lost again. In the next generation Anaxagoras taught that the sun was a vast globe of white-hot iron, and that the stars were material bodies made white-hot by friction with the ether. A generation later the famous Democritus came nearer than any to the truth. The universe was composed of an infinite number of indestructible particles, called "atoms," which had gradually settled from a state of chaotic confusion to their present orderly arrangement in large masses. The sun was a body of enormous size, and the points of light in the Milky Way were similar suns at a tremendous distance from the earth. Our universe, moreover, was only one of an infinite number of universes, and an eternal cycle of destruction and re-formation was running through these myriads of worlds.

By sheer speculation Greece was well on the way of discovery. Then the mists of philosophy fell between the mind of Greece and nature, and the notions of Democritus were rejected with disdain; and then, very speedily, the decay of the brilliant nation put an end to its feverish search for truth. Greek culture passed to Alexandria, where it met the remains of the culture of Egypt, Babylonia, and Persia, and one more remarkable effort was made to penetrate the outlying universe before the night of the Middle Ages fell on the old world.

Astronomy was ardently studied at Alexandria, and was fortunately combined with an assiduous study of mathematics. Aristarchus (about 320-250 B.C.) calculated that the sun was 84,000,000 miles away; a vast expansion of the solar system and, for the time, a remarkable approach to the real figure (92,000,000) Eratosthenes (276-196 B.C.) made an extremely good calculation of the size of the earth, though he held it to be the centre of a small universe. He concluded that it was a globe measuring 27,000 (instead of 23,700) miles in circumference. Posidonius (135-51 B.C.) came even nearer with a calculation that the circumference was between 25,000 and 19,000 miles; and he made a fairly correct estimate of the diameter, and therefore distance, of the sun. Hipparchus (190-120 B.C.) made an extremely good calculation of the distance of the moon.

By the brilliant work of the Alexandrian astronomers the old world seemed to be approaching the discovery of the universe. Men were beginning to think in millions, to gaze boldly into deep abysses of space, to talk of vast fiery globes that made the earth insignificant But the splendid energy gradually failed, and the long line was closed by Ptolemaeus, who once more put the earth in the centre of the system, and so imposed what is called the Ptolemaic system on Europe. The keen school-life of Alexandria still ran on, and there might have been a return to the saner early doctrines, but at last Alexandrian culture was extinguished in the blood of the aged Hypatia, and the night fell. Rome had had no genius for science; though Lucretius gave an immortal expression to the views of Democritus and Epicurus, and such writers as Cicero and Pliny did great service to a later age in preserving fragments of the older discoveries. The curtains were once more drawn about the earth. The glimpses which adventurous Greeks had obtained of the great outlying universe were forgotten for a thousand years. The earth became again the little platform in the centre of a little world, on which men and women played their little parts, preening themselves on their superiority to their pagan ancestors.

I do not propose to tell the familiar story of the revival at any length. As far as the present subject is concerned, it was literally a Renascence, or re-birth, of Greek ideas. Constantinople having been taken by the Turks (1453), hundreds of Greek scholars, with their old literature, sought refuge in Europe, and the vigorous brain of the young nations brooded over the ancient speculations, just as the vigorous young brain of Greece had done two thousand years before. Copernicus (1473-1543) acknowledges that he found the secret of the movements of the heavenly bodies in the speculations of the old Greek thinkers. Galilei (1564-1642) enlarged the Copernican system with the aid of the telescope; and the telescope was an outcome of the new study of optics which had been inspired in Roger Bacon and other medieval scholars by the optical works, directly founded on the Greek, of the Spanish Moors. Giordano Bruno still further enlarged the system; he pictured the universe boldly as an infinite ocean of liquid ether, in which the stars, with retinues of inhabited planets, floated majestically. Bruno was burned at the stake (1600); but the curtains that had so long been drawn about the earth were now torn aside for ever, and men looked inquiringly into the unfathomable depths beyond. Descartes (1596-1650) revived the old Greek idea of a gradual evolution of the heavens and the earth from a primitive chaos of particles, taught that the stars stood out at unimaginable distances in the ocean of ether, and imagined the ether as stirring in gigantic whirlpools, which bore cosmic bodies in their orbits as the eddy in the river causes the cork to revolve.

These stimulating conjectures made a deep impression on the new age. A series of great astronomers had meantime been patiently and scientifically laying the foundations of our knowledge. Kepler (1571-1630) formulated the laws of the movement of the planets; Newton (1642-1727) crowned the earlier work with his discovery of the real agency that sustains cosmic bodies in their relative positions. The primitive notion of a material frame and the confining dome of the ancients were abandoned. We know now that a framework of the most massive steel would be too frail to hold together even the moon and the earth. It would be rent by the strain. The action of gravitation is the all-sustaining power. Once introduce that idea, and the great ocean of ether might stretch illimitably on every side, and the vastest bodies might be scattered over it and traverse it in stupendous paths. Thus it came about that, as the little optic tube of Galilei slowly developed into the giant telescope of Herschel, and then into the powerful refracting telescopes of the United States of our time; as the new science of photography provided observers with a new eye—a sensitive plate that will register messages, which the human eye cannot detect, from far-off regions; and as a new instrument, the spectroscope, endowed astronomers with a power of perceiving fresh aspects of the inhabitants of space, the horizon rolled backward, and the mind contemplated a universe of colossal extent and power.

Let us try to conceive this universe before we study its evolution. I do not adopt any of the numerous devices that have been invented for the purpose of impressing on the imagination the large figures we must use. One may doubt if any of them are effective, and they are at least familiar. Our solar system—the family of sun and planets which had been sheltered under a mighty dome resting on the hill-tops—has turned out to occupy a span of space some 16,000,000,000 miles in diameter. That is a very small area in the new universe. Draw a circle, 100 billion miles in diameter, round the sun, and you will find that it contains only three stars besides the sun. In other words, a sphere of space measuring 300 billion miles in circumference—we will not venture upon the number of cubic miles—contains only four stars (the sun, alpha Centauri, 21,185 Lalande, and 61 Cygni). However, this part of space seems to be below the average in point of population, and we must adopt a different way of estimating the magnitude of the universe from the number of its stellar citizens.

Beyond the vast sphere of comparatively empty space immediately surrounding our sun lies the stellar universe into which our great telescopes are steadily penetrating. Recent astronomers give various calculations, ranging from 200,000,000 to 2,000,000,000, of the number of stars that have yet come within our faintest knowledge. Let us accept the modest provisional estimate of 500,000,000. Now, if we had reason to think that these stars were of much the same size and brilliance as our sun, we should be able roughly to calculate their distance from their faintness. We cannot do this, as they differ considerably in size and intrinsic brilliance. Sirius is more than twice the size of our sun and gives out twenty times as much light. Canopus emits 20,000 times as much light as the sun, but we cannot say, in this case, how much larger it is than the sun. Arcturus, however, belongs to the same class of stars as our sun, and astronomers conclude that it must be thousands of times larger than the sun. A few stars are known to be smaller than the sun. Some are, intrinsically, far more brilliant; some far less brilliant.

Another method has been adopted, though this also must be regarded with great reserve. The distance of the nearer stars can be positively measured, and this has been done in a large number of cases. The proportion of such cases to the whole is still very small, but, as far as the results go, we find that stars of the first magnitude are, on the average, nearly 200 billion miles away; stars of the second magnitude nearly 300 billion; and stars of the third magnitude 450 billion. If this fifty per cent increase of distance for each lower magnitude of stars were certain and constant, the stars of the eighth magnitude would be 3000 billion miles away, and stars of the sixteenth magnitude would be 100,000 billion miles away; and there are still two fainter classes of stars which are registered on long-exposure photographs. The mere vastness of these figures is immaterial to the astronomer, but he warns us that the method is uncertain. We may be content to conclude that the starry universe over which our great telescopes keep watch stretches for thousands, and probably tens of thousands, of billions of miles. There are myriads of stars so remote that, though each is a vast incandescent globe at a temperature of many thousand degrees, and though their light is concentrated on the mirrors or in the lenses of our largest telescopes and directed upon the photographic plate at the rate of more than 800 billion waves a second, they take several hours to register the faintest point of light on the plate.

When we reflect that the universe has grown with the growth of our telescopes and the application of photography we wonder whether we may as yet see only a fraction of the real universe, as small in comparison with the whole as the Babylonian system was in comparison with ours. We must be content to wonder. Some affirm that the universe is infinite; others that it is limited. We have no firm ground in science for either assertion. Those who claim that the system is limited point out that, as the stars decrease in brightness, they increase so enormously in number that the greater faintness is more than compensated, and therefore, if there were an infinite series of magnitudes, the midnight sky would be a blaze of light. But this theoretical reasoning does not allow for dense regions of space that may obstruct the light, or vast regions of vacancy between vast systems of stars. Even apart from the evidence that dark nebulae or other special light-absorbing regions do exist, the question is under discussion in science at the present moment whether light is not absorbed in the passage through ordinary space. There is reason to think that it is. Let us leave precarious speculations about finiteness and infinity to philosophers, and take the universe as we know it.

Picture, then, on the more moderate estimate, these 500,000,000 suns scattered over tens of thousands of billions of miles. Whether they form one stupendous system, and what its structure may be, is too obscure a subject to be discussed here. Imagine yourself standing at a point from which you can survey the whole system and see into the depths and details of it. At one point is a single star (like our sun), billions of miles from its nearest neighbour, wearing out its solitary life in a portentous discharge of energy. Commonly the stars are in pairs, turning round a common centre in periods that may occupy hundreds of days or hundreds of years. Here and there they are gathered into clusters, sometimes to the number of thousands in a cluster, travelling together over the desert of space, or trailing in lines like luminous caravans. All are rushing headlong at inconceivable speeds. Few are known to be so sluggish as to run, like our sun, at only 8000 miles an hour. One of the "fixed" stars of the ancients, the mighty Arcturus, darts along at a rate of more than 250 miles a second. As they rush, their surfaces glowing at a temperature anywhere between 1000 and 20,000 degrees C., they shake the environing space with electric waves from every tiny particle of their body at a rate of from 400 billion to 800 billion waves a second. And somewhere round the fringe of one of the smaller suns there is a little globe, more than a million times smaller than the solitary star it attends, lost in the blaze of its light, on which human beings find a home during a short and late chapter of its history.

Look at it again from another aspect. Every colour of the rainbow is found in the stars. Emerald, azure, ruby, gold, lilac, topaz, fawn—they shine with wonderful and mysterious beauty. But, whether these more delicate shades be really in the stars or no, three colours are certainly found in them. The stars sink from bluish white to yellow, and on to deep red. The immortal fires of the Greeks are dying. Piercing the depths with a dull red glow, here and there, are the dying suns; and if you look closely you will see, flitting like ghosts across the light of their luminous neighbours, the gaunt frames of dead worlds. Here and there are vast stretches of loose cosmic dust that seems to be gathering into embryonic stars; here and there are stars in infancy or in strenuous youth. You detect all the chief phases of the making of a world in the forms and fires of these colossal aggregations of matter. Like the chance crowd on which you may look down in the square of a great city, they range from the infant to the worn and sinking aged. There is this difference, however, that the embryos of worlds sprawl, gigantic and luminous, across the expanse; that the dark and mighty bodies of the dead rush, like the rest, at twenty or fifty miles a second; and that at intervals some appalling blaze, that dims even the fearful furnaces of the living, seems to announce the resurrection of the dead. And there is this further difference, that, strewn about the intermediate space between the gigantic spheres, is a mass of cosmic dust—minute grains, or large blocks, or shoals consisting of myriads of pieces, or immeasurable clouds of fine gas—that seems to be the rubbish left over after the making of worlds, or the material gathering for the making of other worlds.

This is the universe that the nineteenth century discovered and the twentieth century is interpreting. Before we come to tell the fortunes of our little earth we have to see how matter is gathered into these stupendous globes of fire, how they come sometimes to have smaller bodies circling round them on which living things may appear, how they supply the heat and light and electricity that the living things need, and how the story of life on a planet is but a fragment of a larger story. We have to study the birth and death of worlds, perhaps the most impressive of all the studies that modern science offers us. Indeed, if we would read the whole story of evolution, there is an earlier chapter even than this; the latest chapter to be opened by science, the first to be read. We have to ask where the matter, which we are going to gather into worlds, itself came from; to understand more clearly what is the relation to it of the forces or energies—gravitation, electricity, etc.—with which we glibly mould it into worlds, or fashion it into living things; and, above all, to find out its relation to this mysterious ocean of ether in which it is found.

Less than half a century ago the making of worlds was, in popular expositions of science, a comparatively easy business. Take an indefinite number of atoms of various gases and metals, scatter them in a fine cloud over some thousands of millions of miles of space, let gravitation slowly compress the cloud into a globe, its temperature rising through the compression, let it throw off a ring of matter, which in turn gravitation will compress into a globe, and you have your earth circulating round the sun. It is not quite so simple; in any case, serious men of science wanted to know how these convenient and assorted atoms happened to be there at all, and what was the real meaning of this equally convenient gravitation. There was a greater truth than he knew in the saying of an early physicist, that the atom had the look of a "manufactured article." It was increasingly felt, as the nineteenth century wore on, that the atoms had themselves been evolved out of some simpler material, and that ether might turn out to be the primordial chaos. There were even those who felt that ether would prove to be the one source of all matter and energy. And just before the century closed a light began to shine in those deeper abysses of the submaterial world, and the foundations of the universe began to appear.

CHAPTER II. THE FOUNDATIONS OF THE UNIVERSE

To the mind of the vast majority of earlier observers the phrase "foundations of the universe" would have suggested something enormously massive and solid. From what we have already seen we are prepared, on the contrary, to pass from the inconceivably large to the inconceivably small. Our sun is, as far as our present knowledge goes, one of modest dimensions. Arcturus and Canopus must be thousands of times larger than it. Yet our sun is 320,000 times heavier than the earth, and the earth weighs some 6,000,000,000,000,000,000,000 tons. But it is only in resolving these stupendous masses into their tiniest elements that we can reach the ultimate realities, or foundations, of the whole.

Modern science rediscovered the atoms of Democritus, analysed the universe into innumerable swarms of these tiny particles, and then showed how the infinite variety of things could be built up by their combinations. For this it was necessary to suppose that the atoms were not all alike, but belonged to a large number of different classes. From twenty-six letters of the alphabet we could make millions of different words. From forty or fifty different "elements" the chemist could construct the most varied objects in nature, from the frame of a man to a landscape. But improved methods of research led to the discovery of new elements, and at last the chemist found that he had seventy or eighty of these "ultimate realities," each having its own very definite and very different characters. As it is the experience of science to find unity underlying variety, this was profoundly unsatisfactory, and the search began for the great unity which underlay the atoms of matter. The difficulty of the search may be illustrated by a few figures. Very delicate methods were invented for calculating the size of the atoms. Laymen are apt to smile—it is a very foolish smile—at these figures, but it is enough to say that the independent and even more delicate methods suggested by recent progress in physics have quite confirmed them.

Take a cubic millimetre of hydrogen. As a millimetre is less than 1/25th of an inch, the reader must imagine a tiny bubble of gas that would fit comfortably inside the letter "o" as it is printed here. The various refined methods of the modern physicist show that there are 40,000 billion molecules (each consisting of two atoms of the gas) in this tiny bubble. It is a little universe, repeating on an infinitesimal scale the numbers and energies of the stellar universe. These molecules are not packed together, moreover, but are separated from each other by spaces which are enormous in proportion to the size of the atoms. Through these empty spaces the atoms dash at an average speed of more than a thousand miles an hour, each passing something like 6,000,000,000 of its neighbours in the course of every second. Yet this particle of gas is a thinly populated world in comparison with a particle of metal. Take a cubic centimetre of copper. In that very small square of solid matter (each side of the cube measuring a little more than a third of an inch) there are about a quadrillion atoms. It is these minute and elusive particles that modern physics sets out to master.

At first it was noticed that the atom of hydrogen was the smallest or lightest of all, and the other atoms seemed to be multiples of it. A Russian chemist, Mendeleeff, drew up a table of the elements in illustration of this, grouping them in families, which seemed to point to hydrogen as the common parent, or ultimate constituent, of each. When newly discovered elements fell fairly into place in this scheme the idea was somewhat confidently advanced that the evolution of the elements was discovered. Thus an atom of carbon seemed to be a group of 12 atoms of hydrogen, an atom of oxygen 16, an atom of sulphur 32, an atom of copper 64, an atom of silver 108, an atom of gold 197, and so on. But more correct measurements showed that these figures were not quite exact, and the fraction of inexactness killed the theory.

Long before the end of the nineteenth century students were looking wistfully to the ether for some explanation of the mystery. It was the veiled statue of Isis in the scientific world, and it resolutely kept its veil in spite of all progress. The "upper and limpid air" of the Greeks, the cosmic ocean of Giordano Bruno, was now an established reality. It was the vehicle that bore the terrific streams of energy from star to planet across the immense reaches of space. As the atoms of matter lay in it, one thought of the crystal forming in its mother-lye, or the star forming in the nebula, and wondered whether the atom was not in some such way condensed out of the ether. By the last decade of the century the theory was confidently advanced—notably by Lorentz and Larmor—though it was still without a positive basis. How the basis was found, in the last decade of the nineteenth century, may be told very briefly.

Sir William Crookes had in 1874 applied himself to the task of creating something more nearly like a vacuum than the old air-pumps afforded. When he had found the means of reducing the quantity of gas in a tube until it was a million times thinner than the atmosphere, he made the experiment of sending an electric discharge through it, and found a very curious result. From the cathode (the negative electric point) certain rays proceeded which caused a green fluorescence on the glass of the tube. Since the discharge did not consist of the atoms of the gas, he concluded that it was a new and mysterious substance, which he called "radiant matter." But no progress was made in the interpretation of this strange material. The Crookes tube became one of the toys of science—and the lamp of other investigators.

In 1895 Rontgen drew closer attention to the Crookes tube by discovering the rays which he called X-rays, but which now bear his name. They differ from ordinary light-waves in their length, their irregularity, and especially their power to pass through opaque bodies. A number of distinguished physicists now took up the study of the effect of sending an electric discharge through a vacuum, and the particles of "radiant matter" were soon identified. Sir J. J. Thomson, especially, was brilliantly successful in his interpretation. He proved that they were tiny corpuscles, more than a thousand times smaller than the atom of hydrogen, charged with negative electricity, and travelling at the rate of thousands of miles a second. They were the "electrons" in which modern physics sees the long-sought constituents of the atom.

No sooner had interest been thoroughly aroused than it was announced that a fresh discovery had opened a new shaft into the underworld. Sir J. J. Thomson, pursuing his research, found in 1896 that compounds of uranium sent out rays that could penetrate black paper and affect the photographic plate; though in this case the French physicist, Becquerel, made the discovery simultaneously' and was the first to publish it. An army of investigators turned into the new field, and sought to penetrate the deep abyss that had almost suddenly disclosed itself. The quickening of astronomy by Galilei, or of zoology by Darwin, was slight in comparison with the stirring of our physical world by these increasing discoveries. And in 1898 M. and Mme. Curie made the further discovery which, in the popular mind, obliterated all the earlier achievements. They succeeded in isolating the new element, radium, which exhibits the actual process of an atom parting with its minute constituents.

The story of radium is so recent that a few lines will suffice to recall as much as is needed for the purpose of this chapter. In their study of the emanations from uranium compounds the Curies were led to isolate the various elements of the compounds until they discovered that the discharge was predominantly due to one specific element, radium. Radium is itself probably a product of the disintegration of uranium, the heaviest of known metals, with an atomic weight some 240 times greater than that of hydrogen. But this massive atom of uranium has a life that is computed in thousands of millions of years. It is in radium and its offspring that we see most clearly the constitution of matter.

A gramme (less than 15 1/2 grains) of radium contains—we will economise our space—4x10 (superscript)21 atoms. This tiny mass is, by its discharge, parting with its substance at the rate of one atom per second for every 10,000,000,000 atoms; in other words, the "indestructible" atom has, in this case, a term of life not exceeding 2500 years. In the discharge from the radium three elements have been distinguished. The first consists of atoms of the gas helium, which are hurled off at between 10,000 and 20,000 miles a second. The third element (in the order of classification) consists of waves analogous to the Rontgen rays. But the second element is a stream of electrons, which are expelled from the atom at the appalling speed of about 100,000 miles a second. Professor Le Bon has calculated that it would take 340,000 barrels of powder to discharge a bullet at that speed. But we shall see more presently of the enormous energy displayed within the little system of the atom. We may add that after its first transformation the radium passes, much more quickly, through a further series of changes. The frontiers of the atomic systems were breaking down.

The next step was for students (notably Soddy and Rutherford) to find that radio-activity, or spontaneous discharge out of the atomic systems, was not confined to radium. Not only are other rare metals conspicuously active, but it is found that such familiar surfaces as damp cellars, rain, snow, etc., emit a lesser discharge. The value of the new material thus provided for the student of physics may be shown by one illustration. Sir J. J. Thomson observes that before these recent discoveries the investigator could not detect a gas unless about a billion molecules of it were present, and it must be remembered that the spectroscope had already gone far beyond ordinary chemical analysis in detecting the presence of substances in minute quantities. Since these discoveries we can recognise a single molecule, bearing an electric charge.

With these extraordinary powers the physicist is able to penetrate a world that lies immeasurably below the range of the most powerful microscope, and introduce us to systems more bewildering than those of the astronomer. We pass from a portentous Brobdingnagia to a still more portentous Lilliputia. It has been ascertained that the mass of the electron is the 1/1700th part of that of an atom of hydrogen, of which, as we saw, billions of molecules have ample space to execute their terrific movements within the limits of the letter "o." It has been further shown that these electrons are identical, from whatever source they are obtained. The physicist therefore concludes—warning us that on this further point he is drawing a theoretical conclusion—that the atoms of ordinary matter are made up of electrons. If that is the case, the hydrogen atom, the lightest of all, must be a complex system of some 1700 electrons, and as we ascend the scale of atomic weight the clusters grow larger and larger, until we come to the atoms of the heavier metals with more than 250,000 electrons in each atom.

But this is not the most surprising part of the discovery. Tiny as the dimensions of the atom are, they afford a vast space for the movement of these energetic little bodies. The speed of the stars in their courses is slow compared with the flight of the electrons. Since they fly out of the system, in the conditions we have described, at a speed of between 90,000 and 100,000 miles a second, they must be revolving with terrific rapidity within it. Indeed, the most extraordinary discovery of all is that of the energy imprisoned within these tiny systems, which men have for ages regarded as "dead" matter. Sir J. J. Thomson calculates that, allowing only one electron to each atom in a gramme of hydrogen, the tiny globule of gas will contain as much energy as would be obtained by burning thirty-five tons of coal. If, he says, an appreciable fraction of the energy that is contained in ordinary matter were to be set free, the earth would explode and return to its primitive nebulous condition. Mr. Fournier d'Albe tells us that the force with which electrons repel each other is a quadrillion times greater than the force of gravitation that brings atoms together; and that if two grammes of pure electrons could be placed one centimetre apart they would repel each other with a force equal to 320 quadrillion tons. The inexpert imagination reels, but it must be remembered that the speed of the electron is a measured quantity, and it is within the resources of science to estimate the force necessary to project it at that speed. [*]

** See Sir J. J. Thomson, "The Corpuscular Theory of Matter" (1907) and—for a more elementary presentment—"Light Visible and Invisible" (1911); and Mr. Fournier d'Albe, "The Electron Theory" (2nd. ed., 1907).*

Such are the discoveries of the last fifteen years and a few of the mathematical deductions from them. We are not yet in a position to say positively that the atoms are composed of electrons, but it is clear that the experts are properly modest in claiming only that this is highly probable. The atom seems to be a little universe in which, in combination with positive electricity (the nature of which is still extremely obscure), from 1700 to 300,000 electrons revolve at a speed that reaches as high as 100,000 miles a second. Instead of being crowded together, however, in their minute system, each of them has, in proportion to its size, as ample a space to move in as a single speck of dust would have in a moderate-sized room (Thomson). This theory not only meets all the facts that have been discovered in an industrious decade of research, not only offers a splendid prospect of introducing unity into the eighty-one different elements of the chemist, but it opens out a still larger prospect of bringing a common measure into the diverse forces of the universe.

Light is already generally recognised as a rapid series of electro-magnetic waves or pulses in ether. Magnetism becomes intelligible as a condition of a body in which the electrons revolve round the atom in nearly the same plane. The difference between positive and negative electricity is at least partly illuminated. An atom will repel an atom when its equilibrium is disturbed by the approach of an additional electron; the physicist even follows the movement of the added electron, and describes it revolving 2200 billion times a second round the atom, to escape being absorbed in it. The difference between good and bad conductors of electricity becomes intelligible. The atoms of metals are so close together that the roaming electrons pass freely from one atom to another, in copper, it is calculated, the electron combines with an atom and is liberated again a hundred million times a second. Even chemical action enters the sphere of explanation.

However these hypotheses may fare, the electron is a fact, and the atom is very probably a more or less stable cluster of electrons. But when we go further, and attempt to trace the evolution of the electron out of ether, we enter a region of pure theory. Some of the experts conceive the electron as a minute whirlpool or vortex in the ocean of ether; some hold that it is a centre of strain in ether; some regard ether as a densely packed mass of infinitely small grains, and think that the positive and negative corpuscles, as they seem to us, are tiny areas in which the granules are unequally distributed. Each theory has its difficulties. We do not know the origin of the electron, because we do not know the nature of ether. To some it is an elastic solid, quivering in waves at every movement of the particles; to others it is a continuous fluid, every cubic millimetre of which possesses "an energy equivalent to the output of a million-horse-power station for 40.000,000 years" (Lodge); to others it is a close-packed granular mass with a pressure of 10,000 tons per square centimetre. We must wait. It is little over ten years since the vaults were opened and physicists began to peer into the sub-material world. The lower, perhaps lowest, depth is reserved for another generation.

But it may be said that the research of the last ten years has given us a glimpse of the foundations of the universe. Every theory of the electron assumes it to be some sort of nodule or disturbed area in the ether. It is sometimes described as "a particle of negative electricity" and associated with "a particle of positive electricity" in building up the atom. The phrase is misleading for those who regard electricity as a force or energy, and it gives rise to speculation as to whether "matter" has not been resolved into "force." Force or energy is not conceived by physicists as a substantial reality, like matter, but an abstract expression of certain relations of matter or electrons.

In any case, the ether, whether solid or fluid or granular, remains the fundamental reality. The universe does not float IN an ocean of ether: it IS an ocean of ether. But countless myriads of minute disturbances are found in this ocean, and set it quivering with the various pulses which we classify as forces or energies. These points of disturbance cluster together in systems (atoms) of from 1000 to 250,000 members, and the atoms are pressed together until they come in the end to form massive worlds. It remains only to reduce gravitation itself, which brings the atoms together, to a strain or stress in ether, and we have a superb unity. That has not yet been done, but every theory of gravitation assumes that it is a stress in the ether corresponding to the formation of the minute disturbances which we call electrons.

But, it may be urged, he who speaks of foundations speaks of a beginning of a structure; he who speaks of evolution must have a starting-point. Was there a time when the ether was a smooth, continuous fluid, without electrons or atoms, and did they gradually appear in it, like crystals in the mother-lye? In science we know nothing of a beginning. The question of the eternity or non-eternity of matter (or ether) is as futile as the question about its infinity or finiteness. We shall see in the next chapter that science can trace the processes of nature back for hundreds, if not thousands, of millions of years, and has ground to think that the universe then presented much the same aspect as it does now, and will in thousands of millions of years to come. But if these periods were quadrillions, instead of millions, of years, they would still have no relation to the idea of eternity. All that we can say is that we find nothing in nature that points to a beginning or an end. [*]

** A theory has been advanced by some physicists that there is evidence of a beginning. WITHIN OUR EXPERIENCE energy is being converted into heat more abundantly than heat is being converted into other energy. This would hold out a prospect of a paralysed universe, and that stage would have been reached long ago if the system had not had a definite beginning. But what knowledge have we of conversions of energy in remote regions of space, in the depths of stars or nebulae, or in the sub-material world of which we have just caught a glimpse? Roundly, none. The speculation is worthless.*

One point only need be mentioned in conclusion. Do we anywhere perceive the evolution of the material elements out of electrons, just as we perceive the devolution, or disintegration, of atoms into electrons? There is good ground for thinking that we do. The subject will be discussed more fully in the next chapter. In brief, the spectroscope, which examines the light of distant stars and discovers what chemical elements emitted it, finds matter, in the hottest stars, in an unusual condition, and seems to show the elements successively emerging from their fierce alchemy. Sir J. Norman Lockyer has for many years conducted a special investigation of the subject at the Solar Physics Observatory, and he declares that we can trace the evolution of the elements out of the fiery chaos of the young star. The lightest gases emerge first, the metals later, and in a special form. But here we pass once more from Lilliputia to Brobdingnagia, and must first explain the making of the star itself.

CHAPTER III. THE BIRTH AND DEATH OF WORLDS

The greater part of this volume will be occupied with the things that have happened on one small globe in the universe during a certain number of millions of years. It cannot be denied that this has a somewhat narrow and parochial aspect. The earth is, you remember, a million times smaller than the sun, and the sun itself is a very modest citizen of the stellar universe. Our procedure is justified, however, both on the ground of personal interest, and because our knowledge of the earth's story is so much more ample and confident. Yet we must preface the story of the earth with at least a general outline of the larger story of the universe. No sensible man is humbled or dismayed by the vastness of the universe. When the human mind reflects on its wonderful scientific mastery of this illimitable ocean of being, it has no sentiment of being dwarfed or degraded. It looks out with cold curiosity over the mighty scattering of worlds, and asks how they, including our own world, came into being.

We now approach this subject with a clearer perception of the work we have to do. The universe is a vast expanse of ether, and somehow or other this ether gives rise to atoms of matter. We may imagine it as a spacious chamber filled with cosmic dust; recollecting that the chamber has no walls, and that the dust arises in the ether itself. The problem we now approach is, in a word: How are these enormous stretches of cosmic dust, which we call matter, swept together and compressed into suns and planets? The most famous answer to this question is the "nebular hypothesis." Let us see, briefly, how it came into modern science.

We saw that some of the ancient Greek speculators imagined their infinite number of atoms as scattered originally, like dust, throughout space and gradually coming together, as dust does, to form worlds. The way in which they brought their atoms together was wrong, but the genius of Democritus had provided the germ of another sound theory to the students of a more enlightened age. Descartes (1596-1650) recalled the idea, and set out a theory of the evolution of stars and planets from a diffused chaos of particles. He even ventured to say that the earth was at one time a small white-hot sun, and that a solid crust had gradually formed round its molten core. Descartes had taken refuge in Sweden from his persecutors, and it is therefore not surprising that that strange genius Swedenborg shortly afterwards developed the same idea. In the middle of the eighteenth century the great French naturalist, Buffon, followed and improved upon Descartes and Swedenborg. From Buffon's work it was learned by the German philosopher Kant, who published (1755) a fresh theory of the concentration of scattered particles into fiery worlds. Then Laplace (1749-1827) took up the speculation, and gave it the form in which it practically ruled astronomy throughout the nineteenth century. That is the genealogy of the famous nebular hypothesis. It did not spring full-formed from the brain of either Kant or Laplace, like Athene from the brain of Zeus.

Laplace had one great advantage over the early speculators. Not only was he an able astronomer and mathematician, but by his time it was known that nebulae, or vast clouds of dispersed matter, actually existed in the heavens. Here was a solid basis for the speculation. Sir William Herschel, the most assiduous explorer of the heavens, was a contemporary of Laplace. Laplace therefore took the nebula as his starting-point.

A quarter of an ounce of solid matter (say, tobacco) will fill a vast space when it is turned into smoke, and if it were not for the pressure of the atmosphere it would expand still more. Laplace imagined the billions of tons of matter which constitute our solar system similarly dispersed, converted into a fine gas, immeasurably thinner than the atmosphere. This nebula would be gradually drawn in again by gravitation, just as the dust falls to the floor of a room. The collisions of its particles as they fell toward the centre would raise its temperature and give it a rotating movement. A time would come when the centrifugal force at the outer ring of the rotating disk would equal the centripetal (or inward) pull of gravity, and this ring would be detached, still spinning round the central body. The material of the ring would slowly gather, by gravitation, round some denser area in it; the ring would become a sphere; we should have the first, and outermost, planet circling round the sun. Other rings would successively be detached, and form the rest of the planets; and the sun is the shrunken and condensed body of the nebula.

So simple and beautiful a theory of the solar system could not fail to captivate astronomers, but it is generally rejected to-day, in the precise form which Laplace gave it. What the difficulties are which it has encountered, and the modifications it must suffer, we shall see later; as well as the new theories which have largely displaced it. It will be better first to survey the universe from the evolutionary point of view. But I may observe, in passing, that the sceptical remarks one hears at times about scientific theories contradicting and superseding each other are frivolous. One great idea pervades all the theories of the evolution of worlds, and that idea is firmly established. The stars and their planets are enormous aggregations of cosmic dust, swept together and compressed by the action of gravitation. The precise nature of this cosmic dust—whether it was gas, meteorites and gas, or other particles—is open to question.

As we saw in the first chapter, the universe has the word evolution written, literally, in letters of fire across it. The stars are of all ages, from sturdy youth to decrepit age, and even to the darkness of death. We saw that this can be detected on the superficial test of colour. The colours of the stars are, it is true, an unsafe ground to build upon. The astronomer still puzzles over the gorgeous colours he finds at times, especially in double stars: the topaz and azure companions in beta Cygni, the emerald and red of alpha Herculis, the yellow and rose of eta Cassiopeiae, and so on. It is at the present time under discussion in astronomy how far these colours are objective at all, or whether, if they are real, they may not be due to causes other than temperature. Yet the significance of the three predominating colours—blue-white, yellow, and red—has been sustained by the spectroscope. It is the series of colours through which a white-hot bar of iron passes as it cools. And the spectroscope gives us good ground to conclude that the stars are cooling.

When a glowing gas (not under great pressure) is examined by the spectroscope, it yields a few vertical lines or bars of light on a dark background; when a glowing liquid or solid is examined, it gives a continuous rainbow-like stretch of colour. Some of the nebulae give the former type of spectrum, and are thus known to be masses of luminous gas; many of the nebulae and the stars have the latter type of spectrum. But the stretch of light in the spectrum of a star is crossed, vertically, by a number of dark lines, and experiment in the laboratory has taught us how to interpret these. They mean that there is some light-absorbing vapour between the source of light and the instrument. In the case of the stars they indicate the presence of an atmosphere of relatively cool vapours, and an increase in the density of that atmosphere—which is shown by a multiplication and broadening of the dark lines on the spectrum—means an increase of age, a loss of vitality, and ultimately death. So we get the descending scale of spectra. The dark lines are thinnest and least numerous in the blue stars, more numerous in the yellow, heavy and thick in the red. As the body of the star sinks in temperature dense masses of cool vapour gather about it. Its light, as we perceive it, turns yellow, then red. The next step, which the spectroscope cannot follow, will be the formation of a scum on the cooling surface, ending, after ages of struggle, in the imprisonment of the molten interior under a solid, dark crust. Let us see how our sun illustrates this theory.

It is in the yellow, or what we may call the autumnal, stage. Miss Clerke and a few others have questioned this, but the evidence is too strong to-day. The vast globe, 867,000 miles in diameter, seems to be a mass of much the same material as the earth—about forty elements have been identified in it—but at a terrific temperature. The light-giving surface is found, on the most recent calculations, to have a temperature of about 6700 degrees C. This surface is an ocean of liquid or vaporised metals, several thousand miles in depth; some think that the brilliant light comes chiefly from clouds of incandescent carbon. Overlying it is a deep layer of the vapours of the molten metals, with a temperature of about 5500 degrees C.; and to this comparatively cool and light-absorbing layer we owe the black lines of the solar spectrum. Above it is an ocean of red-hot hydrogen, and outside this again is an atmosphere stretching for some hundreds of thousands of miles into space.

The significant feature, from our point of view, is the "sun-spot"; though the spot may be an area of millions of square miles. These areas are, of course, dark only by comparison with the intense light of the rest of the disk. The darkest part of them is 5000 times brighter than the full moon. It will be seen further, on examining a photograph of the sun, that a network or veining of this dark material overspreads the entire surface at all times. There is still some difference of opinion as to the nature of these areas, but the evidence of the spectroscope has convinced most astronomers that they are masses of cooler vapour lying upon, and sinking into, the ocean of liquid fire. Round their edges, as if responding to the pressure of the more condensed mass, gigantic spurts and mountains of the white-hot matter of the sun rush upwards at a rate of fifty or a hundred miles a second, Sometimes they reach a height of a hundred, and even two hundred, thousand miles, driving the red-hot hydrogen before them in prodigious and fantastic flames. Between the black veins over the disk, also, there rise domes and columns of the liquid fire, some hundreds of miles in diameter, spreading and sinking at from five to twenty miles a second. The surface of the sun—how much more the interior!—is an appalling cauldron of incandescent matter from pole to pole. Every yard of the surface is a hundred times as intense as the open furnace of a Titanic. From the depths and from the surface of this fiery ocean, as, on a small scale, from the surface of the tropical sea, the vapours rise high into the extensive atmosphere, discharge some of their heat into space, and sink back, cooler and heavier, upon the disk.

This is a star in its yellow age, as are Capella and Arcturus and other stars. The red stars carry the story further, as we should expect. The heavier lines in their spectrum indicate more absorption of light, and tell us that the vapours are thickening about the globe; while compounds like titanium oxide make their appearance, announcing a fall of temperature. Below these, again, is a group of dark red or "carbon" stars, in which the process is carried further. Thick, broad, dark lines in the red end of the spectrum announce the appearance of compounds of carbon, and a still lower fall of temperature. The veil is growing thicker; the life is ebbing from the great frame. Then the star sinks below the range of visibility, and one would think that we can follow the dying world no farther. Fortunately, in the case of Algol and some thirty or forty other stars, an extinct sun betrays its existence by flitting across the light of a luminous sun, and recent research has made it probable that the universe is strewn with dead worlds. Some of them may be still in the condition which we seem to find in Jupiter, hiding sullen fires under a dense shell of cloud; some may already be covered with a crust, like the earth. There are even stars in which one is tempted to see an intermediate stage: stars which blaze out periodically from dimness, as if the Cyclops were spending his last energy in spasms that burst the forming roof of his prison. But these variable stars are still obscure, and we do not need their aid. The downward course of a star is fairly plain.

When we turn to the earlier chapters in the life of a star, the story is less clear. It is at least generally agreed that the blue-white stars exhibit an earlier and hotter stage. They show comparatively little absorption, and there is an immense preponderance of the lighter gases, hydrogen and helium. They (Sirius, Vega, etc.) are, in fact, known as "hydrogen stars," and their temperature is generally computed at between 20,000 and 30,000 degrees C. A few stars, such as Procyon and Canopus, seem to indicate a stage between them and the yellow or solar type. But we may avoid finer shades of opinion and disputed classes, and be content with these clear stages. We begin with stars in which only hydrogen and helium, the lightest Of elements, can be traced; and the hydrogen is in an unfamiliar form, implying terrific temperature. In the next stage we find the lines of oxygen, nitrogen, magnesium, and silicon. Metals such as iron and copper come later, at first in a primitive and unusual form. Lastly we get the compounds of titanium and carbon, and the densely shaded spectra which tell of the thickly gathering vapours. The intense cold of space is slowly prevailing in the great struggle.

What came before the star? It is now beyond reasonable doubt that the nebula—taking the word, for the moment, in the general sense of a loose, chaotic mass of material—was the first stage. Professor Keeler calculated that there are at least 120,000 nebulae within range of our telescopes, and the number is likely to be increased. A German astronomer recently counted 1528 on one photographic plate. Many of them, moreover, are so vast that they must contain the material for making a great number of worlds. Examine a good photograph of the nebula in Orion. Recollect that each one of the points of light that are dotted over the expanse is a star of a million miles or more in diameter (taking our sun as below the average), and that the great cloud that sprawls across space is at least 10,000 billion miles away; how much more no man knows. It is futile to attempt to calculate the extent of that vast stretch of luminous gas. We can safely say that it is at least a million times as large as the whole area of our solar system; but it may run to trillions or quadrillions of miles.

Nearly a hundred other nebulae are known, by the spectroscope, to be clouds of luminous gas. It does not follow that they are white-hot, and that the nebula is correctly called a "fire-mist." Electrical and other agencies may make gases luminous, and many astronomers think that the nebulae are intensely cold. However, the majority of the nebulae that have been examined are not gaseous, and have a very different structure from the loose and diffused clouds of gas. They show two (possibly more, but generally two) great spiral arms starting from the central part and winding out into space. As they are flat or disk-shaped, we see this structure plainly when they turn full face toward the earth, as does the magnificent nebula in Canes Venatici. In it, and many others, we clearly trace a condensed central mass, with two great arms, each apparently having smaller centres of condensation, sprawling outward like the broken spring of a watch. The same structure can be traced in the mighty nebula in Andromeda, which is visible to the naked eye, and it is said that more than half the nebulae in the heavens are spiral. Knowing that they are masses of solid or liquid fire, we are tempted to see in them gigantic Catherine-wheels, the fireworks of the gods. What is their relation to the stars?

In the first place, their mere existence has provided a solid basis for the nebular hypothesis, and their spiral form irresistibly suggests that they are whirling round on their central axis and concentrating. Further, we find in some of the gaseous nebulae (Orion) comparatively void spaces occupied by stars, which seem to have absorbed the nebulous matter in their formation. On the other hand, we find (in the Pleiades) wisps and streamers of nebulous matter clinging about great clusters of stars, suggesting that they are material left over when these clustered worlds crystallised out of some vast nebula; and enormous stretches of nebulous material covering regions (as in Perseus) where the stars are as thick as grains of silver. More important still, we find a type of cosmic body which seems intermediate between the star and the nebula. It is a more or less imperfectly condensed star, surrounded by nebular masses. But one of the most instructive links of all is that at times a nebula is formed from a star, and a recent case of this character may be briefly described.

In February, 1901, a new star appeared in the constellation Perseus. Knowing what a star is, the reader will have some dim conception of the portentous blaze that lit up that remote region of space (at least 600 billion miles away) when he learns that the light of this star increased 4000-fold in twenty-eight hours. It reached a brilliance 8000 times greater than that of the sun. Telescopes and spectroscopes were turned on it from all parts of the earth, and the spectroscope showed that masses of glowing hydrogen were rushing out from it at a rate of nearly a thousand miles a second. Its light gradually flickered and fell, however, and the star sank back into insignificance. But the photographic plate now revealed a new and most instructive feature. Before the end of the year there was a nebula, of enormous extent, spreading out on both sides from the centre of the eruption. It was suggested at the time that the bursting of a star may merely have lit up a previously dark nebula, but the spectroscope does not support this. A dim star had dissolved, wholly or partially, into a nebula, as a result of some mighty cataclysm. What the nature of the catastrophe was we will inquire presently.

These are a few of the actual connections that we find between stars and nebulae. Probably, however, the consideration that weighs most with the astronomer is that the condensation of such a loose, far-stretched expanse of matter affords an admirable explanation of the enormous heat of the stars. Until recently there was no other conceivable source that would supply the sun's tremendous outpour of energy for tens of millions of years except the compression of its substance. It is true that the discovery of radio-activity has disclosed a new source of energy within the atoms themselves, and there are scientific men, like Professor Arrhenius, who attach great importance to this source. But, although it may prolong the limited term of life which physicists formerly allotted to the sun and other stars, it is still felt that the condensation of a nebula offers the best explanation of the origin of a sun, and we have ample evidence for the connection. We must, therefore, see what the nebula is, and how it develops.

"Nebula" is merely the Latin word for cloud. Whatever the nature of these diffused stretches of matter may be, then, the name applies fitly to them, and any theory of the development of a star from them is still a "nebular hypothesis." But the three theories which divide astronomers to-day differ as to the nature of the nebula. The older theory, pointing to the gaseous nebulae as the first stage, holds that the nebula is a cloud of extremely attenuated gas. The meteoritic hypothesis (Sir N. Lockyer, Sir G. Darwin, etc.), observing that space seems to swarm with meteors and that the greater part of the nebulae are not gaseous, believes that the starting-point is a colossal swarm of meteors, surrounded by the gases evolved and lit up by their collisions. The planetesimal hypothesis, advanced in recent years by Professor Moulton and Professor Chamberlin, contends that the nebula is a vast cloud of liquid or solid (but not gaseous) particles. This theory is based mainly on the dynamical difficulties of the other two, which we will notice presently.

The truth often lies between conflicting theories, or they may apply to different cases. It is not improbable that this will be our experience in regard to the nature of the initial nebula. The gaseous nebulae, and the formation of such nebulae from disrupted stars, are facts that cannot be ignored. The nebulae with a continuous spectrum, and therefore—in part, at least—in a liquid or solid condition, may very well be regarded as a more advanced stage of condensation of the same; their spiral shape and conspicuous nuclei are consistent with this. Moreover, a condensing swarm of meteors would, owing to the heat evolved, tend to pass into a gaseous condition. On the tether hand, a huge expanse of gas stretched over billions of miles of space would be a net for the wandering particles, meteors, and comets that roam through space. If it be true, as is calculated, that our 24,000 miles of atmosphere capture a hundred million meteors a day, what would the millions or billions of times larger net of a nebula catch, even if the gas is so much thinner? In other words, it is not wise to draw too fine a line between a gaseous nebula and one consisting of solid particles with gas.

The more important question is: How do astronomers conceive the condensation of this mixed mass of cosmic dust? It is easy to reply that gravitation, or the pressure of the surrounding ether, slowly drives the particles centre-ward, and compresses the dust into globes, as the boy squeezes the flocculent snow into balls; and it is not difficult for the mathematician to show that this condensation would account for the shape and temperature of the stars. But we must go a little beyond this superficial statement, and see, to some extent, how the deeper students work out the process. [*]

** See, especially, Dr. P. Lowell, "The Evolution of Worlds" (1909). Professor S. Arrhenius, "Worlds in the Making" (1908), Sir N. Lockyer, "The Meteorite Hypothesis" (1890), Sir R. Ball, "The Earth's Beginning" (1909), Professor Moulton, "The Astrophysical Journal (October, 1905), and Chamberlin and Salisbury, "Geology," Vol. II. (1903).*

Taking a broad view of the whole field, one may say that the two chief difficulties are as follows: First, how to get the whole chaotic mass whirling round in one common direction; secondly, how to account for the fact that in our solar system the outermost planets and satellites do not rotate in the same direction as the rest. There is a widespread idea that these difficulties have proved fatal to the old nebular hypothesis, and there are distinguished astronomers who think so. But Sir R. Ball (see note), Professor Lowell (see note), Professor Pickering (Annals of Harvard College Observatory, 53, III), and other high authorities deny this, and work out the newly discovered movements on the lines of the old theory. They hold that all the bodies in the solar system once turned in the same direction as Uranus and Neptune, and the tidal influence of the sun has changed the rotation of most of them. The planets farthest from the sun would naturally not be so much affected by it. The same principle would explain the retrograde movement of the outer satellites of Saturn and Jupiter. Sir R. Ball further works out the principles on which the particles of the condensing nebula would tend to form a disk rotating on its central axis. The ring-theory of Laplace is practically abandoned. The spiral nebula is evidently the standard type, and the condensing nebula must conform to it. In this we are greatly helped by the current theory of the origin of spiral nebulae.

We saw previously that new stars sometimes appear in the sky, and the recent closer scrutiny of the heavens shows this occurrence to be fairly frequent. It is still held by a few astronomers that such a cataclysm means that two stars collided. Even a partial or "grazing" collision between two masses, each weighing billions of tons, travelling (on the average) forty or fifty miles a second—a movement that would increase enormously as they approach each other—would certainly liquefy or vaporise their substance; but the astronomer, accustomed to see cosmic bodies escape each other by increasing their speed, is generally disinclined to believe in collisions. Some have made the new star plunge into the heart of a dense and dark nebula; some have imagined a shock of two gigantic swarms of meteors; some have regarded the outflame as the effect of a prodigious explosion. In one or other new star each or any of these things may have occurred, but the most plausible and accepted theory for the new star of

1901 and some others is that two stars had approached each other too closely in their wandering. Suppose that, in millions of years to come, when our sun is extinct and a firm crust surrounds the great molten ball, some other sun approaches within a few million miles of it. The two would rush past each other at a terrific speed, but the gravitational effect of the approaching star would tear open the solid shell of the sun, and, in a mighty flame, its molten and gaseous entrails would be flung out into space. It has long been one of the arguments against a molten interior of the earth that the sun's gravitational influence would raise it in gigantic tides and rend the solid shell of rock. It is even suspected now that our small earth is not without a tidal influence on the sun. The comparatively near approach of two suns would lead to a terrific cataclysm.

If we accept this theory, the origin of the spiral nebula becomes intelligible. As the sun from which it is formed is already rotating on its axis, we get a rotation of the nebula from the first. The mass poured out from the body of the sun would, even if it were only a small fraction of its mass, suffice to make a planetary system; all our sun's planets and their satellites taken together amount to only 1/100th of the mass of the solar system. We may assume, further, that the outpoured matter would be a mixed cloud of gases and solid and liquid particles; and that it would stream out, possibly in successive waves, from more than one part of the disrupted sun, tending to form great spiral trails round the parent mass. Some astronomers even suggest that, as there are tidal waves raised by the moon at opposite points of the earth, similar tidal outbursts would occur at opposite points on the disk of the disrupted star, and thus give rise to the characteristic arms starting from opposite sides of the spiral nebula. This is not at all clear, as the two tidal waves of the earth are due to the fact that it has a liquid ocean rolling on, not under, a solid bed.

In any case, we have here a good suggestion of the origin of the spiral nebula and of its further development. As soon as the outbursts are over, and the scattered particles have reached the farthest limit to which they are hurled, the concentrating action of gravitation will slowly assert itself. If we conceive this gravitational influence as the pressure of the surrounding ether we get a wider understanding of the process. Much of the dispersed matter may have been shot far enough into space to escape the gravitational pull of the parent mass, and will be added to the sum of scattered cosmic dust, meteors, and close shoals of meteors (comets) wandering in space. Much of the rest will fall back upon the central body But in the great spiral arms themselves the distribution of the matter will be irregular, and the denser areas will slowly gather in the surrounding material. In the end we would thus get secondary spheres circling round a large primary.

This is the way in which astronomers now generally conceive the destruction and re-formation of worlds. On one point the new planetesimal theory differs from the other theories. It supposes that, since the particles of the whirling nebula are all travelling in the same general direction, they overtake each other with less violent impact than the other theories suppose, and therefore the condensation of the material into planets would not give rise to the terrific heat which is generally assumed. We will consider this in the next chapter, when we deal with the formation of the planets. As far as the central body, the sun, is concerned, there can be no hesitation. The 500,000,000 incandescent suns in the heavens are eloquent proof of the appalling heat that is engendered by the collisions of the concentrating particles.

In general outline we now follow the story of a star with some confidence. An internal explosion, a fatal rush into some dense nebula or swarm of meteors, a collision with another star, or an approach within a few million miles of another star, scatters, in part or whole, the solid or liquid globe in a cloud of cosmic dust. When the violent outrush is over, the dust is gathered together once more into a star. At first cold and attenuated, its temperature rises as the particles come together, and we have, after a time, an incandescent nucleus shining through a thin veil of gas—a nebulous star. The temperature rises still further, and we have the blue-hot star, in which the elements seem to be dissociated, and slowly re-forming as the temperature falls. After, perhaps, hundreds of millions of years it reaches the "yellow" stage, and, if it has planets with the conditions of life, there may be a temporary opportunity for living things to enjoy its tempered energy. But the cooler vapours are gathering round it, and at length its luminous body is wholly imprisoned. It continues its terrific course through space, until some day, perhaps, it again encounters the mighty cataclysm which will make it begin afresh the long and stormy chapters of its living history.

Such is the suggestion of the modern astronomer, and, although we seem to find every phase of the theory embodied in the varied contents of the heavens, we must not forget that it is only a suggestion. The spectroscope and telescopic photography, which are far more important than the visual telescope, are comparatively recent, and the field to be explored is enormous. The mist is lifting from the cosmic landscape, but there is still enough to blur our vision. Very puzzling questions remain unanswered. What is the origin of the great gaseous nebulae? What is the origin of the triple or quadruple star? What is the meaning of stars whose light ebbs and flows in periods of from a few to several hundred days? We may even point to the fact that some, at least, of the spiral nebulae are far too vast to be the outcome of the impact or approach of two stars.

We may be content to think that we have found out some truths, by no means the whole truth, about the evolution of worlds. Throughout this immeasurable ocean of ether the particles of matter are driven together and form bodies. These bodies swarm throughout space, like fish in the sea; travelling singly (the "shooting star"), or in great close shoals (the nucleus of a comet), or lying scattered in vast clouds. But the inexorable pressure urges them still, until billions of tons of material are gathered together. Then, either from the sheer heat of the compression, or from the formation of large and unstable atomic systems (radium, etc.), or both, the great mass becomes a cauldron of fire, mantled in its own vapours, and the story of a star is run. It dies out in one part of space to begin afresh in another. We see nothing in the nature of a beginning or an end for the totality of worlds, the universe. The life of all living things on the earth, from the formation of the primitive microbes to the last struggles of the superman, is a small episode of that stupendous drama, a fraction of a single scene. But our ampler knowledge of it, and our personal interest in it, magnify that episode, and we turn from the cosmic picture to study the formation of the earth and the rise of its living population.

CHAPTER IV. THE PREPARATION OF THE EARTH

The story of the evolution of our solar system is, it will now be seen, a local instance of the great cosmic process we have studied in the last chapter. We may take one of the small spiral nebulae that abound in the heavens as an illustration of the first stage. If a still earlier stage is demanded, we may suppose that some previous sun collided with, or approached too closely, another mighty body, and belched out a large part of its contents in mighty volcanic outpours. Mathematical reasoning can show that this erupted material would gather into a spiral nebula; but, as mathematical calculations cannot be given here, and are less safe than astronomical facts, we will be content to see the early shape of our solar system in a relatively small spiral nebula, its outermost arm stretching far beyond the present orbit of Neptune, and its great nucleus being our present sun in more diffused form.

We need not now attempt to follow the shrinking of the central part of the nebula until it becomes a rounded fiery sun. That has been done in tracing the evolution of a star. Here we have to learn how the planets were formed from the spiral arms of the nebula. The principle of their formation is already clear. The same force of gravitation, or the same pressure of the surrounding ether, which compresses the central mass into a fiery globe, will act upon the loose material of the arms and compress it into smaller globes. But there is an interesting and acute difference of opinion amongst modern experts as to whether these smaller globes, the early planets, would become white-hot bodies.

The general opinion, especially among astronomers, is that the compression of the nebulous material of the arms into globes would generate enormous heat, as in the case of the sun. On that view the various planets would begin their careers as small suns, and would pass through those stages of cooling and shrinking which we have traced in the story of the stars. A glance at the photograph of one of the spiral nebulae strongly confirms this. Great luminous knots, or nuclei, are seen at intervals in the arms. Smaller suns seem to be forming in them, each gathering into its body the neighbouring material of the arm, and rising in temperature as the mass is compressed into a globe. The spectroscope shows that these knots are condensing masses of white-hot liquid or solid matter. It therefore seems plain that each planet will first become a liquid globe of fire, coursing round the central sun, and will gradually, as its heat is dissipated and the supply begins to fail, form a solid crust.

This familiar view is challenged by the new "planetesimal hypothesis," which has been adopted by many distinguished geologists (Chamberlin, Gregory, Coleman, etc.). In their view the particles in the arms of the nebula are all moving in the same direction round the sun. They therefore quietly overtake the nucleus to which they are attracted, instead of violently colliding with each other, and much less heat is generated at the surface. In that case the planets would not pass through a white-hot, or even red-hot, stage at all. They are formed by a slow ingathering of the scattered particles, which are called "planetesimals" round the larger or denser masses of stuff which were discharged by the exploding sun. Possibly these masses were prevented from falling back into the sun by the attraction of the colliding body, or the body which caused the eruption. They would revolve round the parent body, and the shoals of smaller particles would gather about them by gravitation. If there were any large region in the arm of the nebula which had no single massive nucleus, the cosmic dust would gather about a number of smaller centres. Thus might be explained the hundreds of planetoids, or minor planets, which we find between Mars and Jupiter. If these smaller bodies came within the sphere of influence of one of the larger planets, yet were travelling quickly enough to resist its attraction, they would be compelled to revolve round it, and we could thus explain the ten satellites of Saturn and the eight of Jupiter. Our moon, we shall see, had a different origin.

We shall find this new hypothesis crossing the familiar lines at many points in the next few chapters. We will consider those further consequences as they arise, but may say at once that, while the new theory has greatly helped us in tracing the formation of the planetary system, astronomers are strongly opposed to its claim that the planets did not pass through an incandescent stage. The actual features of our spiral nebulae seem clearly to exhibit that stage. The shape of the planets—globular bodies, flattened at the poles—strongly suggests that they were once liquid. The condition in which we find Saturn and Jupiter very forcibly confirms this suggestion; the latest study of those planets supports the current opinion that they are still red-hot, and even seems to detect the glow of their surfaces in their mantles of cloud. These points will be considered more fully presently. For the moment it is enough to note that, as far as the early stages of planetary development are concerned, the generally accepted theory rests on a mass of positive evidence, while the new hypothesis is purely theoretical. We therefore follow the prevailing view with some confidence.

Those of the spiral nebulae which face the earth squarely afford an excellent suggestion of the way in which planets are probably formed. In some of these nebulae the arms consist of almost continuous streams of faintly luminous matter; in others the matter is gathering about distinct centres; in others again the nebulous matter is, for the most part, collected in large glowing spheres. They seem to be successive stages, and to reveal to us the origin of our planets. The position of each planet in our solar system would be determined by the chance position of the denser stuff shot out by the erupting sun. I have seen Vesuvius hurl up into the sky, amongst its blasts of gas and steam, white-hot masses of rock weighing fifty tons. In the far fiercer outburst of the erupting sun there would be at least thinner and denser masses, and they must have been hurled so far into space that their speed in travelling round the central body, perhaps seconded by the attraction of the second star, overcame the gravitational pull back to the centre. Recollect the force which, in the new star in Perseus, drove masses of hydrogen for millions of miles at a speed of a thousand miles a second.

These denser nuclei or masses would, when the eruption was over, begin to attract to themselves all the lighter nebulous material within their sphere of gravitational influence. Naturally, there would at first be a vast confusion of small and large centres of condensation in the arms of the nebula, moving in various directions, but a kind of natural selection—and, in this case, survival of the biggest—would ensue. The conflicting movements would be adjusted by collisions and gravitation, the smaller bodies would be absorbed in the larger or enslaved as their satellites, and the last state would be a family of smaller suns circling at vast distances round the parent body. The planets, moreover, would be caused to rotate on their axes, besides revolving round the sun, as the particles at their inner edge (nearer the sun) would move at a different speed from those at the outer edge. In the course of time the smaller bodies, having less heat to lose and less (or no) atmosphere to check the loss, would cool down, and become dark solid spheres, lit only by the central fire.

While the first stage of this theory of development is seen in the spiral nebula, the later stages seem to be well exemplified in the actual condition of our planets. Following, chiefly, the latest research of Professor Lowell and his colleagues, which marks a considerable advance on our previous knowledge, we shall find it useful to glance at the sister-planets before we approach the particular story of our earth.

Mercury, the innermost and smallest of the planets, measuring only some 3400 miles in diameter, is, not unexpectedly, an airless wilderness. Small bodies are unable to retain the gases at their surface, on account of their feebler gravitation. We find, moreover, that Mercury always presents the same face to the sun, as it turns on its axis in the same period (eighty-eight days) in which it makes a revolution round the sun. While, therefore, one half of the globe is buried in eternal darkness, the other half is eternally exposed to the direct and blistering rays of the sun, which is only 86,000,000 miles away. To Professor Lowell it presents the appearance of a bleached and sun-cracked desert, or "the bones of a dead world." Its temperature must be at least 300 degrees C. above that of the earth. Its features are what we should expect on the nebular hypothesis. The slowness of its rotation is accounted for by the heavy tidal influence of the sun. In the same way our moon has been influenced by the earth, and our earth by the sun, in their movement of rotation.

Venus, as might be expected in the case of so large a globe (nearly as large as the earth), has an atmosphere, but it seems, like Mercury, always to present the same face to the sun. Its comparative nearness to the sun (67,000,000 miles) probably explains this advanced effect of tidal action. The consequences that the observers deduce from the fact are interesting. The sun-baked half of Venus seems to be devoid of water or vapour, and it is thought that all its water is gathered into a rigid ice-field on the dark side of the globe, from which fierce hurricanes must blow incessantly. It is a Sahara, or a desert far hotter than the Sahara, on one side; an arctic region on the other. It does not seem to be a world fitted for the support of any kind of life that we can imagine.

When we turn to the consideration of Mars, we enter a world of unending controversy. With little more than half the diameter of the earth, Mars ought to be in a far more advanced stage of either life or decay, but its condition has not yet been established. Some hold that it has a considerable atmosphere; others that it is too small a globe to have retained a layer of gas. Professor Poynting believes that its temperature is below the freezing-point of water all over the globe; many others, if not the majority of observers, hold that the white cap we see at its poles is a mass of ice and snow, or at least a thick coat of hoar-frost, and that it melts at the edges as the springtime of Mars comes round. In regard to its famous canals we are no nearer agreement. Some maintain that the markings are not really an objective feature; some hold that they are due to volcanic activity, and that similar markings are found on the moon; some believe that they are due to clouds; while Professor Lowell and others stoutly adhere to the familiar view that they are artificial canals, or the strips of vegetation along such canals. The question of the actual habitation of Mars is still open. We can say only that there is strong evidence of its possession of the conditions of life in some degree, and that living things, even on the earth, display a remarkable power of adaptation to widely differing conditions.

Passing over the 700 planetoids, which circulate between Mars and Jupiter, and for which we may account either by the absence of one large nucleus in that part of the nebulous stream or by the disturbing influence of Jupiter, we come to the largest planet of the system. Here we find a surprising confirmation of the theory of planetary development which we are following. Three hundred times heavier than the earth (or more than a trillion tons in weight), yet a thousand times less in volume than the sun, Jupiter ought, if our theory is correct, to be still red-hot. All the evidence conspires to suggest that it is. It has long been recognised that the shining disk of the planet is not a solid, but a cloud, surface. This impenetrable mass of cloud or vapour is drawn out in streams or belts from side to side, as the giant globe turns on its axis once in every ten hours. We cannot say if, or to what extent, these clouds consist of water-vapour. We can conclude only that this mantle of Jupiter is "a seething cauldron of vapours" (Lowell), and that, if the body beneath is solid, it must be very hot. A large red area, at one time 30,000 miles long, has more or less persisted on the surface for several decades, and it is generally interpreted, either as a red-hot surface, or as a vast volcanic vent, reflecting its glow upon the clouds. Indeed, the keen American observers, with their powerful telescopes, have detected a cherry-red glow on the edges of the cloud-belts across the disk; and more recent observation with the spectroscope seems to prove that Jupiter emits light from its surface analogous to that of the red stars. The conspicuous flattening of its poles is another feature that science would expect in a rapidly rotating liquid globe. In a word, Jupiter seems to be in the last stage of stellar development. Such, at some remote time, was our earth; such one day will be the sun.

The neighbouring planet Saturn supports the conclusion. Here again we have a gigantic globe, 28,000 miles in diameter, turning on its axis in the short space of ten hours; and here again we find the conspicuous flattening of the poles, the trailing belts of massed vapour across the disk, the red glow lighting the edges of the belts, and the spectroscopic evidence of an emission of light. Once more it is difficult to doubt that a highly heated body is wrapped in that thick mantle of vapour. With its ten moons and its marvellous ring-system—an enormous collection of fragments, which the influence of the planet or of its nearer satellites seems to have prevented from concentrating—Saturn has always been a beautiful object to observe; it is not less interesting in those features which we faintly detect in its disk.

The next planet, Uranus, 32,000 miles in diameter, seems to be another cloud-wrapt, greatly heated globe, if not, as some think, a sheer mass of vapours without a liquid core. Neptune is too dim and distant for profitable examination. It may be added, however, that the dense masses of gas which are found to surround the outer planets seem to confirm the nebular theory, which assumes that they were developed in the outer and lighter part of the material hurled from the sun.

From this encouraging survey of the sister-planets we return with more confidence to the story of the earth. I will not attempt to follow an imaginative scheme in regard to its early development. Take four photographs—one of a spiral nebula without knots in its arms, one of a nebula like that in Canes Venatici, one of the sun, and one of Jupiter—and you have an excellent illustration of the chief stages in its formation. In the first picture a section of the luminous arm of the nebula stretches thinly across millions of miles of space. In the next stage this material is largely collected in a luminous and hazy sphere, as we find in the nebula in Canes Venatici. The sun serves to illustrate a further stage in the condensation of this sphere. Jupiter represents a later chapter, in which the cooler vapours are wrapped close about the red-hot body of the planet. That seems to have been the early story of the earth. Some 6,000,000,000 billion tons of the nebulous matter were attracted to a common centre. As the particles pressed centreward, the temperature rose, and for a time the generation of heat was greater than its dissipation. Whether the earth ever shone as a small white star we cannot say. We must not hastily conclude that such a relatively small mass would behave like the far greater mass of a star, but we may, without attempting to determine its temperature, assume that it runs an analogous course.

One of the many features which I have indicated as pointing to a former fluidity of the earth may be explained here. We shall see in the course of this work that the mountain chains and other great irregularities of the earth's surface appear at a late stage in its development. Even as we find them to-day, they are seen to be merely slight ridges and furrows on the face of the globe, when we reflect on its enormous diameter, but there is good reason to think that in the beginning the earth was much nearer to a perfectly globular form. This points to a liquid or gaseous condition at one time, and the flattening of the sphere at the poles confirms the impression. We should hardly expect so perfect a rotundity in a body formed by the cool accretion of solid fragments and particles. It is just what we should expect in a fluid body, and the later irregularities of the surface are accounted for by the constant crumpling and wearing of its solid crust. Many would find a confirmation of this in the phenomena of volcanoes, geysers, and earthquakes, and the increase of the temperature as we descend the crust. But the interior condition of the earth, and the nature of these phenomena, are much disputed at present, and it is better not to rely on any theory of them. It is suggested that radium may be responsible for this subterraneous heat.

The next stage in the formation of the earth is necessarily one that we can reach only by conjecture. Over the globe of molten fire the vapours and gases would be suspended like a heavy canopy, as we find in Jupiter and Saturn to-day. When the period of maximum heat production was passed, however, the radiation into space would cause a lowering of the temperature, and a scum would form on the molten surface. As may be observed on the surface of any cooling vessel of fluid, the scum would stretch and crack; the skin would, so to say, prove too small for the body. The molten ocean below would surge through the crust, and bury it under floods of lava. Some hold that the slabs would sink in the ocean of metal, and thus the earth would first solidify in its deeper layers. There would, in any case, be an age-long struggle between the molten mass and the confining crust, until at length—to employ the old Roman conception of the activity of Etna—the giant was imprisoned below the heavy roof of rock.

Here again we seem to find evidence of the general correctness of the theory. The objection has been raised that the geologist does not find any rocks which he can identify as portions of the primitive crust of the earth. It seems to me that it would be too much to expect the survival at the surface of any part of the first scum that cooled on that fiery ocean. It is more natural to suppose that millions of years of volcanic activity on a prodigious scale would characterise this early stage, and the "primitive crust" would be buried in fragments, or dissolved again, under deep seas of lava. Now, this is precisely what we find, The oldest rocks known to the geologist—the Archaean rocks—are overwhelmingly volcanic, especially in their lower part. Their thickness, as we know them, is estimated at 50,000 feet; a thickness which must represent many millions of years. But we do not know how much thicker than this they may be. They underlie the oldest rocks that have ever been exposed to the gaze of the geologist. They include sedimentary deposits, showing the action of water, and even probable traces of organic remains, but they are, especially in their deeper and older sections, predominantly volcanic. They evince what we may call a volcanic age in the early story of the planet.

But before we pursue this part of the story further we must interpolate a remarkable event in the record—the birth of the moon. It is now generally believed, on a theory elaborated by Sir G. Darwin, that when the formation of the crust had reached a certain depth—something over thirty miles, it is calculated—it parted with a mass of matter, which became the moon. The size of our moon, in comparison with the earth, is so exceptional among the satellites which attend the planets of our solar system that it is assigned an exceptional origin. It is calculated that at that time the earth turned on its axis in the space of four or five hours, instead of twenty-four. We have already seen that the tidal influence of the sun has the effect of moderating the rotation of the planets. Now, this very rapid rotation of a liquid mass, with a thin crust, would (together with the instability occasioned by its cooling) cause it to bulge at the equator. The bulge would increase until the earth became a pear-shaped body. The small end of the pear would draw further and further away from the rest—as a drop of water does on the mouth of a tap—and at last the whole mass (some 5,000,000,000 cubic miles of matter) was broken off, and began to pursue an independent orbit round the earth.

There are astronomers who think that other cosmic bodies, besides our moon, may have been formed in this way. Possibly it is true of some of the double stars, but we will not return to that question. The further story of the moon, as it is known to astronomers, may be given in a few words. The rotational movement of the earth is becoming gradually slower on account of tidal influence; our day, in fact, becomes an hour longer every few million years. It can be shown that this had the effect of increasing the speed, and therefore enlarging the orbit, of the moon, as it revolved round the earth. As a result, the moon drew further and further away from the earth until it reached its present position, about 240,000 miles away. At the same time the tidal influence of the earth was lessening the rotational movement of the moon. This went on until it turned on its axis in the same period in which it revolves round the earth, and on this account it always presents the same face to the earth.

Through what chapters of life the moon may have passed in the meantime it is impossible to say. Its relatively small mass may have been unable to keep the lighter gases at its surface, or its air and water may, as some think, have been absorbed. It is to-day practically an airless and waterless desert, alternating between the heat of its long day and the intense cold of its long night. Careful observers, such as Professor Pickering, think that it may still have a shallow layer of heavy gases at its surface, and that this may permit the growth of some stunted vegetation during the day. Certain changes of colour, which are observed on its surface, have been interpreted in that sense. We can hardly conceive any other kind of life on it. In the dark even the gases will freeze on its surface, as there is no atmosphere to retain the heat. Indeed, some students of the moon (Fauth, etc.) believe that it is an unchanging desert of ice, bombarded by the projectiles of space.

An ingenious speculation as to the effect on the earth of this dislodgment of 5,000,000,000 cubic miles of its substance is worth noting. It supposes that the bed of the Pacific Ocean represents the enormous gap torn in its side by the delivery of the moon. At each side of this chasm the two continents, the Old World and the New, would be left floating on their molten ocean; and some have even seen a confirmation of this in the lines of crustal weakness which we trace, by volcanoes and earthquakes, on either side of the Pacific. Others, again, connect the shape of our great masses of land, which generally run to a southern point, with this early catastrophe. But these interesting speculations have a very slender basis, and we will return to the story of the development of the earth.

The last phase in preparation for the appearance of life would be the formation of the ocean. On the lines of the generally received nebular hypothesis this can easily be imagined, in broad outline. The gases would form the outer shell of the forming planet, since the heavier particles would travel inward. In this mixed mass of gas the oxygen and hydrogen would combine, at a fitting temperature, and form water. For ages the molten crust would hold this water suspended aloft as a surrounding shell of cloud, but when the surface cooled to about 380 degrees C. (Sollas), the liquid would begin to pour on it. A period of conflict would ensue, the still heated crust and the frequent volcanic outpours sending the water back in hissing steam to the clouds. At length, and now more rapidly, the temperature of the crust would sink still lower, and a heated ocean would settle upon it, filling the hollows of its irregular surface, and washing the bases of its outstanding ridges. From that time begins the age-long battle of the land and the water which, we shall see, has had a profound influence on the development of life.

In deference to the opinion of a number of geologists we must glance once more at the alternative view of the planetesimal school. In their opinion the molecules of water were partly attracted to the surface out of the disrupted matter, and partly collected within the porous outer layers of the globe. As the latter quantity grew, it would ooze upwards, fill the smaller depressions in the crust, and at length, with the addition of the attracted water, spread over the irregular surface. There is an even more important difference of opinion in regard to the formation of the atmosphere, but we may defer this until the question of climate interests us. We have now made our globe, and will pass on to that early chapter of its story in which living things make their appearance.

To some it will seem that we ought not to pass from the question of origin without a word on the subject of the age of the earth. All that one can do, however, is to give a number of very divergent estimates. Physicists have tried to calculate the age of the sun from the rate of its dissipation of heat, and have assigned, at the most, a hundred million years to our solar system; but the recent discovery of a source of heat in the disintegration of such metals as radium has made their calculations useless. Geologists have endeavoured, from observation of the action of geological agencies to-day, to estimate how long it will have taken them to form the stratified crust of the earth; but even the best estimates vary between twenty-five and a hundred million years, and we have reason to think that the intensity of these geological agencies may have varied in different ages. Chemists have calculated how long it would take the ocean, which was originally fresh water, to take up from the rocks and rivers the salt which it contains to-day; Professor Joly has on this ground assigned a hundred million years since the waters first descended upon the crust. We must be content to know that the best recent estimates, based on positive data, vary between fifty and a hundred million years for the story which we are now about to narrate. The earlier or astronomical period remains quite incalculable. Sir G. Darwin thinks that it was probably at least a thousand million years since the moon was separated from the earth. Whatever the period of time may be since some cosmic cataclysm scattered the material of our solar system in the form of a nebula, it is only a fraction of that larger and illimitable time which the evolution of the stars dimly suggests to the scientific imagination.

THE GEOLOGICAL SERIES

[The scale of years adopted—50,000,000 for the stratified rocks—is merely an intermediate between conflicting estimates.]

ERA.	*PERIOD.*	*RELATIVE LENGTH.*
Quaternary	*Holocene* *Pleistocene*	*500,000 years*
Tertiary *or*	*Pliocene* *Miocene*	*5,500,000 years*

Cenozoic	*Oligocene*	
	Eocene	
Secondary	*Cretaceous*	*7,200,000 years*
or	*Jurassic*	*3,600,000 "*
Mesozoic	*Triassic*	*2,500,000 "*
Primary	*Permian*	*2,800,000 years*
or	*Carboniferous*	*6,200,000 "*
Palaeozoic	*Devonian*	*8,000,000 "*
	Silurian	*5,400,000 "*
	Ordovician	*5,400,000 "*
	Cambrian	*8,000,000 "*
Archaean	*Keweenawan*	*Unknown (probably*
	Animikie	*at least*
	Huronian	*50,000,000 years)*
	Keewatin	
	Laurentian	

CHAPTER V. THE BEGINNING OF LIFE

There is, perhaps, no other chapter in the chronicle of the earth that we approach with so lively an interest as the chapter which should record the first appearance of life. Unfortunately, as far as the authentic memorials of the past go, no other chapter is so impenetrably obscure as this. The reason is simple. It is a familiar saying that life has written its own record, the long-drawn record of its dynasties and its deaths, in the rocks. But there were millions of years during which life had not yet learned to write its record, and further millions of years the record of which has been irremediably destroyed. The first volume of the geological chronicle of the earth is the mass of the Archaean (or "primitive") rocks. What the actual magnitude of that volume, and the span of time it covers, may be, no geologist can say. The Archaean rocks still solidly underlie the lowest depth he has ever reached. It is computed, however, that these rocks, as far as they are known to us, have a total depth of nearly ten miles, and seem therefore to represent at least half the story of the earth from the time when it rounded into a globe, or cooled sufficiently to endure the presence of oceans.

Yet all that we read of the earth's story during those many millions of years could be told in a page or two. That section of geology is still in its infancy, it is true. A day may come when science will decipher a long and instructive narrative in the masses of quartz and gneiss, and the layers of various kinds, which it calls the Archaean rocks. But we may say with confidence that it will not discover in them more than a few stray syllables of the earlier part, and none whatever of the earliest part, of the epic of living nature. A few fossilised remains of somewhat advanced organisms, such as shell-fish and worms, are found in the higher and later rocks of the series, and more of the same comparatively high types will probably appear. In the earlier strata, representing an earlier stage of life, we find only thick seams of black shale, limestone, and ironstone, in which we seem to see the ashes of primitive organisms, cremated in the appalling fires of the volcanic age, or crushed out of recognition by the superimposed masses. Even if some wizardry of science were ever to restore the forms that have been reduced to ashes in this Archaean crematorium, it would be found that they are more or less advanced forms, far above the original level of life. No trace will ever be found in the rocks of the first few million years in the calendar of life.

The word impossible or unknowable is not lightly uttered in science to-day, but there is a very plain reason for admitting it here. The earliest living things were at least as primitive of nature as the lowest animals and plants we know to-day, and these, up to a fair level of organisation, are so soft of texture that, when they die, they leave no remains which may one day be turned into fossils. Some of them, indeed, form tiny shells of flint or lime, or, like the corals, make for themselves a solid bed; but this is a relatively late and higher stage of development. Many thousands of species of animals and plants lie below that level. We are therefore forced to conclude, from the aspect of living nature to-day, that for ages the early organisms had no hard and preservable parts. In thus declaring the impotence of geology, however, we are at the same time introducing another science, biology, which can throw appreciable light on the evolution of life. Let us first see what geology tells us about the infancy of the earth.

The distribution of the early rocks suggests that there was comparatively little dry land showing above the surface of the Archaean ocean. Our knowledge of these rocks is not at all complete, and we must remember that some of this primitive land may be now under the sea or buried in unsuspected regions. It is significant, however, that, up to the present, exploration seems to show that in those remote ages only about one-fifth of our actual land-surface stood above the level of the waters. Apart from a patch of some 20,000 square miles of what is now Australia, and smaller patches in Tasmania, New Zealand, and India, nearly the whole of this land was in the far North. A considerable area of eastern Canada had emerged, with lesser islands standing out to the west and south of North America. Another large area lay round the basin of the Baltic; and as Greenland, the Hebrides, and the extreme tip of Scotland, belong to the same age, it is believed that a continent, of which they are fragments, united America and Europe across the North Atlantic. Of the rest of what is now Europe there were merely large islands—one on the border of England and Wales, others in France, Spain, and Southern Germany. Asia was represented by a large area in China and Siberia, and an island or islands on the site of India. Very little of Africa or South America existed.

It will be seen at a glance that the physical story of the earth from that time is a record of the emergence from the waters of larger continents and the formation of lofty chains of mountains. Now this world-old battle of land and sea has been waged with varying fortune from age to age, and it has been one of the most important factors in the development of life. We are just beginning to realise what a wonderful light it throws on the upward advance of animals and plants. No one in the scientific world to-day questions that, however imperfect the record may be, there has been a continuous development of life from the lowest level to the highest. But why there was advance at all, why the primitive microbe climbs the scale of being, during millions of years, until it reaches the stature of humanity, seems to many a profound mystery. The solution of this mystery begins to break upon us when we contemplate, in the geological record, the prolonged series of changes in the face of the earth itself, and try to realise how these changes must have impelled living things to fresh and higher adaptations to their changing surroundings.

Imagine some early continent with its population of animals and plants. Each bay, estuary, river, and lake, each forest and marsh and solid plain, has its distinctive inhabitants. Imagine this continent slowly sinking into the sea, until the advancing arms of the salt water meet across it, mingling their diverse populations in a common world, making the fresh-water lake brackish or salt, turning the dry land into swamp, and flooding the forest. Or suppose, on the other hand, that the land rises, the marsh is drained, the genial climate succeeded by an icy cold, the luscious vegetation destroyed, the whole animal population compelled to change its habits and its food. But this is no imaginary picture. It is the actual story of the earth during millions of years, and it is chiefly in the light of these vast and exacting changes in the environment that we are going to survey the panorama of the advance of terrestrial life.

For the moment it will be enough to state two leading principles. The first is that there is no such thing as a "law of evolution" in the sense in which many people understand that phrase. It is now sufficiently well known that, when science speaks of a law, it does not mean that there is some rule that things MUST act in such and such a way. The law is a mere general expression of the fact that they DO act in that way. But many imagine that there is some principle within the living organism which impels it onward to a higher level of organisation. That is entirely an error. There is no "law of progress." If an animal is fitted to secure its livelihood and breed posterity in certain surroundings, it may remain unchanged indefinitely if these surroundings do not materially change. So the duckmole of Australia and the tuatara of New Zealand have retained primitive features for millions of years; so the aboriginal Australian and the Fuegian have remained stagnant, in their isolation, for a hundred thousand years or more; so the Chinaman, in his geographical isolation, has remained unchanged for two thousand years. There is no more a "conservative instinct" in Chinese than there is a "progressive instinct" in Europeans. The difference is one of history and geography, as we shall see.

To make this important principle still clearer, let us imagine some primitive philosopher observing the advance of the tide over a level beach. He must discover two things: why the water comes onward at all, and why it advances along those particular channels. We shall see later how men of science explain or interpret the mechanism in a living thing which enables it to advance, when it does advance. For the present it is enough to say that new-born animals and plants are always tending to differ somewhat from their parents, and we now know, by experiment, that when some exceptional influence is brought to bear on the parent, the young may differ considerably from her. But, if the parents were already in harmony with their environment, these variations on the part of the young are of no consequence. Let the environment alter, however, and some of these variations may chance to make the young better fitted than the parent was. The young which happen to have the useful variation will have an advantage over their brothers or sisters, and be more likely to survive and breed the next generation. If the change in the environment (in the food or climate, for instance) is prolonged and increased for hundreds of thousands of years, we shall expect to find a corresponding change in the animals and plants.

We shall find such changes occurring throughout the story of the earth. At one important point in the story we shall find so grave a revolution in the face of nature that twenty-nine out of every thirty species of animals and plants on the earth are annihilated. Less destructive and extreme changes have been taking place during nearly the whole of the period we have to cover, entailing a more gradual alteration of the structure of animals and plants; but we shall repeatedly find them culminating in very great changes of climate, or of the distribution of land and water, which have subjected the living population of the earth to the most searching tests and promoted every variation toward a more effective organisation. [*]

** This is a very simple expression of "Darwinism," and will be enlarged later. The reader should ignore the occasional statement of non-scientific writers that Darwinism is "dead" or superseded. The questions which are actually in dispute relate to the causes of the variation of the young from their parents, the magnitude of these variations' and the transmission of changes acquired by an animal during its own life. We shall see this more fully at a later stage. The importance of the environment as I have described it, is admitted by all schools.*

And the second guiding principle I wish to lay down in advance is that these great changes in the face of the earth, which explain the progress of organisms, may very largely be reduced to one simple agency—the battle of the land and the sea. When you gaze at some line of cliffs that is being eaten away by the waves, or reflect on the material carried out to sea by the flooded river, you are—paradoxical as it may seem—beholding a material process that has had a profound influence on the development of life. The Archaean continent that we described was being reduced constantly by the wash of rain, the scouring of rivers, and the fretting of the waves on the coast. It is generally thought that these wearing agencies were more violent in early times, but that is disputed, and we will not build on it. In any case, in the course of time millions of tons of matter were scraped off the Archaean continent and laid on the floor of the sea by its rivers. This meant a very serious alteration of pressure or weight on the surface of the globe, and was bound to entail a reaction or restoration of the balance.

The rise of the land and formation of mountains used to be ascribed mainly to the cooling and shrinking of the globe of the earth. The skin (crust), it was thought, would become too large for the globe as it shrank, and would wrinkle outwards, or pucker up into mountain-chains. The position of our greater mountain-chains sprawling across half the earth (the Pyrenees to the Himalaya, and the Rocky Mountains to the Andes), seems to confirm this, but the question of the interior of the earth is obscure and disputed, and geologists generally conceive the rise of land and formation of mountains in a different way. They are due probably to the alteration of pressure on the crust in combination with the instability of the interior. The floors of the seas would sink still lower under their colossal burdens, and this would cause some draining of the land-surface. At the same time the heavy pressure below the seas and the lessening of pressure over the land would provoke a reaction. Enormous masses of rock would be forced toward and underneath the land-surface, bending, crumpling, and upheaving it as if its crust were but a leather coat. As a result, masses of land would slowly rise above the plain, to be shaped into hills and valleys by the hand of later time, and fresh surfaces would be dragged out of the deep, enlarging the fringes of the primitive continents, to be warped and crumpled in their turn at the next era of pressure.

In point of geological fact, the story of the earth has been one prolonged series of changes in the level of land and water, and in their respective limits. These changes have usually been very gradual, but they have always entailed changes (in climate, etc.) of the greatest significance in the evolution of life. What was the swampy soil of England in the Carboniferous period is now sometimes thousands of feet beneath us; and what was the floor of a deep ocean over much of Europe and Asia at another time is now to be found on the slopes of lofty Alps, or 20,000 feet above the sea-level in Thibet. Our story of terrestrial life will be, to a great extent, the story of how animals and plants changed their structure in the long series of changes which this endless battle of land and sea brought over the face of the earth.

As we have no recognisable remains of the animals and plants of the earliest age, we will not linger over the Archaean rocks. Starting from deep and obscure masses of volcanic matter, the geologist, as he travels up the series of Archaean rocks, can trace only a dim and most unsatisfactory picture of those remote times. Between outpours of volcanic floods he finds, after a time, traces that an ocean and rivers are wearing away the land. He finds seams of carbon among the rocks of the second division of the Archaean (the Keewatin), and deduces from this that a dense sea-weed population already covered the floor of the ocean. In the next division (the Huronian) he finds the traces of extensive ice-action strangely lying between masses of volcanic rock, and sees that thousands of square miles of eastern North America were then covered with an ice-sheet. Then fresh floods of molten matter are poured out from the depths below; then the sea floods the land for a time; and at last it makes its final emergence as the first definitive part of the North American continent, to enlarge, by successive fringes, to the continent of to-day. [*]

I am quoting Professor Coleman's summary of Archaean research in North America (Address to the Geological Section of the British Association, 1909). Europe, as a continent, has had more "ups and downs" than America in the course of geological time.

This meagre picture of the battle of land and sea, with interludes of great volcanic activity and even of an ice age, represents nearly all we know of the first half of the world's story from geology. It is especially disappointing in regard to the living population. The very few fossils we find in the upper Archaean rocks are so similar to those we shall discuss in the next chapter that we may disregard them, and the seams of carbon-shales, iron-ore, and limestone, suggest only, at the most, that life was already abundant. We must turn elsewhere for some information on the origin and early development of life.

The question of the origin of life I will dismiss with a brief account of the various speculations of recent students of science. Broadly speaking, their views fall into three classes. Some think that the germs of life may have come to the earth from some other body in the universe; some think that life was evolved out of non-living matter in the early ages of the earth, under exceptional conditions which we do not at present know, or can only dimly conjecture; and some think that life is being evolved from non-life in nature to-day, and always has been so evolving. The majority of scientific men merely assume that the earliest living things were no exception to the general process of evolution, but think that we have too little positive knowledge to speculate profitably on the manner of their origin.

The first view, that the germs of life may have come to this planet on a meteoric visitor from some other world, as a storm-driven bird may take its parasites to some distant island, is not without adherents to-day. It was put forward long ago by Lord Kelvin and others; it has been revived by the distinguished Swede, Professor Svante Arrhenius. The scientific objection to it is that the more intense (ultra-violet) rays of the sun would frill such germs as they pass through space. But a broader objection, and one that may dispense us from dwelling on it, is that we gain nothing by throwing our problems upon another planet. We have no ground for supposing that the earth is less capable of evolving life than other planets.

The second view is that, when the earth had passed through its white-hot stage, great masses of very complex chemicals, produced by the great heat, were found on its surface. There is one complex chemical substance in particular, called cyanogen, which is either an important constituent of living matter, or closely akin to it. Now we need intense heat to produce this substance in the laboratory. May we not suppose that masses of it were produced during the incandescence of the earth, and that, when the waters descended, they passed through a series of changes which culminated in living plasm? Such is the "cyanogen hypothesis" of the origin of life, advocated by able physiologists such as Pfluger, Verworn, and others. It has the merit of suggesting a reason why life may not be evolving from non-life in nature to-day, although it may have so evolved in the Archaean period.

Other students suggest other combinations of carbon-compounds and water in the early days. Some suggest that electric action was probably far more intense in those ages; others think that quantities of radium may have been left at the surface. But the most important of these speculations on the origin of life in early times, and one that has the merit of not assuming any essentially different conditions then than we find now, is contained in a recent pronouncement of one of the greatest organic chemists in Europe, Professor Armstrong. He says that such great progress has been made in his science—the science of the chemical processes in living things—that "their cryptic character seems to have disappeared almost suddenly." On the strength of this new knowledge of living matter, he ventures to say that "a series of lucky accidents" could account for the first formation of living things out of non-living matter in Archaean times. Indeed, he goes further. He names certain inorganic substances, and says that the blowing of these into pools by the wind on the primitive planet would set afoot chemical combinations which would issue in the production of living matter. [*]

** See his address in Nature, vol. 76, p. 651. For other speculations see Verworn's "General Physiology," Butler Burke's "Origin of Life" (1906), and Dr. Bastian's "Origin of Life" (1911).*

It is evident that the popular notion that scientific men have declared that life cannot be evolved from non-life is very far astray. This blunder is usually due to a misunderstanding of the dogmatic statement which one often reads in scientific works that "every living thing comes from a living thing." This principle has no reference to remote ages, when the conditions may have been different. It means that to-day, within our experience, the living thing is always born of a living parent. However, even this is questioned by some scientific men of eminence, and we come to the third view.

Professor Nageli, a distinguished botanist, and Professor Haeckel, maintain that our experience, as well as the range of our microscopes, is too limited to justify the current axiom. They believe that life may be evolving constantly from inorganic matter. Professor J. A. Thomson also warns us that our experience is very limited, and, for all we know, protoplasm may be forming naturally in our own time. Mr. Butler Burke has, under the action of radium, caused the birth of certain minute specks which strangely imitate the behaviour of bacteria. Dr. Bastian has maintained for years that he has produced living things from non-living matter. In his latest experiments, described in the book quoted, purely inorganic matter is used, and it is previously subjected, in hermetically sealed tubes, to a heat greater than what has been found necessary to kill any germs whatever.

Evidently the problem of the origin of life is not hopeless, but our knowledge of the nature of living matter is still so imperfect that we may leave detailed speculation on its origin to a future generation. Organic chemistry is making such strides that the day may not be far distant when living matter will be made by the chemist, and the secret of its origin revealed. For the present we must be content to choose the more plausible of the best-informed speculations on the subject.

But while the origin of life is obscure, the early stages of its evolution come fairly within the range of our knowledge. To the inexpert it must seem strange that, whereas we must rely on pure speculation in attempting to trace the origin of life, we can speak with more confidence of those early developments of plants and animals which are equally buried in the mists of the Archaean period. Have we not said that nothing remains of the procession of organisms during half the earth's story but a shapeless seam of carbon or limestone?

A simple illustration will serve to justify the procedure we are about to adopt. Suppose that the whole of our literary and pictorial references to earlier stages in the development of the bicycle, the locomotive, or the loom, were destroyed. We should still be able to retrace the phases of their evolution, because we should discover specimens belonging to those early phases lingering in our museums, in backward regions, and elsewhere. They might yet be useful in certain environments into which the higher machines have not penetrated. In the same way, if all the remains of prehistoric man and early civilisation were lost, we could still fairly retrace the steps of the human race, by gathering the lower tribes and races, and arranging them in the order of their advancement. They are so many surviving illustrations of the stages through which mankind as a whole has passed.

Just in the same way we may marshal the countless species of animals and plants to-day in such order that they will, in a general way, exhibit to us the age-long procession of life. From the very start of living evolution certain forms dropped out of the onward march, and have remained, to our great instruction, what their ancestors were millions of years ago. People create a difficulty for themselves by imagining that, if evolution is true, all animals must evolve. A glance at our own fellows will show the error of this. Of one family of human beings, as a French writer has said, one only becomes a Napoleon; the others remain Lucien, Jerome, or Joseph. Of one family of animals or trees, some advance in one or other direction; some remain at the original level. There is no "law of progress." The accidents of the world and hereditary endowment impel some onward, and do not impel others. Hence at nearly every great stage in the upward procession through the ages some regiment of plants or animals has dropped out, and it represents to-day the stage of life at which it ceased to progress. In other words, when we survey the line of the hundreds of thousands of species which we find in nature to-day, we can trace, amid their countless variations and branches, the line of organic evolution in the past; just as we could, from actual instances, study the evolution of a British house, from the prehistoric remains in Devonshire to a mansion in Park Lane or a provincial castle.

Another method of retracing the lost early chapters in the development of life is furnished by embryology. The value of this method is not recognised by all embryologists, but there are now few authorities who question the substantial correctness of it, and we shall, as we proceed, see some remarkable applications of it. In brief, it is generally admitted that an animal or plant is apt to reproduce, during its embryonic development, some of the stages of its ancestry in past time. This does not mean that a higher animal, whose ancestors were at one time worms, at another time fishes, and at a later time reptiles, will successively take the form of a little worm, a little fish, and a little reptile. The embryonic life itself has been subject to evolution, and this reproduction of ancestral forms has been proportionately disturbed. Still, we shall find that animals will tend, in their embryonic development, to reproduce various structural features which can only be understood as reminiscences of ancestral organs. In the lower animals the reproduction is much less disturbed than in the higher, but even in the case of man this law is most strikingly verified. We shall find it useful sometimes at least in confirming our conclusions as to the ancestry of a particular group.

We have, therefore, two important clues to the missing chapters in the story of evolution. Just as the scheme of the evolution of worlds is written broadly across the face of the heavens to-day, so the scheme of the evolution of life is written on the face of living nature; and it is written again, in blurred and broken characters, in the embryonic development of each individual. With these aids we set out to restore the lost beginning of the epic of organic evolution.

CHAPTER VI. THE INFANCY OF THE EARTH

The long Archaean period, into which half the story of the earth is so unsatisfactorily packed, came to a close with a considerable uplift of the land. We have seen that the earth at times reaches critical stages owing to the transfer of millions of tons of matter from the land to the depths of the ocean, and the need to readjust the pressure on the crust. Apparently this stage is reached at the end of the Archaean, and a great rise of the land—probably protracted during hundreds of thousands of years—

takes place. The shore-bottoms round the primitive continent are raised above the water, their rocks crumpling like plates of lead under the overpowering pressure. The sea retires with its inhabitants, mingling their various provinces, transforming their settled homes. A larger continent spans the northern ocean of the earth.

In the shore-waters of this early continent are myriads of living things, representing all the great families of the animal world below the level of the fish and the insect. The mud and sand in which their frames are entombed, as they die, will one day be the "Cambrian" rocks of the geologist, and reveal to him their forms and suggest their habits. No great volcanic age will reduce them to streaks of shapeless carbon. The earth now buries its dead, and from their petrified remains we conjure up a picture of the swarming life of the Cambrian ocean.

A strange, sluggish population burrows in the mud, crawls over the sand, adheres to the rocks, and swims among the thickets of sea-weed. The strangest and most formidable, though still too puny a thing to survive in a more strenuous age, is the familiar Trilobite of the geological museum; a flattish animal with broad, round head, like a shovel, its back covered with a three-lobed shell, and a number of fine legs or swimmers below. It burrows in the loose bottom, or lies in it with its large compound eyes peeping out in search of prey. It is the chief representative of the hard-cased group (Crustacea) which will later replace it with the lobster, the shrimp, the crab, and the water-flea. Its remains form from a third to a fourth of all the buried Cambrian skeletons. With it, swimming in the water, are smaller members of the same family, which come nearer to our familiar small Crustacea.

Shell-fish are the next most conspicuous inhabitants. Molluscs are already well represented, but the more numerous are the more elementary Brachiopods ("lampshells"), which come next to the Trilobites in number and variety. Worms (or Annelids) wind in and out of the mud, leaving their tracks and tubes for later ages. Strange ball or cup-shaped little animals, with a hard frame, mounted on stony stalks and waving irregular arms to draw in the food-bearing water, are the earliest representatives of the Echinoderms. Some of these Cystids will presently blossom into the wonderful sea-lily population of the next age, some are already quitting their stalks, to become the free-moving star-fish, of which a primitive specimen has been found in the later Cambrian. Large jelly-fishes (of which casts are preserved) swim in the water; coral-animals lay their rocky foundations, but do not as yet form reefs; coarse sponges rise from the floor; and myriads of tiny Radiolaria and Thalamophores, with shells of flint and lime, float at the surface or at various depths.

This slight sketch of the Cambrian population shows us that living things had already reached a high level of development. Their story evidently goes back, for millions of years, deep into those mists of the Archaean age which we were unable to penetrate. We turn therefore to the zoologist to learn what he can tell us of the origin and family-relations of these Cambrian animals, and will afterwards see how they are climbing to higher levels under the eye of the geologist.

At the basis of the living world of to-day is a vast population of minute, generally microscopic, animals and plants, which are popularly known as "microbes." Each consists, in scientific language, of one cell. It is now well known that the bodies of the larger animals and plants are made up of millions of these units of living matter, or cells—the atoms of the organic world—and I need not enlarge on it. But even a single cell lends itself to infinite variety of shape, and we have to penetrate to the very lowest level of this luxuriant world of one-celled organisms to obtain some idea of the most primitive living things. Properly speaking, there were no "first living things." It cannot be doubted by any student of nature that the microbe developed so gradually that it is as impossible to fix a precise term for the beginning of life as it is to say when the night ends and the day begins. In the course of time little one-celled living units appeared in the waters of the earth, whether in the shallow shore waters or on the surface of the deep is a matter of conjecture.

We are justified in concluding that they were at least as rudimentary in structure and life as the lowest inhabitants of nature to-day. The distinction of being the lowest known living organisms should, I think, be awarded to certain one-celled vegetal organisms which are very common in nature. Minute simple specks of living matter, sometimes less than the five-thousandth of an inch in diameter, these lowly Algae are so numerous that it is they, in their millions, which cover moist surfaces with the familiar greenish or bluish coat. They have no visible organisation, though, naturally, they must have some kind of structure below the range of the microscope. Their life consists in the absorption of food-particles, at any point of their surface, and in dividing into two living microbes, instead of dying, when their bulk increases. A very lowly branch of the Bacteria (Nitrobacteria) sometimes dispute their claim to the lowest position in the hierarchy of living nature, but there is reason to suspect that these Bacteria may have degenerated from a higher level.

Here we have a convenient starting-point for the story of life, and may now trace the general lines of upward development. The first great principle to be recognised is the early division of these primitive organisms into two great classes, the moving and the stationary. The clue to this important divergence is found in diet. With exceptions on both sides, we find that the non-moving microbes generally feed on inorganic matter, which they convert into plasm; the moving microbes generally feed on ready-made plasm—on the living non-movers, on each other, or on particles of dead organic matter. Now, inorganic food is generally diffused in the waters, so that the vegetal feeders have no incentive to develop mobility. On the other hand, the power to move in search of their food, which is not equally diffused, becomes a most important advantage to the feeders on other organisms. They therefore develop various means of locomotion. Some flow or roll slowly along like tiny drops of oil on an inclined surface; others develop minute outgrowths of their substance, like fine hairs, which beat the water as oars do. Some of them have one strong oar, like the gondolier (but in front of the boat); others have two or more oars; while some have their little flanks bristling with fine lashes, like the flanks of a Roman galley.

If we imagine this simple principle at work for ages among the primitive microbes, we understand the first great division of the living world, into plants and animals. There must have been a long series of earlier stages below the plant and animal. In fact, some writers insist that the first organisms were animal in nature, feeding on the more elementary stages of living matter. At last one type develops chlorophyll (the green matter in leaves), and is able to build up plasm out of inorganic matter; another type develops mobility, and becomes a parasite on the plant world. There is no rigid distinction of the two worlds. Many microscopic plants move about just as animals do, and many animals live on fixed stalks; while many plants feed on organic matter. There is so little "difference of nature" between the plant and the animal that the experts differ in classifying some of these minute creatures. In fact, we shall often find plants and animals crossing the line of division. We shall find animals rooting themselves to the floor, like plants, though they will generally develop arms or streamers for bringing the food to them; and we shall find plants becoming insect-catchers. All this merely shows that the difference is a natural tendency, which special circumstances may overrule. It remains true that the great division of the organic world is due to a simple principle of development; difference of diet leads to difference of mobility.

But this simple principle will have further consequences of a most important character. It will lead to the development of mind in one half of living nature and leave it undeveloped in the other. Mind, as we know it in the lower levels of life, is not confined to the animal at all. Many even of the higher plants are very delicately sensitive to stimulation, and at the lowest level many plants behave just like animals. In other words, this sensitiveness to stimuli, which is the first form of mind, is distributed according to mobility. To the motionless organism it is no advantage; to the pursuing and pursued organism it is an immense advantage, and is one of the chief qualities for natural selection to foster.

For the moment, however, we must glance at the operation of this and other natural principles in the evolution of the one-celled animals and plants, which we take to represent the primitive population of the earth. As there are tens of thousands of different species even of "microbes," it is clear that we must deal with them in a very summary way. The evolution of the plant I reserve for a later chapter, and I must be content to suggest the development of one-celled animals on very broad lines. When some of the primitive cells began to feed on each other, and develop mobility, it is probable that at least two distinct types were evolved, corresponding to the two lowest animal organisms in nature to-day. One of these is a very minute and very common (in vases of decaying flowers, for instance) speck of plasm, which moves about by lashing the water with a single oar (flagellum), or hair-like extension of its substance. This type, however, which is known as the Flagellate, may be derived from the next, which we will take as the primitive and fundamental animal type. It is best seen in the common and familiar Amoeba, a minute sac of liquid or viscid plasm, often not more than a hundredth of an inch in diameter. As its "skin" is merely a finer kind of the viscous plasm, not an impenetrable membrane, it takes in food at any part of its surface, makes little "stomachs," or temporary cavities, round the food at any part of its interior, ejects the useless matter at any point, and thrusts out any part of its body as temporary "arms" or "feet."

Now it is plain that in an age of increasing microbic cannibalism the toughening of the skin would be one of the first advantages to secure survival, and this is, in point of fact, almost the second leading principle in early development. Naturally, as the skin becomes firmer, the animal can no longer, like the Amoeba, take food at, or make limbs of, any part of it. There must be permanent pores in the membrane to receive food or let out rays of the living substance to act as oars or arms. Thus we get an immense variety amongst these Protozoa, as the one-celled animals are called. Some (the Flagellates) have one or two stout oars; some (the Ciliates) have numbers of fine hairs (or cilia). Some have a definite mouth-funnel, but no stomach, and cilia drawing the water into it. Some (Vorticella, etc.), shrinking from the open battlefield, return to the plant-principle, live on stalks, and have wreaths of cilia round the open mouth drawing the water to them. Some (the Heliozoa) remain almost motionless, shooting out sticky rays of their matter on every side to catch the food. Some form tubes to live in; some (Coleps) develop horny plates for armour; and others develop projectiles to pierce their prey (stinging threads).

This miniature world is full of evolutionary interest, but it is too vast for detailed study here. We will take one group, which we know to have been already developed in the Cambrian, and let a study of its development stand for all. In every lecture or book on "the beauties of the microscope" we find, and are generally greatly puzzled by, minute shells of remarkable grace and beauty that are formed by some of these very elementary animals They are the Radiolaria (with flinty shells, as a rule) and the Thalamophora (with chalk frames). Evolution furnishes a simple key to their remarkable structure.

As we saw, one of the early requirements to be fostered by natural selection in the Archaean struggle for life was a "thick skin," and the thick skin had to be porous to let the animal shoot out its viscid substance in rays and earn its living. This stage above the Amoeba is beautifully illustrated in the sun-animalcules (Heliozoa). Now the lowest types of Radiolaria are of this character. They have no shell or framework at all. The next stage is for the little animal to develop fine irregular threads of flint in its skin, a much better security against the animal-eater. These animalcules, it must be recollected, are bits of almost pure plasm, and, as they live in crowds, dividing and subdividing, but never dying, make excellent mouthfuls for a small feeder. Those with the more flint in their skins were the more apt to survive and "breed." The threads of flint increase until they form a sort of thorn-thicket round a little social group, or a complete lattice round an individual body. Next, spikes or spines jut out from the lattice, partly for additional protection, partly to keep the little body afloat at the surface of the sea. In this way we get a bewildering variety and increasing complexity of forms, ascending in four divergent lines from the naked ancestral type to the extreme grace and intricacy of the Calocyclas monumentum or the Lychnaspis miranda. These, however, are rare specimens in the 4000 species of Radiolaria. I have hundreds of them, on microscopic slides, which have no beauty and little regularity of form. We see a gradual evolution, on utilitarian principles, as we run over the thousands of forms; and, when we recollect the inconceivable numbers in which these little animals have lived and struggled for life—passively—during tens of millions of years, we are not surprised at the elaborate protective frames of the higher types.

The Thalamophores, the sister-group of one-celled animals which largely compose our chalk and much of our limestone, are developed on the same principle. The earlier forms seem to have lived in a part of the ocean where silica was scarce, and they absorbed and built their protective frames of lime. In the simpler types the frame is not unlike a wide-necked bottle, turned upside-down. In later forms it takes the shape of a spirally coiled series of chambers, sometimes amounting to several thousand. These wonderful little houses are not difficult to understand. The original tiny animal covers itself with a coat of lime. It feeds, grows, and bulges out of its chamber. The new part of its flesh must have a fresh coat, and the process goes on until scores, or hundreds, or even thousands, of these tiny chambers make up the spiral shell of the morsel of living matter.

With this brief indication of the mechanical principles which have directed the evolution of two of the most remarkable groups of the one-celled animals we must be content, or the dimensions of this volume will not enable us even to reach the higher and more interesting types. We must advance at once to the larger animals, whose bodies are composed of myriads of cells.

The social tendency which pervades the animal world, and the evident use of that tendency, prepare us to understand that the primitive microbes would naturally come in time to live in clusters. Union means effectiveness in many ways, even when it does not mean strength. We have still many loose associations of one-celled animals in nature, illustrating the approach to a community life. Numbers of the Protozoa are social; they live either in a common jelly-like matrix, or on a common stalk. In fact, we have a singularly instructive illustration of the process in the evolution of the sponges.

It is well known that the horny texture to which we commonly give the name of sponge is the former tenement and shelter of a colony of one-celled animals, which are the real Sponges. In other groups the structure is of lime; in others, again, of flinty material. Now, the Sponges, as we have them to-day, are so varied, and start from so low a level, that no other group of animals "illustrates so strikingly the theory of evolution," as Professor Minchin says. We begin with colonies in which the individuals are (as in Proterospongia) irregularly distributed in their jelly-like common bed, each animal lashing the water, as stalked Flagellates do, and bringing the food to it. Such a colony would be admirable food for an early carnivore, and we soon find the protective principle making it less pleasant for the devourer. The first stage may be—at least there are such Sponges even now—that the common bed is strewn or sown with the cast shells of Radiolaria. However that may be, the Sponges soon begin to absorb the silica or lime of the sea-water, and deposit it in needles or fragments in their bed. The deposit goes on until at last an elaborate framework of thorny, or limy, or flinty material is constructed by the one-celled citizens. In the higher types a system of pores or canals lets the food-bearing water pass through, as the animals draw it in with their lashes; in the highest types the animals come still closer together, lining the walls of little chambers in the interior.

Here we have a very clear evolutionary transition from the solitary microbe to a higher level, but, unfortunately, it does not take us far. The Sponges are a side-issue, or cul de sac, from the Protozoic world, and do not lead on to the higher. Each one-celled unit remains an animal; it is a colony of unicellulars, not a many-celled body. We may admire it as an instructive approach toward the formation of a many-celled body, but we must look elsewhere for the true upward advance.

The next stage is best illustrated in certain spherical colonies of cells like the tiny green Volvox (now generally regarded as vegetal) of our ponds, or Magosphoera. Here the constituent cells merge their individuality in the common action. We have the first definite many-celled body. It is the type to which a moving close colony of one-celled microbes would soon come. The round surface is well adapted for rolling or spinning along in the water, and, as each little cell earns its own living, it must be at the surface, in contact with the water. Thus a hollow, or fluid-filled, little sphere, like the Volvox, is the natural connecting-link between the microbe and the many-celled body, and may be taken to represent the first important stage in its development.

The next important stage is also very clearly exhibited in nature, and is more or less clearly reproduced in the embryonic development of all animals. We may imagine that the age of microbes was succeeded by an age of these many-celled larger bodies, and the struggle for life entered upon a new phase. The great principle we have already recognised came into play once more. Large numbers of the many-celled bodies shrank from the field of battle, and adopted the method of the plant. They rooted themselves to the floor of the ocean, and developed long arms or lashes for creating a whirlpool movement in the water, and thus bringing the food into their open mouths. Forfeiting mobility, they have, like the plant, forfeited the greater possibilities of progress, and they remain flowering to-day on the floors of our waters, recalling the next phase in the evolution of early life. Such are the hydra, the polyp, the coral, and the sea-anemone. It is not singular that earlier observers could not detect that they were animals, and they were long known in science as "animal-plants" (Zoophytes).

When we look to the common structure of these animals, to find the ancestral type, we must ignore the nerve and muscle-cells which they have developed in some degree. Fundamentally, their body consists of a pouch, with an open mouth, the sides of the pouch consisting of a double layer of cells. In this we have a clue to the next stage of animal development. Take a soft india-rubber ball to represent the first many-celled animal. Press in one half of the ball close upon the other, narrow the mouth, and you have something like the body-structure of the coral and hydra. As this is the course of embryonic development, and as it is so well retained in the lowest groups of the many-celled animals, we take it to be the next stage. The reason for it will become clear on reflection. Division of labour naturally takes place in a colony, and in that way certain cells in the primitive body were confined to the work of digestion. It would be an obvious advantage for these to retire into the interior, leaving the whole external surface free for the adjustment of the animal's relations to the outer world.

Again we must refrain from following in detail the development of this new world of life which branches off in the Archaean ocean. The evolution of the Corals alone would be a lengthy and interesting story. But a word must be said about the jelly-fish, partly because the inexpert will be puzzled at the inclusion of so active an animal, and partly because its story admirably illustrates the principle we are studying. The Medusa really descends from one of the plant-like animals of the early Archaean period, but it has abandoned the ancestral stalk, turned upside down, and developed muscular swimming organs. Its past is betrayed in its embryonic development. As a rule the germ develops into a stalked polyp, out of which the free-swimming Medusa is formed. This return to active and free life must have occurred early, as we find casts of large Medusae in the Cambrian beds. In complete harmony with the principle we laid down, the jelly-fish has gained in nerve and sensitiveness in proportion to its return to an active career.

But this principle is best illustrated in the other branch of the early many-celled animals, which continued to move about in search of food. Here, as will be expected, we have the main stem of the animal world, and, although the successive stages of development are obscure, certain broad lines that it followed are clear and interesting.

It is evident that in a swarming population of such animals the most valuable qualities will be speed and perception. The sluggish Coral needs only sensitiveness enough, and mobility enough, to shrink behind its protecting scales at the approach of danger. In the open water the most speedy and most sensitive will be apt to escape destruction, and have the larger share in breeding the next generation. Imagine a selection on this principle going on for millions of years, and the general result can be conjectured. A very interesting analogy is found in the evolution of the boat. From the clumsy hollowed tree of Neolithic man natural selection, or the need of increasing speed, has developed the elongated, evenly balanced modern boat, with its distinct stem and stern. So in the Archaean ocean the struggle to overtake food, or escape feeders, evolved an elongated two-sided body, with head and tail, and with the oars (cilia) of the one-celled ancestor spread thickly along its flanks. In other words, a body akin to that of the lower water-worms would be the natural result; and this is, in point of fact, the next stage we find in the hierarchy of living nature.

Probably myriads of different types of this worm-like organisation were developed, but such animals leave no trace in the rocks, and we can only follow the development by broad analogies. The lowest flat-worms of to-day may represent some of these early types, and as we ascend the scale of what is loosely called "worm" organisation, we get some instructive suggestions of the way in which the various organs develop. Division of labour continues among the colony of cells which make up the body, and we get distinct nerve-cells, muscle-cells, and digestive cells. The nerve-cells are most useful at the head of an organism which moves through the water, just as the look-out peers from the head of the ship, and there they develop most thickly. By a fresh division of labour some of these cells become especially sensitive to light, some to the chemical qualities of matter, some to movements of the water; we have the beginning of the eyes, the nose, and the ears, as simple little depressions in the skin of the head, lined with these sensitive cells. A muscular gullet arises to protect the digestive tube; a simple drainage channel for waste matter forms under the skin; other channels permit the passage of the fluid food, become (in the higher worms) muscular blood-vessels, and begin to contract—somewhat erratically at first—and drive the blood through the system.

Here, perhaps, are millions of years of development compressed into a paragraph. But the purpose of this work is chiefly to describe the material record of the advance of life in the earth's strata, and show how it is related to great geological changes. We must therefore abstain from endeavouring to trace the genealogy of the innumerable types of animals which were, until recently, collected in zoology under the heading "Worms." It is more pertinent to inquire how the higher classes of animals, which we found in the Cambrian seas, can have arisen from this primitive worm-like population.

The struggle for life in the Archaean ocean would become keener and more exacting with the appearance of each new and more effective type. That is a familiar principle in our industrial world to-day, and we shall find it illustrated throughout our story. We therefore find the various processes of evolution, which we have already seen, now actively at work among the swarming Archaean population, and producing several very distinct types. In some of these struggling organisms speed is developed, together with offensive and defensive weapons, and a line slowly ascends toward the fish, which we will consider later. In others defensive armour is chiefly developed, and we get the lines of the heavy sluggish shell-fish, the Molluscs and Brachiopods, and, by a later compromise between speed and armour, the more active tough-coated Arthropods. In others the plant-principle reappears; the worm-like creature retires from the free-moving life, attaches itself to a fixed base, and becomes the Bryozoan or the Echinoderm. To trace the development of these types in any detail is impossible. The early remains are not preserved. But some clues are found in nature or in embryonic development, and, when the types do begin to be preserved in the rocks, we find the process of evolution plainly at work in them. We will therefore say a few words about the general evolution of each type, and then return to the geological record in the Cambrian rocks.

The starfish, the most familiar representative of the Echinoderms, seems very far removed from the kind of worm-like ancestor we have been imagining, but, fortunately, the very interesting story of the starfish is easily learned from the geological chronicle. Reflect on the flower-like expansion of its arms, and then imagine it mounted on a stalk, mouth side upward, with those arms—more tapering than they now are—waving round the mouth. That, apparently, was the past of the starfish and its cousins. We shall see that the earliest Echinoderms we know are cup-shaped structures on stalks, with a stiff, limy frame and (as in all sessile animals) a number of waving arms round the mouth. In the next geological age the stalk will become a long and flexible arrangement of muscles and plates of chalk, the cup will be more perfectly compacted of chalky plates, and the five arms will taper and branch until they have an almost feathery appearance; and the animal will be considered a "sea-lily" by the early geologist.

The evidence suggests that both the free-moving and the stalked Echinoderms descend from a common stalked Archaean ancestor. Some primitive animal abandoned the worm-like habit, and attached itself, like a polyp, to the floor. Like all such sessile animals, it developed a wreath of arms round the open mouth. The "sea-cucumber" (Holothurian) seems to be a type that left the stalk, retaining the little wreath of arms, before the body was heavily protected and deformed. In the others a strong limy skeleton was developed, and the nerves and other organs were modified in adaptation to the bud-like or flower-like structure. Another branch of the family then abandoned the stalk, and, spreading its arms flat, and gradually developing in them numbers of little "feet" (water-tubes), became the starfish. In the living Comatula we find a star passing through the stalked stage in its early development, when it looks like a tiny sea-lily. The sea-urchin has evolved from the star by folding the arms into a ball. [*]

** See the section on Echinoderms, by Professor MacBride, in the "Cambridge Natural History," I.*

The Bryozoa (sea-mats, etc.) are another and lower branch of the primitive active organisms which have adopted a sessile life. In the shell-fish, on the other hand, the principle of armour-plating has its greatest development. It is assuredly a long and obscure way that leads from the ancestral type of animal we have been describing to the headless and shapeless mussel or oyster. Such a degeneration is, however, precisely what we should expect to find in the circumstances. Indeed, the larva, of many of the headless Molluscs have a mouth and eyes, and there is a very common type of larva—the trochosphere—in the Mollusc world which approaches the earlier form of some of the higher worms. The Molluscs, as we shall see, provide some admirable illustrations of the process of evolution. In some of the later fossilised specimens (Planorbis, Paludina, etc.) we can trace the animal as it gradually passes from one species to another. The freshening of the Caspian Sea, which was an outlying part of the Mediterranean quite late in the geological record, seems to have evolved several new genera of Molluscs.

Although, therefore, the remains are not preserved of those primitive Molluscs in which we might see the protecting shell gradually thickening, and deforming the worm-like body, we are not without indications of the process. Two unequal branches of the early wormlike organisms shrank into strong protective shells. The lower branch became the Brachiopods; the more advanced branch the Molluscs. In the Mollusc world, in turn, there are several early types developed. In the Pelecypods (or

Lamellibranchs—the mussel, oyster, etc.) the animal retires wholly within its fortress, and degenerates. The Gastropods (snails, etc.) compromise, and retain a certain amount of freedom, so that they degenerate less. The highest group, the Cephalopods, "keep their heads," in the literal sense, and we shall find them advancing from form to form until, in the octopus of a later age, they discard the ancestral shell, and become the aristocrats of the Mollusc kingdom.

The last and most important line that led upward from the chaos of Archaean worms is that of the Arthropods. Its early characteristic was the acquisition of a chitinous coat over the body. Embryonic indications show that this was at first a continuous shield, but a type arose in which the coat broke into sections covering each segment of the body, giving greater freedom of movement. The shield, in fact, became a fine coat of mail. The Trilobite is an early and imperfect experiment of the class, and the larva of the modern king-crab bears witness that it has not perished without leaving descendants. How later Crustacea increase the toughness of the coat by deposits of lime, and lead on to the crab and lobster, and how one early branch invades the land, develops air-breathing apparatus, and culminates in the spiders and insects, will be considered later. We shall see that there is most remarkable evidence connecting the highest of the Arthropods, the insect, with a remote Annelid ancestor.

We are thus not entirely without clues to the origin of the more advanced animals we find when the fuller geological record begins. Further embryological study, and possibly the discovery of surviving primitive forms, of which Central Africa may yet yield a number, may enlarge our knowledge, but it is likely to remain very imperfect. The fossil records of the long ages during which the Mollusc, the Crustacean, and the Echinoderm slowly assumed their characteristic forms are hopelessly lost. But we are now prepared to return to the record which survives, and we shall find the remaining story of the earth a very ample and interesting chronicle of evolution.

CHAPTER VII. THE PASSAGE TO THE LAND

Slender as our knowledge is of the earlier evolution of the Invertebrate animals, we return to our Cambrian population with greater interest. The uncouth Trilobite and its livelier cousins, the sluggish, skulking Brachiopod and Mollusc, the squirming Annelids, and the plant-like Cystids, Corals, and Sponges are the outcome of millions of years of struggle. Just as men, when their culture and their warfare advanced, clothed themselves with armour, and the most completely mailed survived the battle, so, generation after generation, the thicker and harder-skinned animals survived in the Archaean battlefield, and the Cambrian age opened upon the various fashions of armour that we there described. But, although half the story of life is over, organisation is still imperfect and sluggish. We have now to see how it advances to higher levels, and how the drama is transferred from the ocean to a new and more stimulating environment.

The Cambrian age begins with a vigorous move on the part of the land. The seas roll back from the shores of the "lost Atlantis," and vast regions are laid bare to the sun and the rains. In the bays and hollows of the distant shores the animal survivors of the great upheaval adapt themselves to their fresh homes and continue the struggle. But the rivers and the waves are at work once more upon the land, and, as the Cambrian age proceeds, the fringes of the continents are sheared, and the shore-life steadily advances upon the low-lying land. By the end of the Cambrian age a very large proportion of the land is covered with a shallow sea, in which the debris of its surface is deposited. The levelling continues through the next (Ordovician) period. Before its close nearly the whole of the United States and the greater part of Canada are under water, and the new land that had appeared on the site of Europe is also for the most part submerged. The present British Isles are almost reduced to a strip of north-eastern Ireland, the northern extremity of Scotland, and large islands in the south-west and centre of England.

We have already seen that these victories of the sea are just as stimulating, in a different way, to animals as the victories of the land. American geologists are tracing, in a very instructive way, the effect on that early population of the encroachment of the sea. In each arm of the sea is a distinctive fauna. Life is still very parochial; the great cosmopolitans, the fishes, have not yet arrived. As the land is revelled, the arms of the sea approach each other, and at last mingle their waters and their populations, with stimulating effect. Provincial characters are modified, and cosmopolitan characters increase in the great central sea of America. The vast shallow waters provide a greatly enlarged theatre for the life of the time, and it flourishes enormously. Then, at the end of the Ordovician, the land begins to rise once more. Whether it was due to a fresh shrinking of the crust, or to the simple process we have described, or both, we need not attempt to determine; but both in Europe and America there is a great emergence of land. The shore-tracts and the shallow water are narrowed, the struggle is intensified in them, and we pass into the Silurian age with a greatly reduced number but more advanced variety of animals. In the Silurian age the sea advances once more, and the shore-waters expand. There is another great "expansive evolution" of life. But the Silurian age closes with a fresh and very extensive emergence of the land, and this time it will have the most important consequences. For two new things have meantime appeared on the earth. The fish has evolved in the waters, and the plant, at least, has found a footing on the land.

These geological changes which we have summarised and which have been too little noticed until recently in evolutionary studies, occupied 7,000,000 years, on the lowest estimate, and probably twice that period. The impatient critic of evolutionary hypotheses is apt to forget the length of these early periods. We shall see that in the last two or three million years of the earth's story most extraordinary progress has been made in plant and animal development, and can be very fairly traced. How much advance should we allow for these seven or fourteen million years of swarming life and changing environments?

We cannot nearly cover the whole ground of paleontology for the period, and must be content to notice some of the more interesting advances, and then deal more fully with the evolution of the fish, the forerunner of the great land animals.

The Trilobite was the most arresting figure in the Cambrian sea, and its fortunes deserve a paragraph. It reaches its climax in the Ordovician sea, and then begins to decline, as more powerful animals come upon the scene. At first (apparently) an eyeless organism, it gradually develops compound eyes, and in some species the experts have calculated that there were 15,000 facets to each eye. As time goes on, also, the eye stands out from the head on a kind of stalk, giving a wider range of vision. Some of the more sluggish species seem to have been able to roll themselves up, like hedgehogs, in their shells, when an enemy approached. But another branch of the same group (Crustacea) has meantime advanced, and it gradually supersedes the dwindling Trilobites. Toward the close of the Silurian great scorpion-like Crustaceans (Pterygotus, Eurypterus, etc.) make their appearance. Their development is obscure, but it must be remembered that the rocks only give the record of shore-life, and only a part of that is as yet opened by geology. Some experts think that they were developed in inland waters. Reaching sometimes a length of five or six feet, with two large compound eyes and some smaller eye-spots (ocelli), they must have been the giants of the Silurian ocean until the great sharks and other fishes appeared.

The quaint stalked Echinoderm which also we noticed in the Cambrian shallows has now evolved into a more handsome creature, the sea-lily. The cup-shaped body is now composed of a large number of limy plates, clothed with flesh; the arms are long, tapering, symmetrical, and richly fringed; the stalk advances higher and higher, until the flower-like animal sometimes waves its feathery arms from the top of a flexible pedestal composed of millions of tiny chalk disks. Small forests of these sea-lilies adorn the floor of the Silurian ocean, and their broken and dead frames form whole beds of limestone. The primitive Cystids dwindle and die out in the presence of such powerful competitors. Of 250 species only a dozen linger in the Silurian strata, though a new and more advanced type—the Blastoid—holds the field for a time. It is the age of the Crinoids or sea-lilies. The starfish, which has abandoned the stalk, does not seem to prosper as yet, and the brittle-star appears. Their age will come later. No sea-urchins or sea-cucumbers (which would hardly be preserved) are found as yet. It is precisely the order of appearance which our theory of their evolution demands.

The Brachiopods have passed into entirely new and more advanced species in the many advances and retreats of the shores, but the Molluscs show more interesting progress. The commanding group from the start is that of the Molluscs which have "kept their head," the Cephalopods, and their large shells show a most instructive evolution. The first great representative of the tribe is a straight-shelled Cephalopod, which becomes "the tyrant and scavenger of the Silurian ocean" (Chamberlin). Its tapering, conical shell sometimes runs to a length of fifteen feet, and a diameter of one foot. It would of itself be an important evolutionary factor in the primitive seas, and might explain more than one advance in protective armour or retreat into heavy shells. As the period advances the shell begins to curve, and at last it forms a close spiral coil. This would be so great an advantage that we are not surprised to find the coiled type (Goniatites) gain upon and gradually replace the straight-shelled types (Orthoceratites). The Silurian ocean swarms with these great shelled Cephalopods, of which the little Nautilus is now the only survivor.

We will not enlarge on the Sponges and Corals, which are slowly advancing toward the higher modern types. Two new and very powerful organisms have appeared, and merit the closest attention. One is the fish, the remote ancestor of the birds and mammals that will one day rule the earth. The other may be the ancestor of the fish itself, or it may be one of the many abortive outcomes and unsuccessful experiments of the stirring life of the time. And while these new types are themselves a result of the great and stimulating changes which we have reviewed and the incessant struggle for food and safety, they in turn enormously quicken the pace of development. The Dreadnought appears in the primitive seas; the effect on the fleets of the world of the evolution of our latest type of battleship gives us a faint idea of the effect, on all the moving population, of the coming of these monsters of the deep. The age had not lacked incentives to progress; it now obtains a more terrible and far-reaching stimulus.

To understand the situation let us see how the battle of land and sea had proceeded. The Devonian Period had opened with a fresh emergence of the land, especially in Europe, and great inland seas or lakes were left in the hollows. The tincture of iron which gives a red colour to our characteristic Devonian rocks, the Old Red Sandstone, shows us that the sand was deposited in inland waters. The fish had already been developed, and the Devonian rocks show it swarming, in great numbers and variety, in the enclosed seas and round the fringe of the continents.

The first generation was a group of strange creatures, half fish and half Crustacean, which are known as the Ostracoderms. They had large armour-plated heads, which recall the Trilobite, and suggest that they too burrowed in the mud of the sea or (as many think) of the inland lakes, making havoc among the shell-fish, worms, and small Crustacea. The hind-part of their bodies was remarkably fish-like in structure. But they had no backbone—though we cannot say whether they may not have had a rod of cartilage along the back—and no articulated jaws like the fish. Some regard them as a connecting link between the Crustacea and the fishes, but the general feeling is that they were an abortive development in the direction of the fish. The sharks and other large fishes, which have appeared in the Silurian, easily displace these clumsy and poor-mouthed competitors One almost thinks of the aeroplane superseding the navigable balloon.

Of the fishes the Arthrodirans dominated the inland seas (apparently), while the sharks commanded the ocean. One of the Arthrodirans, the Dinichthys ("terrible fish"), is the most formidable fish known to science. It measured twenty feet from snout to tail. Its monstrous head, three feet in width, was heavily armoured, and, instead of teeth, its great jaws, two feet in length, were sharpened, and closed over the victim like a gigantic pair of clippers. The strongly plated heads of these fishes were commonly a foot or two feet in width. Life in the waters became more exacting than ever. But the Arthrodirans were unwieldy and sluggish, and had to give way before more progressive types. The toothed shark gradually became the lord of the waters.

The early shark ate, amongst other things, quantities of Molluscs and Brachiopods. Possibly he began with Crustacea; in any case the practice of crunching shellfish led to a stronger and stronger development of the hard plate which lined his mouth. The prickles of the plate grew larger and harder, until—as may be seen to-day in the mouth of a young shark—the cavity was lined with teeth. In the bulk of the Devonian sharks these developed into what are significantly called "pavement teeth." They were solid plates of enamel, an inch or an inch and a half in width, with which the monster ground its enormous meals of Molluscs, Crustacea, sea-weed, etc. A new and stimulating element had come into the life of the invertebrate world. Other sharks snapped larger victims, and developed the teeth on the edges of their jaws, to the sacrifice of the others, until we find these teeth in the course of time solid triangular masses of enamel, four or five inches long, with saw-like edges. Imagine these terrible mouths—the shears of the Arthrodiran, and the grindstones and terrible crescents of the giant sharks—moving speedily amongst the crowded inhabitants of the waters, and it is easy to see what a stimulus to the attainment of speed and of protective devices was given to the whole world of the time.

What was the origin of the fish? Here we are in much the same position as we were in regard to the origin of the higher Invertebrates. Once the fish plainly appears upon the scene it is found to be undergoing a process of evolution like all other animals. The vast majority of our fishes have bony frames (or are Teleosts); the fishes of the Devonian age nearly all have frames of cartilage, and we know from embryonic development that cartilage is the first stage in the formation of bone. In the teeth and tails, also, we find a gradual evolution toward the higher types. But the earlier record is, for reasons I have already given, obscure; and as my purpose is rather to discover the agencies of evolution than to strain slender evidence in drawing up pedigrees, I need only make brief reference to the state of the problem.

Until comparatively recent times the animal world fell into two clearly distinct halves, the Vertebrates and the Invertebrates. There were several anatomical differences between the two provinces, but the most conspicuous and most puzzling was the backbone. Nowhere in living nature or in the rocks was any intermediate type known between the backboned and the non-backboned animal. In the course of the nineteenth century, however, several animals of an intermediate type were found. The sea-squirt has in its early youth the line of cartilage through the body which, in embryonic development, represents the first stage of the backbone; the lancelet and the Appendicularia have a rod of cartilage throughout life; the "acorn-headed worm" shows traces of it. These are regarded as surviving specimens of various groups of animals which, in early times, fell between the Invertebrate and Vertebrate worlds, and illustrate the transition.

With their aid a genealogical tree was constructed for the fish. It was assumed that some Cambrian or Silurian Annelid obtained this stiffening rod of cartilage. The next advantage—we have seen it in many cases—was to combine flexibility with support. The rod was divided into connected sections (vertebrae), and hardened into bone. Besides stiffening the body, it provided a valuable shelter for the spinal cord, and its upper part expanded into a box to enclose the brain. The fins were formed of folds of skin which were thrown off at the sides and on the back, as the animal wriggled through the water. They were of use in swimming, and sections of them were stiffened with rods of cartilage, and became the pairs of fins. Gill slits (as in some of the highest worms) appeared in the throat, the mouth was improved by the formation of jaws, and—the worm culminated in the shark.

Some experts think, however, that the fish developed directly from a Crustacean, and hold that the Ostracoderms are the connecting link. A close discussion of the anatomical details would be out of place here, [*] and the question remains open for the present. Directly or indirectly, the fish is a descendant of some Archaean Annelid. It is most probable that the shark was the first true fish-type. There are unrecognisable fragments of fishes in the Ordovician and Silurian rocks, but the first complete skeletons (Lanarkia, etc.) are of small shark- like creatures, and the low organisation of the group to which the shark belongs, the Elasmobranchs, makes it probable that they are the most primitive. Other remains (Palaeospondylus) show that the fish-like lampreys had already developed.

** See, especially, Dr. Gaskell's "Origin of Vertebrates" (1908).*

Two groups were developed from the primitive fish, which have great interest for us. Our next step, in fact, is to trace the passage of the fish from the water to the land, one of the most momentous chapters in the story of life. To that incident or accident of primitive life we owe our own existence and the whole development of the higher types of animals. The advance of natural history in modern times has made this passage to the land easy to understand. Not only does every frog reenact it in the course of its development, but we know many fishes that can live out of water. There is an Indian perch—called the "climbing perch," but it has only once been seen by a European to climb a tree—which crosses the fields in search of another pool, when its own pool is evaporating. An Indian marine fish

(Periophthalmus) remains hunting on the shore when the tide goes out. More important still, several fishes have lungs as well as gills. The Ceratodus of certain Queensland rivers has one lung; though, I was told by the experts in Queensland, it is not a "mud-fish," and never lives in dry mud. However, the Protopterus of Africa and the Lepidosiren of South America have two lungs, as well as gills, and can live either in water or, in the dry season, on land.

When the skeletons of fishes of the Ceratodus type were discovered in the Devonian rocks, it was felt that we had found the fish-ancestor of the land Vertebrates, but a closer anatomical examination has made this doubtful. The Devonian lung-fish has characters which do not seem to lead on to the Amphibia. The same general cause probably led many groups to leave the water, or adapt themselves to living on land as well as in water, and the abundant Dipoi or Dipneusts ("double-breathers") of the Devonian lakes are one of the chief of these groups, which have luckily left descendants to our time. The ancestors of the Amphibia are generally sought amongst the Crossopterygii, a very large group of fishes in Devonian times, with very few representatives to-day.

It is more profitable to investigate the process itself than to make a precarious search for the actual fish, and, fortunately, this inquiry is more hopeful. The remains that we find make it probable that the fish left the water about the beginning of the Devonian or the end of the Silurian. Now this period coincides with two circumstances which throw a complete light on the step; one is the great rise of the land, catching myriads of fishes in enclosed inland seas, and the other is the appearance of formidable carnivores in the waters. As the seas evaporated [*] and the great carnage proceeded, the land, which was already covered with plants and inhabited by insects, offered a safe retreat for such as could adopt it. Emigration to the land had been going on for ages, as we shall see. Curious as it must seem to the inexpert, the fishes, or some of them, were better prepared than most other animals to leave the water. The chief requirement was a lung, or interior bag, by which the air could be brought into close contact with the absorbing blood vessels. Such a bag, broadly speaking, most of the fishes possess in their floating-bladder: a bag of gas, by compressing or expanding which they alter their specific gravity in the water. In some fishes it is double; in some it is supplied with blood-vessels; in some it is connected by a tube with the gullet, and therefore with the atmosphere.

It is now usually thought that the inland seas were the theatre of the passage to land. I must point out, however, that the wide distribution of our Dipneusts, in Australia, tropical Africa, and South America, suggests that they were marine though they now live in fresh water. But we shall see that a continent united the three regions at one time, and it may afford some explanation.

Thus we get very clear suggestions of the transition from water to land. We must, of course, conceive it as a slow and gradual adaptation. At first there may have been a rough contrivance for deriving oxygen directly and partially from the atmosphere, as the water of the lake became impure. So important an advantage would be fostered, and, as the inland sea became smaller, or its population larger or fiercer, the fishes with a sufficiently developed air-breathing apparatus passed to the land, where, as yet, they would find no serious enemy. The fact is beyond dispute; the theory of how it occurred is plausible enough; the consequences were momentous. Great changes were preparing on the land, and in a comparatively short time we shall find its new inhabitant subjected to a fierce test of circumstances that will carry it to an enormously higher level than life had yet reached.

I have said that the fact of this transition to the land is beyond dispute. The evidence is very varied, but need not all be enlarged upon here. The widespread Dipneust fishes of the Devonian rocks bear strong witness to it, and the appearance of the Amphibian immediately afterwards makes it certain. The development of the frog is a reminiscence of it, on the lines of the embryonic law which we saw earlier. An animal, in its individual development, more or less reproduces the past phases of its ancestry. So the free-swimming jelly-fish begins life as a fixed polyp; a kind of star-fish (Comatula) opens its career as a stalked sea-lily; the gorgeous dragon-fly is at first an uncouth aquatic animal, and the ethereal butterfly a worm-like creature. But the most singular and instructive of all these embryonic reminiscences of the past is found in the fact that all the higher land-animals of to-day clearly reproduce a fish-stage in their embryonic development.

In the third and fourth weeks of development the human embryo shows four (closed) slits under the head, with corresponding arches. The bird, the dog, the horse—all the higher land animals, in a word, pass through the same phase. The suggestion has been made that these structures do not recall the gill-slits and gill-arches of the fish, but are folds due to the packing of the embryo in the womb. In point of fact, they appear just at the time when the human embryo is only a fifth of an inch long, and there is no such compression. But all doubt as to their interpretation is dispelled when we remove the skin and examine the heart and blood-vessels. The heart is up in the throat, as in the fish, and has only two chambers, as in the fish (not four, as in the bird and mammal); and the arteries rise in five pairs of arches over the swellings in the throat, as they do in the lower fish, but do not in the bird and mammal. The arrangement is purely temporary—lasting only a couple of weeks in the human embryo—and purposeless. Half these arteries will disappear again. They quite plainly exist to supply fine blood-vessels for breathing at the gill-clefts, and are never used, for the embryo does not breathe, except through the mother. They are a most instructive reminder of the Devonian fish which quitted its element and became the ancestor of all the birds and mammals of a later age.

Several other features of man's embryonic development—the budding of the hind limbs high up, instead of at the base of, the vertebral column, the development of the ears, the nose, the jaws, etc.—have the same lesson, but the one detailed illustration will suffice. The millions of years of stimulating change and struggle which we have summarised have resulted in the production of a fish which walks on four limbs (as the South American mud-fish does to-day), and breathes the atmosphere.

We have been quite unable to follow the vast changes which have meantime taken place in its organisation. The eyes, which were mere pits in the skin, lined with pigment cells, in the early worm, now have a crystalline lens to concentrate the light and define objects on the nerve. The ears, which were at first similar sensitive pits in the skin, on which lay a little stone whose movements gave the animal some sense of direction, are now closed vesicles in the skull, and begin to be sensitive to waves of sound. The nose, which was at first two blind, sensitive pits in the skin of the head, now consists of two nostrils opening into the mouth, with an olfactory nerve spreading richly over the passages. The brain, which was a mere clump of nerve-cells connecting the rough sense-impressions, is now a large and intricate structure, and already exhibits a little of that important region (the cerebrum) in which the varied images of the outside world are combined. The heart, which was formerly was a mere swelling of a part of one of the blood-vessels, now has two chambers.

We cannot pursue these detailed improvements of the mechanism, as we might, through the ascending types of animals. Enough if we see more or less clearly how the changes in the face of the earth and the rise of its successive dynasties of carnivores have stimulated living things to higher and higher levels in the primitive ocean. We pass to the clearer and far more important story of life on land, pursuing the fish through its continuous adaptations to new conditions until, throwing out side-branches as it progresses, it reaches the height of bird and mammal life.

CHAPTER VIII. THE COAL-FOREST

With the beginning of life on land we open a new and more important volume of the story of life, and we may take the opportunity to make clearer certain principles or processes of development which we may seem hitherto to have taken for granted. The evolutionary work is too often a mere superficial description of the strange and advancing classes of plants and animals which cross the stage of geology. Why they change and advance is not explained. I have endeavoured to supply this explanation by putting the successive populations of the earth in their respective environments, and showing the continuous and stimulating effect on them of changes in those environments. We have thus learned to decipher some lines of the decalogue of living nature. "Thou shalt have a thick armour," "Thou shalt be speedy," "Thou shalt shelter from the more powerful," are some of the laws of primeval life. The appearance of each higher and more destructive type enforces them with more severity; and in their observance animals branch outward and upward into myriads of temporary or permanent forms.

But there is no consciousness of law and no idea of evading danger. There is not even some mysterious instinct "telling" the animal, as it used to be said, to do certain things. It is, in fact, not strictly accurate to say that a certain change in the environment stimulates animals to advance. Generally speaking, it does not act on the advancing at all, but on the non-advancing, which it exterminates. The procedure is simple, tangible, and unconscious. Two invading arms of the sea meet and pour together their different waters and populations. The habits, the foods, and the enemies of many types of animals are changed; the less fit for the new environment die first, the more fit survive longest and breed most of the new generation. It is so with men when they migrate to a more exacting environment, whether a dangerous trade or a foreign clime. Again, take the case of the introduction of a giant Cephalopod or fish amongst a population of Molluscs and Crustacea. The toughest, the speediest, the most alert, the most retiring, or the least conspicuous, will be the most apt to survive and breed. In hundreds or thousands of generations there will be an enormous improvement in the armour, the speed, the sensitiveness, the hiding practices, and the protective colours, of the animals which are devoured. The "natural selection of the fittest" really means the "natural destruction of the less fit."

The only point assumed in this is that the young of an animal or plant tend to differ from each other and from their parents. Darwin was content to take this as a fact of common observation, as it obviously is, but later science has thrown some light on the causes of these variations. In the first place, the germs in the parent's body may themselves be subject to struggle and natural selection, and not share equally in the food-supply. Then, in the case of the higher animals (or the majority of animals), there is a clear source of variation in the fact that the mature germ is formed of certain elements from two different parents, four grandparents, and so on. In the case of the lower animals the germs and larvae float independently in the water, and are exposed to many influences. Modern embryologists have found, by experiment, that an alteration of the temperature or the chemical considerable effect on eggs and larvae. Some recent experiments have shown that such changes may even affect the eggs in the mother's ovary. These discoveries are very important and suggestive, because the geological changes which we are studying are especially apt to bring about changes of temperature and changes in the freshness or saltiness of water.

Evolution is, therefore, not a "mere description" of the procession of living things; it is to a great extent an explanation of the procession. When, however, we come to apply these general principles to certain aspects of the advance in organisation we find fundamental differences of opinion among biologists, which must be noted. As Sir E. Ray Lankester recently said, it is not at all true that Darwinism is questioned in zoology to-day. It is true only that Darwin was not omniscient or infallible, and some of his opinions are disputed.

Let me introduce the subject with a particular instance of evolution, the flat-fish. This animal has been fitted to survive the terrible struggle in the seas by acquiring such a form that it can lie almost unseen upon the floor of the ocean. The eye on the under side of the body would thus be useless, but a glance at a sole or plaice in a fishmonger's shop will show that this eye has worked upward to the top of the head. Was the eye shifted by the effort and straining of the fish, inherited and increased slightly in each generation? Is the explanation rather that those fishes in each generation survived and bred which happened from birth to have a slight variation in that direction, though they did not inherit the effect of the parent's effort to strain the eye? Or ought we to regard this change of structure as brought about by a few abrupt and considerable variations on the part of the young? There you have the three great schools which divide modern evolutionists: Lamarckism, Weismannism, and Mendelism (or Mutationism). All are Darwinians. No one doubts that the flat-fish was evolved from an ordinary fish—the flat-fish is an ordinary fish in its youth—or that natural selection (enemies) killed off the old and transitional types and overlooked (and so favoured) the new. It will be seen that the language used in this volume is not the particular language of any one of these schools. This is partly because I wish to leave seriously controverted questions open, and partly from a feeling of compromise, which I may explain. [*]

** Of recent years another compromise has been proposed between the Lamarckians and Weismannists. It would say that the efforts of the parent and their effect on the position* of the eye—in our case—are not inherited, but might be of use in sheltering an embryonic variation in the direction of a displaced eye.

First, the plain issue between the Mendelians and the other two schools—whether the passage from species to species is brought about by a series of small variations during a long period or by a few large variations (or "mutations") in a short period—is open to an obvious compromise. It is quite possible that both views are correct, in different cases, and quite impossible to find the proportion of each class of cases. We shall see later that in certain instances where the conditions of preservation were good we can sometimes trace a perfectly gradual advance from species to species. Several shellfish have been traced in this way, and a sea-urchin in the chalk has been followed, quite gradually, from one end of a genus to the other. It is significant that the advance of research is multiplying these cases. There is no reason why we may not assume most of the changes of species we have yet seen to have occurred in this way. In fact, in some of the lower branches of the animal world (Radiolaria, Sponges, etc.) there is often no sharp division of species at all, but a gradual series of living varieties.

On the other hand we know many instances of very considerable sudden changes. The cases quoted by Mendelists generally belong to the plant world, but instances are not unknown in the animal world. A shrimp (Artemia) was made to undergo considerable modification, by altering the proportion of salt in the water in which it was kept. Butterflies have been made to produce young quite different from their normal young by subjecting them to abnormal temperature, electric currents, and so on; and, as I said, the most remarkable effects have been produced on eggs and embryos by altering the chemical and physical conditions. Rats—I was informed by the engineer in charge of the refrigerating room on an Australian liner—very quickly became adapted to the freezing temperature by developing long hair. All that we have seen of the past changes in the environment of animals makes it probable that these larger variations often occur. I would conclude, therefore, that evolution has proceeded continuously (though by no means universally) through the ages, but there were at times periods of more acute change with correspondingly larger changes in the animal and plant worlds.

In regard to the issue between the Lamarckians and Weismannists—whether changes acquired by the parent are inherited by the young—recent experiments again suggest something of a compromise. Weismann says that the body of the parent is but the case containing the germ-plasm, so that all modifications of the living parent body perish with it, and do not affect the germ, which builds the next generation. Certainly, when we reflect that the 70,000 ova in the human mother's ovary seem to have been all formed in the first year of her life, it is difficult to see how modifications of her muscles or nerves can affect them. Thus we cannot hope to learn anything, either way, by cutting off the tails of cows, and experiments of that kind. But it is acknowledged that certain diseases in the blood, which nourishes the germs, may affect them, and recent experimenters have found that they can reach and affect the germs in the body by other agencies, and so produce inherited modifications in the parent. [*] If this claim is sustained and enlarged, it may be concluded that the greater changes of environment which we find in the geological chronicle may have had a considerable influence of this kind.

* See a paper read by Professor Bourne to the Zoological Section of the British Association, 1910. It must be understood that when I speak of Weismannism I do not refer to this whole theory of heredity, which, he acknowledges, has few supporters. The Lamarckian view is represented in Britain by Sir W. Turner and Professor Darwin. In other countries it has a larger proportion of distinguished supporters. On the whole subject see Professor J. A. Thomson's "Heredity" (1909), Dewar and Finn's "Making of Species" (1909—a Mendelian work), and, for essays by the leaders of each school, "Darwinism and Modern Science" (1909).

The general issue, however, must remain open. The Lamarckian and Weismannist theories are rival interpretations of past events, and we shall not find it necessary to press either. When the fish comes to live on land, for instance, it develops a bony limb out of its fin. The Lamarckian says that the throwing of the weight of the body on the main stem of the fin strengthens it, as practice strengthens the boxer's arm, and the effect is inherited and increased in each generation, until at last the useless paddle of the fin dies away and the main stem has become a stout, bony column. Weismann says that the individual modification, by use in walking, is not inherited, but those young are favoured which have at birth a variation in the strength of the stem of the fin. As each of these interpretations is, and must remain, purely theoretical, we will be content to tell the facts in such cases. But these brief remarks will enable the reader to understand in what precise sense the facts we record are open to controversy.

Let us return to the chronicle of the earth. We had reached the Devonian age, when large continents, with great inland seas, existed in North America, north-west Europe, and north Asia, probably connected by a continent across the North Atlantic and the Arctic region. South America and South Africa were emerging, and a continent was preparing to stretch from Brazil, through South Africa and the Antarctic, to Australia and India. The expanse of land was, with many oscillations, gaining on the water, and there was much emigration to it from the over-populated seas. When the fish went on land in the Devonian, it must have found a diet (insects, etc.) there, and the insects must have been preceded by a plant population. We have first, therefore, to consider the evolution of the plant, and see how it increases in form and number until it covers the earth with the luxuriant forests of the Carboniferous period.

The plant world, we saw, starts, like the animal world, with a great kingdom of one-celled microscopic representatives, and the same principles of development, to a great extent, shape it into a large variety of forms. Armour-plating has a widespread influence among them. The graceful Diatom is a morsel of plasm enclosed in a flinty box, often with a very pretty arrangement of the pores and markings. The Desmid has a coat of cellulose, and a less graceful coat of cellulose encloses the Peridinean. Many of these minute plants develop locomotion and a degree of sensitiveness (Diatoms, Peridinea, Euglena, etc.). Some (Bacteria) adopt animal diet, and rise in power of movement and sensitiveness until it is impossible to make any satisfactory distinction between them and animals. Then the social principle enters. First we have loose associations of one-celled plants in a common bed, then closer clusters or many-celled bodies. In some cases (Volvox) the cluster, or the compound plant, is round and moves briskly in the water, closely resembling an animal. In most cases, the cells are connected in chains, and we begin to see the vague outline of the larger plant.

When we had reached this stage in the development of animal life, we found great difficulty in imagining how the chief lines of the higher Invertebrates took their rise from the Archaean chaos of early many-celled forms. We have an even greater difficulty here, as plant remains are not preserved at all until the Devonian period. We can only conclude, from the later facts, that these primitive many-celled plants branched out in several different directions. One section (at a quite unknown date) adopted an organic diet, and became the Fungi; and a later co-operation, or life-partnership, between a Fungus and a one-celled Alga led to the Lichens. Others remained at the Alga-level, and grew in great thickets along the sea bottoms, no doubt rivalling or surpassing the giant sea-weeds, sometimes 400 feet long, off the American coast to-day. Other lines which start from the level of the primitive many-celled Algae develop into the Mosses (Bryophyta), Ferns (Pteridophyta), Horsetails (Equisetalia), and Club-mosses (Lycopodiales). The mosses, the lowest group, are not preserved in the rocks; from the other three classes will come the great forests of the Carboniferous period.

The early record of plant-life is so poor that it is useless to speculate when the plant first left the water. We have somewhat obscure and disputed traces of ferns in the Ordovician, and, as they and the Horsetails and Club-mosses are well developed in the Devonian, we may assume that some of the sea-weeds had become adapted to life on land, and evolved into the early forms of the ferns, at least in the Cambrian period. From that time they begin to weave a mantle of sombre green over the exposed land, and to play a most important part in the economy of nature.

We saw that at the beginning of the Devonian there was a considerable rise of the land both in America and Europe, but especially in Europe. A distant spectator at that time would have observed the rise of a chain of mountains in Scotland and a general emergence of land north-western Europe. A continent stretched from Ireland to Scandinavia and North Russia, while most of the rest of Europe, except large areas of Russia, France, Germany, and Turkey, was under the sea. Where we now find our Alps and Pyrenees towering up to the snow-line there were then level stretches of ocean. Even the north-western continent was scooped into great inland seas or lagoons, which stretched from Ireland to Scandinavia, and, as we saw, fostered the development of the fishes.

As the Devonian period progressed the sea gained on the land, and must have restricted the growth of vegetation, but as the lake deposits now preserve the remains of the plants which grow down to their shores, or are washed into them, we are enabled to restore the complexion of the landscape. Ferns, generally of a primitive and generalised character, abound, and include the ferns such as we find in warm countries to-day. Horsetails and Club-mosses already grow into forest-trees. There are even seed-bearing ferns, which give promise of the higher plants to come, but as yet nothing approaching our flower and fruit-bearing trees has appeared. There is as yet no certain indication of the presence of Conifers. It is a sombre and monotonous vegetation, unlike any to be found in any climate to-day.

We will look more closely into its nature presently. First let us see how these primitive types of plants come to form the immense forests which are recorded in our coal-beds. Dr. Russel Wallace has lately represented these forests, which have, we shall see, had a most important influence on the development of life, as somewhat mysterious in their origin. If, however, we again consult the geologist as to the changes which were taking place in the distribution of land and water, we find a quite natural explanation. Indeed, there are now distinguished geologists (e.g. Professor Chamberlin) who doubt if the Coal-forests were so exceptionally luxuriant as is generally believed. They think that the vegetation may not have been more dense than in some other ages, but that there may have been exceptionally good conditions for preserving the dead trees. We shall see