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POPULAR LECTURES.

The Life History of a World

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THE history of the Earth has always been a favourite subject of speculation and inquiry. Ever since mankind began to take an intelligent interest in the causes of phenomena there has been the desire to investigate the past history of our planet, and in ancient times these speculations generally took the form of more or less fantastic imaginings built upon assumptions and theories, and with little or no basis of actual fact.

Later, when observations multiplied exceedingly and were compared together, the conclusions arrived at became more and more sure, until to-day we are able to present such an array of facts as justify us in holding clearly defined opinions regarding much of the past life of the Earth.

Applying to the other planets the knowledge we have gained of our own world, we are assisted in the interpretation of many phenomena, and when we carry the analogy of the solar system into the other parts of the visible universe we are enabled to understand much that would otherwise have no meaning.

At the outset of our investigation we are oppressed by our limitations. The world remains very much the same sort of world during the lifetime of a man, there has indeed been little or no change in the Earth since the commencement of recorded history, and a man might well imagine the world to be permanent and immutable.

Consider for a moment how the world would look to a mosquito, or, better still, to one of the day flies, those curious creatures which only live for a few hours, and eat no food, having no mouth. Such a fly would see flowers, trees, grass, but would see neither change nor growth, and if it could judge only by what it could see it would be justified in believing that the leaves of the tree and the petals of the flower had existed always and would last for ever. It would seem to such a fly that to speak of the growth of a tree or of a flower would be almost a verbal absurdity. The lifetime of a day fly is all too short to judge of growths that require weeks or months or years to become manifest.

Just in the same way the life of a man is too short to observe changes in the Earth's condition, even the lifetime of the human race only covers the later stages of the life of the world, and carries us back but a little way in its life history.

In fact, we are dependent not so much on what we can see as on the inferences and deductions and calculations we are able to make, in order to arrive at any clear knowledge of the past history of the world and of the solar system, or of a stellar system.

When we inquire into the history of the world the first change we discover was in comparatively recent times, about 100,000 years ago. At that time the climate of northern Europe, including the British Isles, was positively Arctic. Most of Europe was buried under a thick coat of ice, which persisted all the year round. When geologists found evidence of great masses of ice in Great Britain and other parts of Europe they called the period in which this arctic climate existed the glacial epoch, and the cause of the glacial epoch gave rise to much speculation until it was discovered that there is an astronomical explanation.

The Earth revolves round the Sun, as you know, in an orbit, that is nearly a circle. It is not quite a circle, but is an ellipse, a circle a bit drawn out in one direction. If the Earth's orbit were a circle the Sun would be in the middle of it, but being an ellipse the Sun is not in the middle but in a focus of the ellipse. So that as the Earth's orbit is an ellipse, and the Sun is in one focus of the ellipse, the Earth, as it revolves round the Sun in its orbit, is a little nearer the Sun as it passes round the focus of the ellipse and is a little further from the Sun as it passes round the further portion of the orbit. At present the Earth is nearest the Sun when it is winter and furthest when it is summer, in the northern hemisphere. That means that the Earth is passing round the furthest and longest part of its orbit in the summer, giving a long mild summer, and that the shorter and nearer part of the orbit is traversed in winter, giving a short and warm winter.

In the southern hemisphere the conditions are reversed, and the winter is long and cold and the summer is short and warm. It is not so much the warmth of the months when the Earth is nearest the Sun that has the greatest effect on the climate, but the season which is longest, and in the southern hemisphere the summer, being short, although it is warm, is not long enough to counteract the cooling of the long cold winter, and consequently the antarctic regions are cooler than the arctic, and the antarctic ice is of greater extent than the arctic.

Now just imagine what would be the result of an exaggeration of these differences of climate. Suppose that the Earth's orbit, instead of being almost a circle, was really a much more pronounced ellipse, a good deal more drawn out in one direction, say four times as much. This would have the effect of making the long antarctic winter very much longer, and the summer much shorter, while in the arctic regions the summer would be much longer and the winter would be shorter. It is clear that under these circumstances the antarctic ice would increase very greatly, and would probably extend into South America and Africa, while the arctic ice would melt away.

We have already imagined that the Earth's orbit is, so to speak, more elliptical ; now please imagine that the direction of the Earth's axis swings slowly round the pole of the orbit. that the Earth reels as it rotates, so that the Earth may be furthest from the Sun when it is winter in the northern hemisphere. Then we should have a long cold winter in the northern hemisphere with a short warm summer, and instead of a great increase of antarctic ice the antarctic ice would melt and dwindle away and the arctic ice would increase and extend. The cold in these long winters would be so intense that the ice would not be melted in summer, and almost the whole of Europe and the whole of northern Asia would be gradually covered with a thick sheet of ice. We should, indeed, have a glacial epoch, so that if the conditions I have asked you to imagine could ever have come to pass there must have resulted a glacial epoch.

Now the eccentricity of the Earth's orbit is not always the same, it varies, and 200,000 years ago it actually was four times as much as it is now, so that 200,000 years ago there must have been a glacial epoch. Moreover, owing to the way in which the attraction of the Sun and the Moon acts upon the equatorial bulge of the Earth, the Earth's axis is continually changing in direction, and its direction changes in such a way as to bring each of the seasons in turn to that part of the orbit which is nearest to the Sun, the whole circuit taking over 20,000 years. The effect of this is that whereas now the southern hemisphere has a long cold winter, 10,000 years ago the conditions were reversed and the northern hemisphere had the long winter. So, you see, when there was a glacial epoch the glacial condition oscillated from the southern to the northern hemisphere and back again to the southern hemisphere, and so on, each oscillation taking about 10,000 years. During a glacial epoch the arctic ice would gradually, for 10,000 years, extend southward over Europe till it reached a maximum, and then gradually recede, for another 10,000 years, while the antarctic ice is extending, and then again the arctic ice extends. In one glacial epoch there may be more than one such oscillation, giving an alternation of an arctic climate with a mild or warm climate, each lasting roughly 10,000 years, including the period of transition. The last glacial epoch extended more or less continuously for about 150,000 years, and terminated less than 100,000 years ago.

The visible rocks upon the Earth's surface are, broadly, of two kinds, those that are sedimentary, formed by the consolidation of deposits thrown down in shallow seas and other shallow waters, and those that were formed with the help of the action of fire. The deposits which have become the sedimentary rocks must of course have been formed exceedingly slowly, and as their total thickness is many thousands of feet the time during which these rocks were being formed can only be estimated in millions of years, and saw many changes in the Earth.

The sedimentary rocks often bear evidence of movement since their formation; sometimes the strata, instead of being horizontal, are tilted up to a more or less steep slant, sometimes they are sheared off by one part having slipped down or having been upheaved, and sometimes the strata are split or crumpled into folds. This folding or crumpling or splitting of the Earth's crust is responsible for most of the great mountain ranges, such as the Andes, the Rocky Mountains, the Alps, and the Himalaya. It is probable that the Pacific Ocean was formed at the same time as the Andes, and the land to the west of South America disappeared then.

The lines of the great earthfolds, along which mountain ranges have been formed, perhaps I should say are still being formed, may be easily discerned. You see the line of folds running more or less continuously from the Pyrenees to the Himalaya and down through Burma and Sumatra, and another running round the Pacific, on the eastern side of the Pacific giving rise to the mountain chains and on the western side passing through Japan, and a succession of islands to New Zealand.

Geologists divide up the whole time in which the sedimentary rocks have been deposited into periods, which are distinguished from each other by the character of the rocks deposited in each and the fossils they contain. Geologists are not agreed as to the precise length of time that any of these periods occupied, the only thing that appears certain is that they were very long, many of them, perhaps all of them, millions of years. For convenience these geological periods are grouped into three eras, called, beginning with the oldest, the Palæozoic, the Mesozoic, and the Kainozoic.

In the most recent of these three eras, the Kainozoic, there have been many changes in the arrangement of land and water. It has seen the linking of Europe and Asia, the separation of America from the arctic land, and of Great Britain from the continent of Europe, the raising of the Andes, and the disappearance into the Pacific of the high land which was to the west of South America. In the middle of the Kainozoic era there was an outbreak of volcanic activity accompanied by Earth movements which involved much change in the land and sea areas, before this there was a quiet interval, and at the beginning of the era we find another outburst of volcanic energy.

The previous era, the Mesozoic, was marked by quiet, during which the Earth movements were slow and comparatively slight.

Then we come to the Palæozoic era, and here we find the changes were so considerable that we must look at them a little more in detail. Near the end of the Palæozoic era was the carboniferous period, in which the coal measures of the world were formed, and towards the end of the carboniferous period there was an outbreak of volcanic activity, and violent Earth movements that did untold damage to the world's store of coal, especially in India. Coal having been formed over enormous areas, the Earth movements split, tore, crushed and sheared in all directions the strata containing coal. In some places portions of the strata were lifted, and adjacent portions sunk, so that the displacement of the strata is as much as many hundreds of feet, and the shearing of the strata is visible now as what geologists call a fault, where the strata have moved and there is a vertical split, so that across the split the strata are not continuous. Not content with raising large parts of the coal strata high into the air where the weather has gradually denuded and washed away all traces of coal, laying bare the underlying rocks, there was at the same time much volcanic activity which forced molten rock into the strata of coal, burning up and destroying a very large quantity.

We have endeavoured to reconstruct the outlines of the land in each period by a study of the arrangement of the plants and animals as shown by their fossil remains, but it is like reading a book of which many pages are missing, but more and more of Nature's manuscript is being discovered and deciphered every day, and the new facts are being sorted into their places like missing parts of a zig-zag puzzle.

In the carboniferous period the northern flora indicate a continent which connected Europe and America, and another which connected India, Australia, South Africa and Brazil.

The period before the carboniferous, the Devonian, was a period of great volcanic activity. There were active volcanoes in many parts of the world which are not recognised as actively volcanic now, such as the British Isles.

Before the Devonian there was a quiet period, the Silurian, in which the Earth movements were slow. A map of North America in Silurian times has been prepared by Mr. Bailey Willis. It shows North America as a series of islands, not recognisable as his native land by an American citizen of to-day.

The period before the Silurian, the Ordovician, was a period marked by extremely active volcanoes and great Earth movements, and a map of the world in the Ordovician period would show a curious reversal of land and water ; indeed, it is remarkable that whenever we find a continent to have been submerged we find some evidence suggesting that on the opposite point of the Earth's surface a sea has become dry land.

Now we come to the earliest period in which the sedimentary rocks contain fossil remains of plants and animals, the Cambrian period. This was a period of comparative volcanic calm though there were plenty of volcanoes in this period.

An attempt to reconstruct the arrangement of land and water in Cambrian times by making a map of that period, would show that the southern countries of South America, Chili, the Argentine, Uruguay, etc., were under water. The British Isles were apparently joined to Norway and perhaps also to Greenland and Canada, while India, most of Europe and Eastern Asia, most of Africa, and Australia were connected together, and there was a Pacific continent, whose limits we of course do not know.

In maps of the world of all these periods India is shown as dry land. India is indeed one of the oldest countries in the world. As far as we know, peninsular India, that is the southern portion of India, is one of the few parts of the Earth's surface that has never been submerged under the ocean during the ages covered by the geological record; compared with it the whole of northern and middle India, including the Palæozoic coal measures may be called young, and even the great mountains on our northern frontier are of but yesterday. Are they not, indeed, still growing?

Beyond the Palæozoic era we come to the very interesting Eozoic era during which life first appeared on the Earth and only the most primitive forms of life existed. This era may have been very long, even as long or longer than any of the three which I have roughly sketched, but the geological record is meagre. But we know that in the latter part of this era there was little volcanic action, though at an earlier stage volcanoes were numerous and violent.

There is proof that in several of the geological periods there was ice in many parts of the world where now there is none, proving that those parts had a colder climate in some past ages than they have now. Even as far back as the Cambrian period, the earliest in the Palæozoic era, there are evidences of ice in, for example, Australia. This might lead one to suppose that the world is warmer now than in the Cambrian period. I described to you at some length the causes which operate to produce an ice age, and there can be no doubt that whenever in the Cambrian period the Earth's eccentricity was sufficiently large, there must have been a glacial epoch, and ice in Australia then is exactly what one would expect. But the ice age in the southern hemisphere, or indeed anywhere in the world, would not continue throughout the Cambrian period.

No conclusion regarding the average climate of the world in the Cambrian period can therefore be based upon finding traces of ice having been present at that time, the recurring glacial epochs fully account for all such manifestations and the world may have been on the whole appreciably hotter than now, in spite of ice having scratched the rocks in Australia.

Having got so far it will be interesting to review the facts recorded. We have seen that throughout the geological ages during which the stratified rocks were formed volcanic activity and quiescence alternated, and Earth movements of various degrees of slowness interchanged the areas of land and sea in most parts of the globe, and tilted, folded and crumpled the strata in very many places, and we look for some explanation. To find this we must look a long way below the surface of the Earth, and here again we are at a serious disadvantage. Our deepest mine is only a depth of something like one mile from the surface, only one four-thousandth part of the way to the centre. I am afraid these figures do not convey a very clear idea. A four-thousandth part of course means a very little, but how little ? Let me illustrate. Imagine a globe eight feet in diameter, the size of an ordinary projected picture on the screen, on the same scale the thickness of a finger nail would represent a mile.

But although the depth to which we have penetrated is as nothing in comparison with the size of the Earth, yet we have learned some very valuable and suggestive lessons. In the first place, the temperature increases as we go down. The rate of increase is difficult to measure, and is said not to be exactly the same in every place, but if we say that the temperature increases everywhere at the rate of between 80 and 90 degrees for a mile of depth we shall state the facts with all needful accuracy.

We do not know whether the temperature goes on increasing indefinitely at the same rate. For instance, is the temperature at a depth of 20 miles 1,600°, at 50 miles 4,000°, and so on ? The temperature probably does not increase continuously towards the centre of the Earth, but at what depth does the increase of temperature cease and what is the temperature of the central part of the Earth ?

These are questions we cannot answer, but we have no doubt it is very hot. Perhaps only as hot as a steel-making furnace, perhaps as hot as the electric arc, perhaps even hotter.

Whatever be the temperature of the interior of the Earth it is clear that as it is hotter than the surface the internal heat must be continually conducted through to the cooler surface, and radiated away into space. The Earth is therefore cooling down. As the Earth is cooling it must be contracting, all substances, even rocks, contract as they cool. If the Earth is contracting it must be sensibly smaller than it was many millions of years ago, and this would fully account for crumplings and foldings of the Earth's rocky crust, as it endeavoured to adjust itself to the reducing circumference. This would also account for those Earth movements which have alternately raised land and again submerged it below the surface of the ocean. As the Earth contracted the crust would be subjected to strains of compression, and as soon as these strains increased beyond what the materials could stand, a part would slip or crumple, or a large area would be depressed. It must be remembered that such depressions or crumplings of the Earth's surface only refer to a thin film, as it were on the surface. Coming back for a moment to our imaginary globe, 10 feet in diameter, the average height of a continent would not amount to as much as a coat of paint. The height of the highest mountain does not amount to as much as $\frac{1}{8}$ of an inch, while another $\frac{1}{8}$ of an inch would represent the depth of the deepest ocean. Consequently all the Earth movements we are able to see are contained in a crust measuring an average of less than $\frac{1}{16}$ of an inch in thickness on our 10 feet globe. There is no difficulty, therefore, in assuming all the upheavals and depressions in the Earth's surface to be due to deformation of the crust caused by contraction as the Earth gradually cools.

Some light is thrown upon the interior of the Earth by several lines of investigation. In the first place we know that the weight of the Earth is between 5 and 6 times as much as the weight of a globe of the same size would be. We know also that the weight of the rocks on the surface is about $2\frac{1}{2}$ times the weight of water. So that the Earth is more than twice as heavy as it consisted only of rocks like those on the surface.

The radio-activity of the surface of the Earth is such as to suggest that the layer of radio-active minerals is 45 miles thick, and that the whole globe of the Earth, except the outer layer 45 miles thick, is composed of some other materials not radio-active. Iron is a mineral of which there is a great deal in the solar system, it is not radio-active, and a large central core consisting largely of iron would seem to meet all these requirements.

Much may be learned also regarding the Earth by a study of earthquakes. An earthquake sends out vibrations all around. One set of these vibrations passes along the surface of the ground. These are undulations just like waves of the sea or ripples on a pond. But at a considerable distance from the centre of the earthquake the vertical movement is lost and the only movement is horizontal. Suppose that an earthquake occurs at this point, the vibration waves pass round the surface in this direction and they also travel through the substance of the Earth in all directions, so an observer stationed at this point marked C would be able to record two sets of vibrations, one set arriving to him through the substance of the Earth and the other set arriving around the surface: the direct line through the Earth being so much shorter these vibrations arrive earlier. Moreover these vibrations travel more quickly than those on the surface; this proves that the Earth is more and more solid the deeper we go, because vibrations are transmitted more rapidly in more rigid material. Professor Milne, the seismologist, thinks that the Earth has a rocky crust about 40 miles thick and that below that depth there is harder material. If an earthquake occurs at a given point the vibration would travel to a point on the Earth 30 degrees away at a speed of 5 miles per second, 70 degrees away at 5¼ miles per second and right across to the opposite side 5½ miles per second, showing that the rigidity of the materials of the globe increases towards the centre. It is interesting to enquire how far the known materials that we find on the Earth's surface will account for the speed at which earthquake vibrations pass through the Earth. The most complete investigations of the rigidity of rocks are those which have been made in Japan, and these show that the elasticity and rigidity of some kinds of Eozoic rocks would account for a wave speed of 1¾ miles per second, some of the Palæozoic rocks 2¾ to 3½ miles per second, and some of the oldest Archæn rocks over 4 miles per second, so that it is clear that the oldest of the igneous rocks are more solid, so to speak, more rigid than the geologically newer rocks, but that even these igneous rocks, which form the foundation of the Earth's crust, are not sufficiently solid to account for the speeds at which vibrations are conveyed through the interior of the Earth. There is another series of vibrations set up by earthquakes. The vibrations which we have just been considering are waves of compression, but there are also waves of distortion, which tend to twist the substance through which they are propagated. Waves of distortion travel at a slower speed than waves of compression and they are differently affected, they move more slowly through a more solid substance, and it is found that waves of distortion while they travel at approximately the same speed through the substance of the Earth in all directions as long as they do not reach the centre, they are retarded if they pass right through the middle. The paths of the vibrations are curved which is perhaps the manner in which vibrations travel through the Earth going deeper than the straight path because of the different rigidity at greater depths. I have referred several times to the crust of the Earth, but I do not wish it to be supposed that below the crust there is anything like a fluid interior. The interior of the Earth may be very hot, may in fact be as hot as molten metal and it may act in many respects as though the material were fluid, and it may flow, but such effects are due merely to the enormous weight of the strata above. The weight is so great that at a sufficient depth any metal would flow like a liquid. The Earth is in fact as rigid as a ball of iron, but iron itself is plastic even under the comparatively high pressure to which we can subject it, which are as nothing to the pressures for in the interior of the Earth. Even under the 40-mile crust of the rocks we find on the surface the pressure is more than 100 tons on every square inch, a pressure under which a somewhat brittle rock like marble becomes quite plastic, and this depth is only represented by the width of one's finger on a 10 feet globe. Earthquakes originate at comparatively small depths below the surface, probably none more than about 20 miles depth, at which the Assam Earthquake of 1897 has been supposed to have been originated.

This earthquake, by the way, was the greatest earthquake that has been recorded in history, that is to say, it was felt as a great earthquake over a larger area than any other has been, which indicates that it had an unusually deep origin. The Charleston Earthquake of 1886 originated at a depth of about 12 miles. The earthquakes which have been seriously felt over a considerable area have been what has been called earthquakes of dislocation, readjustments of the crust of the Earth which has become strained in some way, generally by shrinkage, until it is no longer able to resist the strain and a more or less sudden adjustment is made involving enormous masses of rock whose sudden movement sets up vibration in the Earth which are transmitted through the whole globe. Frequently distances that have actually been measured have been found shorter after an earthquake, showing that the Earth has actually contracted, so that the strata have been crumpled to the extent that the distance between two points on the surface has become less.

As the Earth is cooling and contracting there must have been a past age when it was very much hotter, and if the cooling has been continuous we have only to imagine a period sufficiently far back to arrive at a stage when the Earth was a molten globe, still further back it must have been very largely vapour, and still further back we can imagine the Earth expanded to a globe of vapour reaching out to the Moon, which at once leads us to enquire where the Moon was then. It was Professor George Darwin who first investigated mathematically the history of the connection between the Earth and the Moon. From consideration of the tides raised upon the Earth by the action of the Moon he was able to show, and indeed it appeared to be quite clear when once he had pointed it out, that the action of the tides upon the Earth is such as to cause by their friction a gradual retardation of the Earth's rotation, so that the Earth is rotating more and more slowly than it used to. While the tides are retarding the Earth's rotation, they are also retarding the Moon's revolution round the Earth. This seems a very curious proposition, but the method of its action is this : The Moon's attraction raises the tide upon the Earth, and the rotation of the Earth carries that tide, the raised tidal wave, away from the point which is just opposite the Moon, so that the tide upon the Earth is always behind the point where the Moon is straight overhead and the tidal wave raised upon the Earth also of course attracts the Moon, and as the position of the tidal wave on the Earth is always well behind, its attraction on the Moon is not in the same line as the attraction of the solid body of the Earth, but is tending to pull the Moon back and retard its motion of revolution. By its retardation of the Moon's motion in its orbit, it is compelling the Moon to recede further from the Earth, so that the orbit of the Moon is increasing in size owing to the action of the tides on the Earth.

We, therefore, see that in past ages the Moon was nearer the Earth than it is now, and when the Moon was nearer the tides it raised on the Earth were of course greater and had greater effect both in retarding the Earth's rotation and in retarding the Moon's motion in its orbit. Pursuing this line of argument, there must have been a previous time when the Moon was touching the Earth, was indeed part of the Earth. Precisely how it came to separate, it is more than difficult to say, but that it did in some way separate off from the Earth when the Earth was very young, appears as far as we know now to be fairly certain. We have now carried back the history of the Earth to a time when it was molten, perhaps largely vapour, and to a time when the Moon and the Earth were one body, before the Moon's mass separated off from its parent mass, and it will be interesting to see whether we can find in any other parts of the solar system or in the depths of space indications of similar processes having gone on elsewhere.

The planet which is nearest in size to the Earth is Mars. Mars is much smaller than the Earth, not very much more than half the diameter, and it travels round the Sun in an orbit which is half as large as that of the Earth. As Mars is on the side farther from the Sun when it is nearest to the Earth it is well illuminated and well placed for observation in this position. The most distinctive feature in photographs of Mars is the little spot on the visible pole which looks like polar ice. There are some very clearly visible markings which appear on many photographs as a blurry equatorial belt. Observers have at first often expected to see Mars more like the charts which have been published, and which are the result not of one observation but of several, and show some of the well-known "canals," as they have been called, in Mars, lines generally fairly straight, joining dark points, many of which would otherwise be isolated. Expectations of this kind are not realised, but the permanent markings on Mars are generally so hidden by white masses which are thought to be clouds that one may look for them again and again without seeing them. On account of the uncertainty of whether in looking at any point on Mars you may be looking at a cloud or at the real surface or perhaps at an area where there is a slight fog sufficient to obscure all but the most strongly marked and salient features, doubt has been expressed as to whether the canals have any real existence, as to whether they may not be optical illusions induced by long staring at the various points on the surface, and some very curious and interesting experiments have been made by gazing at unconnected points, to see whether the eye could trace lines apparently connecting such points. A series of experiments of this kind were described by Mr. Lane some years ago in which he used a drawing approximately like the principal dark shadings on Mars, but omitting all the fine lines. It was drawn 3½ inches diameter and placed at 20 feet from the person to whom it was shown, in a not very good light. It was shown to several people successively at this distance under this illumination, and they were asked to draw it on paper, and what they produced were very remarkable. They drew imaginary lines connecting the points on the shaded portions. They were not told to draw particular lines, but they were asked to particularly notice the differences in shade, and in the shapes of the points. One of them produced a drawing in which were a complicated series of lines, some parallel. The 5th person to whom the drawing was submitted drew no lines at all. Two of the four were school boys who knew nothing of Mars or its markings. These experiments may perhaps throw some light on the minutest details which are said to have been seen, or on the other hand these markings perhaps really are there on the surface of Mars. It is at any rate clear that if the dark areas on Mars represent water the shapes of the continents and seas on Mars are greatly different to those upon the Earth, the greater part being land and not water. Mars has atmosphere even as we have, and its atmosphere frequently contains cloudy masses which obscure our view of the surface of the planet just as cloudy masses in the Earth's atmosphere would obscure the view of the Earth's surface from another planet, and there are polar caps of something white which looks like ice, and which vary from summer to winter just as polar ice would be expected to do. If Mars has lived through a hot stage as the Earth has, it is now in an older condition than the Earth. It is becoming in fact somewhat elderly. If we assume that Mars really did pass through similar hot stages that we find the Earth has apparently passed through, and compare Mars and the Earth at the same corresponding age, that is in the same condition, we should find that the Earth would retain its heat much longer than Mars. The mass of the Earth, that is what we may call the weight of the Earth if we had suitable scales to weigh both Mars and the Earth, the mass of the Earth is 9 times as great as that of Mars, and therefore under similar conditions of heating the Earth would have 9 times as much heat to part with, but surfaces which are cooling only part with their heat in proportion to their area, and the two globes would lose heat in proportion to their surfaces, so although the Earth would have 9 times as much heat it would only part with $3\frac{1}{2}$ times as much heat in any given period, so that the heat in the Earth would last longer than the heat in Mars in the proportion of 9 to $3\frac{1}{2}$. Mars would, therefore cool and grow older nearly 3 times as fast as the Earth, and if they were formed at the same time Mars would, eventually, cool so as to be in a different condition to the Earth, and to present features which would indicate a greater age.

After Mars let us examine the largest of the planets, the great planet Jupiter. In size Jupiter is a contrast to Mars. There are two well-defined features which are easily seen, one is the darker equatorial bulge and the other is the polar compression caused by the rapidity with which Jupiter rotates. Although he is so large, more than 10 times the diameter of the Earth, his period of rotation is only 10 hours, consequently the equatorial bulge and polar compression are very marked. The lighter markings on Jupiter are no doubt clouds, and the darker markings are rifts through which we see down towards the surface of the planet. Jupiter's atmosphere is very deep, so deep and so continually full of cloud that it is more than doubtful whether we have ever seen the real surface of the planet. We see these cloudy shapes changing more or less slowly or rapidly, but the surface of Jupiter far below is out of our sight, and we do not know what the real diameter of the solid globe may be: we cannot even guess. If the constitution of Jupiter's atmosphere is anything like that of the Earth and under similar conditions, it is not difficult to judge of the depth of the atmosphere. For the purpose of comparison with Jupiter we will take the depth of the Earth's atmosphere in which clouds are formed, similar in appearance to those of Jupiter, to be 7 miles. The upper surface of such a cloud layer in the Earth's atmosphere would be at about a quarter the atmospheric pressure at the Earth's surface. Now if Jupiter's atmosphere is like the Earth's atmosphere the upper surface of his cloud layer is at the same atmospheric pressure. Jupiter is so large and his total weight is so enormous that the force of gravity is 2½ times as great upon Jupiter as upon the Earth, and it is easy to calculate what the pressure must be on Jupiter at any given depth below the upper surface of the cloud layer. If the cloud layer is 13 miles in depth, the pressure on the surface of Jupiter would be over 5½ tons per square inch and the atmosphere would be so compressed that it would be as heavy as water and would be liquified. We know that the atmosphere of Jupiter is not only 13 miles in depth, but at least a hundred miles and perhaps several times as much. Stars have been seen through the edge of the cloud layer as Jupiter has passed in front of them, and although it is difficult to say through what depth of atmosphere such stars have been seen it is at least certain that the depth was many miles. Of course this is a rare phenomenon, because generally the cloud masses are so dense that nothing can be seen through them, but the observation has been made sufficiently often to place it beyond doubt. We are, therefore, faced by this dilemma that the atmosphere is of very great depth, but if it has an atmosphere like that of the Earth the pressures are such as would render most of it liquid.

The whole of the great globe of Jupiter is very much lighter, size for size, than the Earth,indeed it is only about 1½ times the weight of a similar volume of water. If the materials of which Jupiter is composed are at all similar to any of those which are found upon the surface of the Earth, Jupiter would be nearly twice as heavy as he actually is, so that we are obliged to assume either that the materials which form Jupiter's globe are altogether different to the substances of which the smaller planets are composed, or that they exist in Jupiter under very different conditions. In the present state of our knowledge it would be a venturesome, one might also say a wild, assumption, to assume that Jupiter is composed of substances greatly different to those found elsewhere in the solar system, and consequently we are more or less compelled to fall back upon the only remaining possibility, namely, that the globe of Jupiter is in some different condition which makes it and its atmosphere both lighter than the conditions obtaining on the Earth would oblige us to expect. We have only to suppose that Jupiter is in a highly heated condition in order to be able to explain the differences which are apparent between that planet and the Earth, and heat is quite enough to account for the smallness of Jupiter's density, and we are therefore unable to avoid the conclusion that Jupiter is extremely hot.

A very prominent feature on Jupiter is the marking which has been called the Great Red Spot, and which has persisted for many years. It is generally explained as an area from which in some way clouds were removed, and we could see down through the cloud layer to, or near to, the surface of the planet. Exactly what kind of disturbance can have had the effect of clearing Jupiter's atmosphere of cloud over such a large area, and of keeping it clear to such an extent, we have no means even of guessing, but it must have been of the most stupendous character. If we suppose Jupiter and the Earth to have both been at the same extremely hot temperature in some past age, we should find that Jupiter would remain hot far longer than the Earth, because his mass is 315 times that of the Earth and he would therefore obtain 315 times as much heat, while his surface area is only 114 times as great as that of the Earth's surface. So that the heat of Jupiter would last about 3 times as long, and the Earth would cool down 3 times as quickly as Jupiter, so that after the lapse of a certain length of time the Earth would present the appearance of being older than Jupiter, and it is clear from what we have found of the hot condition in which Jupiter exists to-day, that Jupiter, whatever his real age may be, is in a more youthful state than the Earth.

Saturn is the second largest planet in the solar system, it travels round the Sun in an orbit nearly 10 times the diameter of the Earth's orbit and takes nearly 30 years to make a revolution. Its diameter is about 9 times the Earth's diameter. The conclusions to which we were obliged to come respecting the constitution of Jupiter, apply also similarly to Saturn, and Saturn is therefore an extremely hot planet. The rings of Saturn present a phenomenon quite different to anything appearing in connection with all the other planets. It is not necessary for us to go into details as to their constitution, but we may note that Saturn rings could not exist if they were solid, they are subjected to such disturbing forces that they would be broken up even if they consisted of a tenacious metal such as iron or steel. It is, therefore, believed that they consist of a flight of small bodies, solid or liquid, or both, travelling together as a cloud in the shape of a thin ring revolving round the planet. The outer planets, Uranus and Neptune, are somewhat similar to each other in size and smallness of density, each planet being rather more than four times the diameter of the Earth. Their lightness indicates that they also must be hot.

We have seen how the smaller a planet is the more rapidly it must cool, and this is a matter that depends upon the proportion between the surface of a sphere and its volume, and therefore when we examine the smallest astronomical body available to us we should expect to see evidences of old age.

We will consider now the heavenly body which is best placed for observation, being nearest to us, the Moon. Illumination at Full Moon is so direct, with such absence of shadow, that details are not easily seen. A picture of the Moon a little before it is full shows the difference which the angle of illumination makes at the edge, where the hollows and raised portions are so much more clearly defined. You see the darkness of one area, which is called a sea, not because it is really water, but for want of any better and more descriptive term. With oblique illumination it is seen that even this dark space is covered with craters and craterlets and walled plains. Craters of extinct volcanoes are among the most conspicuous objects on the Moon's surface. The diameter of one is over 50 miles and the depth inside the crater is some 17,000 feet. Another is nearly 60 miles in diameter and is some 12,000 feet deep inside. If they are viewed under a small angle of illumination, we can well understand their real shape, and the shadow under one edge of the crater indicates the depth. If you see the crater just at sunrise as it were, the Sun's ray strikes on the very middle of the crater and perhaps lights up a central hill, in one case really a mountain a couple of thousand feet high. The fact that there is no twilight on the Moon, but that there is an absolutely sharp distinction between the full blaze of sunlight and the complete darkness of night, shows that there is no atmosphere, which is also separately proved by observation of stars across which the Moon travels in the sky. The Moon is therefore cold and dead, with the exception of such heat as is received from the Sun during its long day of a fortnight, which heat it parts with in its long night of two weeks' duration.

Let us turn to the Sun, the ruler of the solar system. Here we meet with all the features we found when examining Jupiter but very greatly exaggerated. The Sun is as much larger than Jupiter as Jupiter is larger than the Earth. The Sun is also heavier, bulk for bulk than Jupiter, so that the force of gravity is very much greater on the Sun than on Jupiter. A weight of 4 lbs. on the Earth if taken to Jupiter and weighed there with a spring balance would weigh 10 lbs., and if taken to the Sun and weighed there it would weigh a hundred weight. With this greater force of gravity on the Sun the difficulty of accounting for an atmosphere of considerable depth is enormously increased, but the Sun is manifestly hot, and the explanation occurs to us at once that the great heat renders possible an atmosphere of great depth. The heat of the Sun is so great that it is difficult to suggest any figures that help one to realise its real temperature.

The Sun is, therefore, in an extremely youthful state, so hot that every known substance is vaporised, so hot that in spite of the force of gravity being so great its atmosphere is thousands of miles deep, so hot that rain and hail on the Sun are not water and ice, but iron and other things which only melt at a high temperature.

A sunspot is a space in the outer atmosphere through which we can look down into the depths below. It looks quite dark by comparison with the blazing, glowing clouds around it.

Whatever the age of the Sun may be, measured in centuries, it is still in the enjoyment of the energy of youth, and will not have cooled down to the condition of even the hot giant planets until untold ages have passed.

Let us briefly review what we have noted respecting the solar system. Every body in that system is cooling, and we find that they are in various stages of cooling much as from their different sizes we should expect them. There was therefore probably a time when the Sun was hotter and larger, and a previous time when the Sun was so large as to fill the orbit of the Earth; before that perhaps even the orbit of Neptune. But, then, the Sun would be a nebulous cloud of glowing gas.

The movements of the planets afford some interesting reflections; all the planets revolve round the Sun in planes not greatly inclined to each other and all in the same direction. Moreover the direction of revolution of the planets is the same as the direction of rotation of the Sun. Now what is the probability that these movements are accidentally in the same direction and what are the chances that there is some physical connection between these movements? If a man tells us that he tossed a rupee five times and it came "Heads" every time, we should think it very extraordinary. If he should say that it came heads 10 times successively, we should not readily believe it, for the chances are a thousand to one against, and if he said it happened twenty times consecutively we should feel sure it was not true, for the chances against this are a million to one

When 7 planets were known the probability that uniformity of direction of movement indicated some relation was very great, and as each successive planet was discovered the probability became greater, until now that hundreds of planets are known, the probability is too great for expression, and it becomes a certainty that the identity of direction of revolution of the planets and the rotation of the Sun are in some way connected.

We are thus driven to the belief that the Sun has contracted from a nebula occupying a vast extent of space and that the formation of the planets and the rotation of the Sun were in some way related.

It has been supposed that the Sun has captured bodies wandering through space and that these have formed the planets, and that the planets have similarly captured their satellites, but there are mathematical difficulties.

It is not understood, for example, how Jupiter could capture a satellite. Jupiter could capture a small body, which might become a minor planet revolving round the Sun; he did capture a comet, which now revolves in a closed orbit, but we do not know of a body which could capture a satellite for Jupiter.

From the solar system we turn to the depths of space, to see whether we find anything which helps us in our investigation anything analogous to what we have seen and have found in our own system.

In the first place, we find the depths of space strewn with stars; as far as the telescope can reach we find stars innumerable.

Many of the names given to astronomical objects, especially by the ancients, show a highly developed imagination, but the appearance of some objects really did suggest their names, for example the Crab Nebula, which seemed like a crab before we photographed it and could see so much of its structure. There is also the America Nebula which obviously suggests North America, and the Trifid Nebula in Sagittarius. It has been suggested that the rifts visible are not really rifts but are caused by the obscuring of the light by some dark body between us and the nebula. Then there is the nebula known as the Owl Nebula from its appearance of having two eyes in the centre. Here again photography has somewhat altered the appearance as it is seen in ordinary telescopes. We might also mention the Dumbbell Nebula which in ordinary telescopes looks much more like a dumbbell than as photographed.

Having found that the solar system may in some bygone time have consisted of a diffused nebula, having probably some motion of rotation, we search the sky to see whether we can find any evidence of the existence of a nebula with these characteristics. In the central portion of the great nebula of Andromeda, there is some suggestion of movement around the centre, but it is not very clearly defined. Here again there are curious rifts or dark places in the nebula, the shape of which in this nebula certainly suggests the presence of dark matter between us and the nebula, perhaps the nearest outlying portions of this nebula are not glowing, or perhaps some other body between us and the nebula cuts off its light. In one photograph of a nebula which is clearly spiral in shape we have once more a rift or dark patch which again may be caused by some dark matter driven across between us and glowing nebula; in another spiral nebula, there is some suggestion of a Catherine Wheel. All these nebulæ bear evidence of movement which may have originated within the nebula itself or may have resulted from two nebulæ meeting each other; not meeting quite directly but at a little distance or so as to graze, then they would capture each other and begin to circle round their joint centre and would show a spiral appearance. If there are many spiral nebulæ in the heavens some of these must be seen by us edgewise, and we should accordingly expect to find a number in the sky presenting not their flat rotating side but their edge, and a nebula in the constellation of the Whale has a distinct suggestion of a spiral nebula seen rather obliquely or edgewise, and another nebula which looks like the edge of a lens, and which we are obliged to believe is a spiral, which must of course of necessity be flat, and in another case the outer portions of the spiral are dark and cut off the light of the glowing central portion.

Thousands of nebulæ have been photographed; of these it is believed that half are spiral, and in gazing upon these spirals it may be that we are looking at the earliest stages in the construction of systems similar to our solar system, and this is in progress all over the visible universe as far as the astronomical camera can see.

If you will allow me I will conclude by quoting "A Dream of Infinity" by DeQuincey, after Richter.

God called up, from dreams, a man into the vestibule of Heaven, saying, "Come thou hither, and see the glories of my kingdom." And to the angels that stood around his throne, God said, "Take him; strip from him his robes of flesh; cleanse his vision, and put a new breath into his nostrils: only, touch not with any change his human heart, the heart that weeps and trembles." It was done; and with a mighty angel for his guide, the man stood ready for his infinite voyage ; and from the terraces of heaven, without sound of farewell, they passed into infinite space.

Sometimes, with the solemn sweep of angel wings, they passed through Saharas of darkness, through wildernesses of death, that divided the worlds of life. Sometimes they passed over threshholds quickening under prophetic motions. Then, from beyond depths counted only in heaven, light dawned as from a sleepy film. By unutterable pace they passed to the light, the light by unutterable pace to them. In a moment, the rush of planets was around them, in a moment, the blaze of suns was upon them.

Then came eternities of twilight, that revealed but were not revealed. On the right hand and on the left hand towered gigantic constellations, that by self repetitions, by answers from afar, by counterpositions, built up triumphal gateways, whose archways and architraves, horizontal, upright, rested, rose, at altitude, by spans, that seemed ghostly from infinitude. Without number were the archways, beyond memory the gateways, past counting the architraves. Within were stairs that scaled the extremities around. Above was below, below was above, to the man stripped of gravitating body. Depth was swallowed up by height insurmountable, height was swallowed up by depth unfathomable.

On a sudden—as thus they rode from infinite to infinite ; on a sudden—as thus they tilted over abysmal worlds ; a mighty cry arose that systems more mysterious, worlds more billowy, other heights, other depths, were coming, were nearing, were at hand !

Then the man sighed and paused, shuddered and wept ; his overladen heart uttered itself in tears ; and he said : " Angel, I will go no farther ; for the spirit of man acheth with this infinitude. Insufferable is the glory. Let me lie down and hide me in the grave from the persecution of the infinite ; for end I see there is none." And from all the listening stars that shone around there issued a choral voice, " Angel, thou knowest that the man speaks truly ; end is there none that ever yet we heard of." " Is there no end ? " The angel solemnly demanded : " Is there indeed no end ? And is this the sorrow that kills you ? "

But no voice answered, that he might answer himself.

Then the angel threw up his glorious hands to the heaven of heavens, saying :—

" End is there none to the Universe ; Lo ! also there is no beginning."