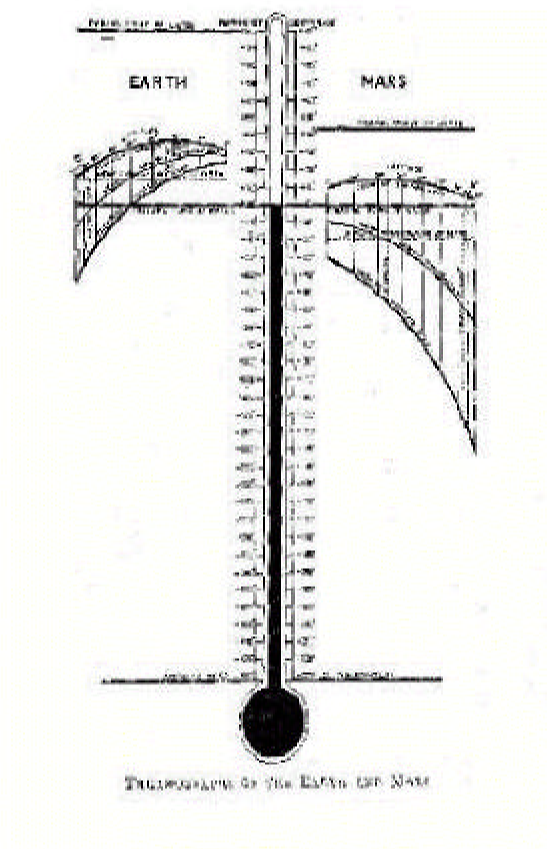

Figure 1

experience. Here, then, our enquiry must end, for it is an enquiry of physical science; the search for living material organisms endowed with intelligence. How life first came upon this Earth, or when, or where, is beyond the power of science to determine. Yet it did come. There was a time when there was no life here; none, not even the humblest form of it; nor was there any hint or fore- shadowing of it, still less of all its infinities of form, and possibilities of development. Once Life was not, yet Life came, and now, life is abundant, but abundant only in worlds quite exceptional in their conditions, and therefore few in number; it is even conceivable that this Earth of ours may be unique. But life as we know it, protoplasmic life, life dependent upon water, the life of intelligence united to the material organism, is under sentence of death. Has it any future beyond that veil? Is there any kind of life not subject to these narrow limitations; not under the inexorable decree? To questions such as these Science has no reply to give; it is even more helpless to answer them than to determine how life first came; its experience does not reach so far. Science can examine the present conditions of physical life, but whether or no that life can undergo a change greater than that which passed upon the old inorganic world, it cannot determine. It has no experience. But if Science is dumb, if the utmost exertion of human energy and power of research can throw no light on a future of which we have no experience, we are not left without an answer. A voice has been heard, the voice of the Son of God Him- self: "I am the Resurrection and the Life. He that believeth on Me, though he were dead, yet shall he live." And accepting His word, the Church in all ages, and among all nations, peoples, and tongues, has made reply: "I look for the resurrection of the dead and the life of the world to come"

motionless; the celestial lights seemed to be small, and moved, and shone. The earth was then regarded as the fixed centre of the universe, but the Copernican theory has since deprived it of this pride of place. Yet from another point of view the new conception of its position involves a promotion, since the earth itself is now regarded as a heavenly body of the same order as some of those which shine down upon us. It is amongst them, and it too moves and shines, - shines as some of them do, by reflecting the light of the sun. Could we transport ourselves to a neighbouring world, the earth would seem a star, not distinguishable in kind from the rest. But as men realized this, they began to ask: "since this world from a distant standpoint must appear as a star, would not a star, if we could get near enough to it, show itself also as a world? This world teems with life; above all, it is the home of human life. Men and women, gifted with feeling, intelligence, and character, look upward from its surface and watch the shining members of the heavenly host. Are none of these the home of beings gifted with like powers, who watch in their turn the movements of that shining point which is our world? " This is the meaning of the controversy on the Plurality of Worlds which excited so much interest some sixty years ago, and has been with us more such less ever since. It is the desire to recognize the presence in the orbs around us of beings like ourselves, possessed of personality and intelligence, lodged in an organic body. This is what is meant when we speak of a world being "inhabited." It would not, for example, at all content us if we could ascertain that Jupiter was covered by a shoreless ocean, rich in every variety of fish; or that the hard rocks of the Moon were delicately veiled by lichens. Just as no richness of vegetation and no fullness and complexity of animal life would justify an explorer in describing some land that he had discovered as being "inhabited" if no men were there, so we cannot rightly speak of any other world as being "inhabited" if it is not the home of intelligent life. If the life did not rise above the level of algae or oysters, the globe on which they flourish would be uninhabited in our estimation, and its chief interest would lie in the possibility that in the course of ages life might change its forms and develop here- after into manifestations with which we could claim a nearer kinship. On the other hand, of necessity we are precluded from extending our enquiry to the case of disembodied intelligences, if such be conceived possible. All created existences must be conditioned, but if we have no knowledge of what those conditions may be, or means for attaining such knowledge, we cannot discuss them. Nothing can be affirmed, nothing denied, concerning the flints so slightly shaped that it is in dispute whether they may not have been so broken by the action of torrents. But there are only two theories about them; either they were so chipped by natural action, or they were designedly so chipped by creatures resembling ourselves in head and hand. The question that has been dealt with in this volume is a scientific one, and the attempt has been made to treat it as such, and to argue from known physical facts as to the conditions of worlds which we cannot visit. But by many the question is generally discussed wholly apart from physical fact at all, and it becomes one of sentiment and of religious sympathy. Yet, curiously enough, the division between those who think that all worlds must be inhabited and those who think that our own world stands alone is not coincident with any line of theological divisions, but rather cuts across all such. Some believers in Christianity argue that since God has filled this world with Life, Life has been His purpose in the world, and must therefore have been His purpose in all other worlds-they too must be filled with Life in like manner. Other believers argue that this world was the scene of the Incarnation of Our Lord, and is therefore unique in that respect; and that this uniqueness sets its stamp upon this world in all respects. Opponents to Christianity are divided into the same two classes, the one arguing that wherever there is matter the inevitable course of evolution will produce life, and eventually intelligent life. The other class are equally clear that all forms of life are special, the result of the particular environment, and that it is unreasonable to expect that any other world has had the same history as our own, or that the same special conditions have prevailed elsewhere. In other words the belief that there are other inhabited worlds has depended chiefly neither on science nor on religious belief, but upon sentiment. There are some who like to think themselves, and the race to which they belong, altogether exceptional; others delight in finding themselves reflected wherever they look. So far as Science has progressed and can return an answer to an enquiry that exceeds so far the bounds of our direct observation, it dissents from both orders of thought. The conditions of life are indeed narrow, special, restricted; intelligent, organic life must, relatively speaking, be a rarity in the universe, but, we lack the information that would enable us to affirm with any confidence that such life is only to be found upon this world of ours. Heavy as the odds are against any particular world being an inhabited one, yet when the limitless extent of space is considered, and the innumerable numbers of stars and systems of stars, it seems but reasonable to conclude that though inhabited worlds are relatively rare, the absolute number of them may be considerable; considerable, if not at

is not at all as to how life is generated on a world, but as to whether, if once, in action on a particular world, its activities could I be carried on.

CHAPTER II
THE LIVING ORGANISM

A world for habitation, then, is a world whereon living organisms can exist that are comparable in intelligence with men. But “men" presuppose the existence of living organisms of inferior grades. Therefore a world for habitation must first of all be one upon which it is possible for living organisms, as such, to exist. It does not concern us in the present connection how life first came into existence on this planet. It is sufficient that we know from experience that it does exist here; and in whatsoever way it was generated here, in that same way we may consider that it could have been generated on another planet. Nor need any question trouble us as to the precise line of demarkation to be drawn between inorganic and organic substances, or amongst the latter, between plants and animals. These are important subjects for discussion, but they do not affect us here, for we are essentially concerned with the highest form of organism, the one furthest from these two dividing lines. It suffices that living organisms do exist here, and exist under well-defined conditions. Wanting these conditions, they perish. We can, to a varying degree, determine the physical conditions prevailing upon the heavenly bodies, and we can ascertain whether these physical conditions would be favourable, unfavourable, or fatal to the living organism. What is a living organism? A living organism is such that, though it is continually changing its substance, its identity, as a whole, remains essentially the same. This definition is incomplete, but it gives us a first essential approximation, it indicates the continuance of the whole, with the unceasing change of the details. Were this definition complete, a river would furnish us with a perfect example of a living organism, because, while the river remains, the individual drops of water are continually changing. There is then something more in the living organism than the continuity of the whole, with the change of the details. An analogy, given by Max Verworn, carries us a step further. He likens life to a flame, and takes a gas flame with its butterfly shape as a particularly appropriate illustration. Here the shape of the flame remains constant, even in its details. Immediately above the burner, at the base of the flame, there is a completely dark space; surrounding this, a bluish zone that is faintly luminous; and beyond this again, the broad spread of the two wings that. are brightly luminous. The flame, like the river, preserves its identity of supply our cities with the first necessity of life. We find, then, in this universe so far as we can know it, that Space is lavishly provided, Matter is lavishly scattered, Time is unsparingly drawn upon, but Life in any form, and especially in its highest form, is, relatively speaking, very sparsely given. That very circumstance surely points to the overwhelming importance of conscious, intelligent Life, and the insignificance of lifeless matter in comparison with it. We have to exhaust arithmetic in computing the size, the mass, the output of heat and light of our Sun, yet it is but the hearth-fire and lamp of terrestrial life; and its amazing agglomeration of matter and energy is ungrudgingly devoted to this humble purpose. Whatever view we hold as to the scheme of the universe; whether with the unthinking we fail to recognize Thought and Purpose behind its marvellous manifestations, or, with the thoughtful, realize that only Infinite Thought could provide so wonderfully for the bringing forth of thought in living material organisms, the conclusion still remains: living intelligences are, by the direct testimony of the universe itself, its noblest and i most precious product. The plea is often made that as we find life adapting itself to a great variety of conditions on this Earth, we must not set limits to its power of adaption to the conditions of other worlds. But this plea is an unthinking one. The range of conditions through which we find life on this Earth is as nothing to the range given by the varied sizes and positions of the different planets; and even on our Earth, life in the unfavoured regions- the tops of mountains, the polar snows, the water- less deserts, the ocean depths-is only possible because there are more favoured regions close at hand, and there are, as it were, “crumbs that fall from the rich man's table." A well-known litterateur in setting forth " a hundred ways of making money" gave great prominence to the method of living as caretaker in an empty house. But residing in an empty house does not, in itself, supply the means of sustenance; these have to be furnished by the wealthier man who employs the caretaker. Another plea for vague sentiment in this matter is that we cannot expect that intelligent beings on other worlds would have the same form as man, and if not the same form, then, that the same conditions of existence would not hold good for them as for us. Both contentions are unsound. Protoplasm is the physical basis of all: the life that we know, whatever its form; though these forms are to be counted by the million, and are as diverse as they are numerous. And everywhere and always, water is found essential to protoplasmic life. Of life of any other kind we do not know any examples; we have no instance; if such exist, then they are beyond our ken. And neither anthropologist nor biologist would admit that the form of intelligent

the life process. The whole complex of these chemical transformations is generally called *Metabolism*. Inorganic matter contrasts strikingly with living substance. However long a crystal or piece of metal is kept in observation, there is no change of the substance, and the molecules remain the same and in the same number. For living matter the continuous change of substances is an indispensable condition of existence. To stop the supply of food material for a certain time is sufficient to cause a serious lesion of the life process or even the death of the cell. But the same happens when we hinder the passing out of products of chemical transformation from the cell. On the other hand, we may keep a crystal of lifeless matter in a glass tube carefully shut up from all exchange of substance with the external world for as many years as we like. The existence of this crystal will continue without end and without change of any of its properties. There is no living organism which could remain in a resting state for an infinitely long period of time. The longest lived are perhaps the spores of mosses which can exist in a dry state more than a hundred years. As a rule the seeds of higher plants show their vital power already weakened after ten years; most of them do not germinate if kept more than twenty to thirty years. These experiences lead to the opinion that even dry seeds and spores of lower plants in their period of rest of vegetation continue the processes of metabolism to a certain degree. This supposition is confirmed by the fact that a very slight respiration and production of carbonic acid can be proved when the seeds contain a small percentage of water. It seems as if life were weakened in these plant organs to a quite imperceptible degree, but never, not even temporarily, really suspended.

“Life is, therefore, quite inseparable from chemical reactions, and on the whole what we call life is nothing else but a complex of innumerable chemical reactions in the living substance which we call protoplasm.”***** The essential quality, therefore, of life is continual change, but not mere change in general. It is that special process of the circulation of matter which we call metabolism, and this circulation is always connected with a particular chemical substance-protoplasm. In this substance five elements are always present and predominant- carbon, oxygen, nitrogen, hydrogen, and sulphur. The compounds which these five elements form with each other are most complex and varied, and they also admit to combination –but in smaller proportions –some of the other elements, of which phosphorus, potassium, calcium, magnesium and iron are the most important. For protoplasm –using the term in the most general sense find a place upon it. Let us sum shortly what we know and what we conclude. We know that this, our Earth, is a habitable globe, for we ourselves are living upon it. We know what constitutes the physical basis of our life, and under what conditions on this Earth it flourishes, and under what conditions it is destroyed. If we turn our eyes from this, our Earth, and look out upon the starry skies, we see the other planets of our system, and the suns which are the centres of other systems. From the consideration of the planets in our own system, we have seen how stringent and how many are the conditions imposed for Life to be possible. Round our Sun there is but a narrow zone in which a habitable world may circle; in this zone there is room for but few worlds, and we actually know of three alone, the Earth, the Moon, and Venus. We know that the Earth can be and is inhabited; that the Moon is not and cannot be inhabited; and that Venus, though of habitable size, may yet be subject to the fatal disqualification of always turning the same face to the Sun. Of other planetary systems than our own, we actually know of none, but we assume that there are such, and as numerous as there are suns in the starry depths. But of these planetary systems we can rule out, as containing no habitable member, all such as circle round double or multiple suns or, indeed, round any single star that, from whatever cause, is largely variable and, therefore, much less stable than our own. Mira Ceti, which in 5 months increases its brightness 1000 times, may stand as an example. Probably these disqualifications rule out of court the great proportion of the stellar systems. Of the few, comparatively speaking, single and stable suns that remain in the heavenly abyss, we must conclude, from what we know of our solar system, that they, too, have but a narrow zone, outside of which no world would be fit to dwell in; whilst in the zone the few worlds which might exist must violate no one of many strict conditions. If we assume that there are a hundred million stars within the ken of our telescopes, we may well believe that not more than one in a hundred of these would fulfill the condition of being a single and stable sun, such as ours. Of the planets revolving round these million suns- stable and efficient suns-can we expect that in more cases than one in a hundred there will be a planet in the habitable zone fulfilling all the other conditions of habitability, of size, mass, inclination of axis, circular orbit, and rotation? Of these ten thousand earths which may be made fit for the habitation of Man, can we assume that even one in a hundred is now at that epoch in its history when it is no longer "without form and void," when a division has been made between the waters under the firmament and those that are above the firmament; when the waters Under the heaven have been gathered

narrowest space. Most plant cells do not exceed 0.1 to 0.5 millimetres in diameter. Their greatest volume therefore can only be an eighth of a cubic millimetre. Nevertheless, in this minute space we notice in every stage of cell life a considerable number of chemical reactions which carried on contemporaneously, without one disturbing the other in the slightest degree."** It is clear if organic bodies were built up of chemical compounds of small complexity and great stability that this continuous range of chemical reactions, this unceasing metabolism, could not take place. It is therefore a necessary condition for organic substances that they should be built up of chemical compounds that are most complex and unstable. Exactly those substances which are most important for life possess a very high molecular weight, and consequently very large molecules, in comparison with inorganic matter. For example: egg-albumin is said to have the molecular weight of at least 15,000, starch more than 30,000, whilst the molecular weight of hydrogen is 2, of sulphuric acid and of potassium nitrate about I00, and the molecular weight of the heaviest metal salts does not exceed about
300. *** To sum up: the living organism; whether it be can simple cell, or the ordered community of cells making up the perfect plant or animal, is an entity, a living

* Wonders of Life, pp. 127-8.
** Chemical Phenomena in Life, p. 58.
*** Ibid,. p. 22.

individual, wherein highly complex and unstable compounds are unceasingly under-going chemical reactions, a metabolism essentially associated with protoplasm. But these complex compounds are, nevertheless, formed by the combinations of but a few of the elements now known to us. Many writers on the subject of the habitability of other worlds, from contemplating the rich and; apparently limitless variety of the forms of life, and the diversity of the conditions under which they exist, have been led to assume that the basis of life must itself also in like manner be infinitely broad and infinitely varied. In this they are mistaken. As have seen, the elements entering into the composition of organic bodies are, in the main, few in number. The temperatures at which they can exist are likewise strictly limited. But, above all, that circulation of matter which we call Life-the metabolism of vital processes-requires for its continuance the presence of one indispensable factor-WATER. Protoplasm itself, as Czapek puts it, is practically an albumin sol, that perceived, but where the two are not greatly unequal in brightness, so that the spectrum of the one does not overpower that of the other. The" Algol variables" are cases where the two components are of very unequal brightness, and, being very close to each other, are so placed with respect to the Earth that the fainter partly eclipses the brighter in its revolution round it, and so causes a temporary diminution in its light at regular intervals. All these three classes of binary systems are now known to be very numerous. Prof. Campbell estimates that fully one star in six is a spectroscopic binary. But there must be many binary systems that do not reveal themselves-double stars where the companion is too faint or too close to be detected, Algol systems where the companion does not pass before its primary-and it seems almost certain that simple systems, like that of which our Sun is the unchallenged autocrat, must be comparatively rare. But the problem of the movements of a planet attendant upon t\\'o or more suns is one of amazing complexity, and our greatest mathematicians have as yet only been able to deal with the approximate solution of a few very special cases. These are, however, sufficient to show that the orbit of a planet so placed would be most irregular; the variations in the supplies of light and heat received would be as great as even comets experience within the solar system, and, what would be more disastrous still, these variations would not be periodic but irregular. One year would be unlike that which preceded it, and would be followed by changed conditions in the next. Plants and animals would never have the chance of acclimatizing themselves to these ever-changing vicissitudes. The stability of condition essential for the maintenance of water in a liquid state would be wanting; and, in consequence, Life could neither come into existence, nor persist if it once appeared. So far, therefore, our line of thought has led us to recognize that Life can exist in comparatively few of the innumerable stellar systems strewn through infinite space, and in any given system it can at best find only one or two homes. The conditions for a Life-bearing planet are thus both numerous and stringent-there is no elasticity about them. It is not sufficient that a planet might fulfill many or even most of these conditions; failure in one is failure altogether; "one black ball excludes; " the candidate who fails in a single subject is "ploughed" without mercy. And in most cases the failure is final; no opportunity is given to the candidate to "sit " again. But Space is not the only horizon along which our thought must be directed; there is also the horizon of Time. Every world must have its Past and its Future, as well as its Present. For some worlds the conditions are so fixed that, like Jupiter and Saturn, they are not now worlds that can be dwelt in,

connection with this planet. The assumption' is a mistaken one, as has been well pointed out by Garrett P. Serviss, a charming writer on astronomical subjects: "On the Earth we find animated existence confined to the surface of the crust of the globe, to the lower and denser strata of the atmosphere, and to the film of water that constitutes the oceans. It does not exist in the heart of the rocks forming the body of the planet nor in the void of space surrounding it outside the atmosphere. As the Earth condensed from the original nebula, and cooled and solidified, a certain quantity of matter remained at its surface in the form of free gases and unstable compounds, and, within the narrow precincts where these things were lying like a thin shell between the huge inert globe of permanently combined elements below, and the equally unchanging realm of the ether above, life, a phenomenon depending upon ceaseless changes, combinations and re-combinations of chemical elements in unstable and temporary union, made its appearance, and there only we find it at present time."*****

***** Other Worlds, by Garrett P. Serviss, pp. 63-4.

“The huge inert globe of permanently combined elements below, and the equally unchanging realm of the ether above," offer no home for the living organism; least of all for the highest of such organisms-Man. Both must be tempered to a condition which will permit and favour continual change, the metabolism which is the essential feature of life. “When the earth had to be prepared for the habitation of man, a veil, as it were, of intermediate being was spread between him and its darkness, in which were joined, in a subdued measure, the stability and the insensibility of the Earth, and the passion and perishing of mankind. “But the heavens, also, had to be prepared for his habitation. Between their burning light, -their deep vacuity, and man, as between the earth's gloom of iron substance, and man, a veil had to be spread of intermediate being ; -which should appease the unendurable glory to the level of human feebleness, and sign the changeless motion of the heavens with the semblance of human vicissitude. Between the earth and man arose the leaf. Between the heaven and man came the cloud. His life being partly as the falling leaf and partly as the flying vapour ."* The leaf and the cloud are the signs of a habitable world. The leaf-that is to say, plant life, vegetation-is necessary because animal life is not capable of building itself up from inorganic material. This step must have been previously taken by the plant. The cloud, that is to say water-vapour, is necessary because the plant in its turn cannot directly assimilate to the equator to the plane of the orbit is 82°, If this were the case for the Earth, the noonday sun for London would be, at the spring equinox, 38.5° high as at present, but its altitude day by day would increase with great rapidity, and before the end of April, the Sun at noon would be right in the zenith, and 13° above the horizon at midnight. At midsummer, indeed, it would be only 59° high at noonday, but it would be north of the zenith instead of south, and at technical midnight, it would still be 44° in altitude, thus moving round in a very small circle, only 15° in diameter. From about April 18 to August 25 - that is to say, for 129 days, -the Sun would never set, and unlike the summer day of our own polar regions now, wherein the Sun, though always present, is always low down in the sky, for much of that period it would pass the meridian quite close to the zenith. As the year of Uranus is 84 times the length of our year, the London of Uranus would have to endure not far short of 30 years continuous scorching. And the winter would be as long; the perpetual day of summer would be replaced by a night as enduring. More than 29 years of unbroken dark- ness, of unmitigated cold, cannot possibly ever consist with the conditions necessary for life upon a planet. Whatever the brightness of the imagined sun of Uranus, if for 29 years at a time that sun were below the horizon, the water on the planet must be congealed, and during the 29 years of unbroken day all the water would be as certainly evaporated. Thus, though Uranus is not burdened by the enormous mass of Jupiter, nor overshadowed, like Saturn, by a system of rings, the extraordinary inclination of its axis introduces a condition which is as fatal to it, as a world to dwell in, as any of the disabilities of the other planets. It is curious that these four outer planets, that resemble each other so strikingly in many of their conditions-in their vast size, high albedo, low density, and vaporous envelopes, that show, in their spectra, not merely the lines of reflected sun- light, but also special lines due to their own atmospheres (the chief of these being common to all the four planets)- should yet, in the inclination of their axes to the plane of their orbits, display every possible variety. The axis of Jupiter is almost normal to its orbit that of Uranus lies almost in the plane of its orbit. The axes of Saturn and Neptune have a mean inclination, but it would appear that the rotation of Neptune is in the reverse direction to that of planets in general, so that the true inclination is usually taken as being the complement of the observed angle, as if the axis were turned right over. It is uncertain whether this would have any important effect upon the habitability of the planet, but it supplies the fourth possible case for the position of the axis.

yet it is of such importance 10 the maintenance of life on this planet, and by parity of reasoning to life on any other planet, that are view of its conditions forms a necessary introduction to our subject. Further, those conditions themselves will bring out certain principles that are of necessary application when we come to consider the case of particular planets. The distance of the Sun from the Earth is often spoken of as the " astronomical unit "; it is the fundamental measure of astronomy, and all our information as to the sizes and distances of the various planets rests upon it. And, as we shall shortly see, the particular problem with which we are engaged
-the habitability of worlds-is directly connected with these two factors: the size of the world in question, and its distance from the Sun. The distance of the Sun has been determined by several different methods the principles of which wil1not concern us here, but they agree in giving the mean distance of the Sun as a little less than 93,000,000 miles; that is to say, it would require 11,720 worlds as large as our own to be put side by side in order to bridge the chasm between the two. Or a traveller going round the Earth at its equator would have to repeat the journey 3730 times before he had traversed a space equal to the Sun's distance. But knowing the Sun's distance, we are able to deduce its actual diameter, its superficial extent, and its volume, for its apparent diameter can readily be measured. Its actual diameter then comes out as 866,400 miles, or 109.4 times that of the Earth. Its surface exceeds that of the Earth 11,970 times; its volume, 1,310,000 times. But the weight of the Sun is known as well as its size; this follows as a consequence of gravitation. For the planets move in orbits under the influence of the Sun's attraction; the dimensions of their orbits are known, and the times taken in describing them; the amount of the attractive force therefore is also known, that is to say, the mass of the Sun. This is 332,000 times the mass of the Earth; and as the latter has been determined as equal to about 6,000,000,000,000,000,000,000 tons that of the Sun would be equal to 2,000,000,000,000,000,000,000,000,000 tons. It will be seen that the proportion of the volume of the Sun to that of the Earth is greater than the proportion of its mass to the Earth's mass
-almost exactly four times greater; so that the mean density of the Sun can be only one-fourth that of the Earth. Yet, if we calculate the force of gravity at the surfaces of both Sun and Earth, we find that the Sun has a great preponderance. Its mass is 332,000times that of the Earth, but to compare it with the attraction of the Earth's surface we must divide by $(109.4)^2$, since the distance of the Sun's centre from its surface is 109.4 times as great as the corresponding distance

quite seven, and the force of gravity at the surface will be greater than that of the Earth in the same proportion. A man who here weighs 150 lb. will there weigh over 1000 lb.; and the muscular effort of movement will be increased in the same ratio. The athlete who here can clear a height 5 ft. 8 in. will there, with like pains, surmount 10 inches; and other efforts will be in the same proportion. The atmosphere, supposing it to be in proportion to the mass of Jupiter, will exercise a pressure of 46 "atmospheres," or more than 680 lb., to the square inch. Following on this enormous pressure at the surface would be the rapidity with which the atmosphere would thin out in the up- ward direction. The level of half-pressure would be attained by ascending less than half a mile in height; that is to say, there would be a difference of pressure of 340 lb. on the square inch from that experienced at the sea-level. We know from the fact that fishes live at enormous depths in the ocean, that living organisms can be constructed to endure great pressures, but they are not constructed to endure great alterations of pressure. The deep-sea fishes are as instantly killed by being brought up to the surface, as the surface fishes or the land animals would be if they were plunged into the depths. And it is clear that on Jupiter a low range of hills that on the Earth would be considered only an easy climb, would be an impassable barrier, not only from the immense exertion of mounting it, but chiefly from the unendurable change of pressure which the ascent would involve. The sevenfold gravity of Jupiter, taken in connection with this enormous atmospheric pressure, would tend to make the meteorological disturbances of the planet violent far beyond anything of which the Earth can furnish an example. The atmosphere would possess a high viscosity, and differences in condition, pressure and saturation would tend to accumulate, until at length the balance would be restored with explosive suddenness and force. Here our most violent tornadoes may reach a speed of 100 miles an hour; on Jupiter, gales of five or six times that velocity would be common. We cannot conceive that living organisms would be able to grow, flourish and multiply where the conditions were so cataclysmic. This difficulty must always exist where the planet is great in mass, and the force of gravity high at the surface. The case of Saturn is not so extreme as that of Jupiter, though it is probably sufficiently severe to exclude it from the ranks of worlds that could ever be dwelt in. The atmospheric pressure would be about 21 “atmospheres," or more than 300 lb. on the square inch. The level of half-pressure would be reached at about three-quarters of a mile, and the force of gravity be nearly 4.5 times that of the Earth. But the serious condition for Saturn would come from that

us. In the celebrated balloon ascent made by Mr. Coxwell and Mr. Glaisher on September 5, 1861, an even greater height was attained, and it \vas estimated that the barometer fell at its lowest reading to seven inches, which would correspond to a height of 39,000 feet. But on the Sun, where the force of gravity is 27.65 times as great as at the surface of the Earth, it would, if all the other conditions were similar, only be necessary to ascend one furlong, instead of three and a third miles, in order to reach the level of half the surface pressure, and an ascent of two furlongs would bring us to the level of quarter pressure, and so on. If then the solar atmosphere extends inwards, below the apparent surface, it should approximately double in density with each furlong of descent. These considerations, if taken alone, would point to a mean density of the Sun not as we know it to be, less than that of the Earth, but immeasurably greater; but the discordance is sufficiently explained when we come to another to class of facts. These relate to the temperature of the Sun, and to the enormous amount of light and heat which it radiates forth continually. This entirely transcends our power to understand or appreciate. Nevertheless, the astonishing figures which the best authorities give us may, by their vastness, convey some rough general impression that may be of service. Thus Prof. C. A. Young puts the total quantity of sunlight as equivalent to 1,575,000,000,000,000,000,000,000,000 standard candles. The intensity of sunlight at each point of the Sun's surface is variously expressed as 190,000 times that of a standard candle, 5300 times that of the metal in a Bessemer converter, 146 times that of a calcium light, or, 3.4 times that of an electric arc. The same authority estimates at 30 calories the value of the Solar Constant, that is to say, the heat which, if our atmosphere were removed, would be received from the Sun in a minute of time upon a square metre of the Earth's surface that had the Sun in its zenith, would be sufficient to raise the temperature of a kilogram of water 30 degrees Centigrade. This would involve that the heat radiation from each square metre of the Sun's surface would equal 1,340,000 calories; or sufficient to melt through in each minute of time a shell of ice surrounding the Sun to the thickness of 58.2 feet. Prof. Abbot's most recent determination of the solar constant diminishes these estimates by one third; but he still gives the probable temperature of the solar surface as not far short of 7000 degrees Centigrade, or about 12,000 degrees Fahrenheit. The Sun, then, presents us with temperatures and pressures which entirely surpass our experience on the Earth. The temperatures, on the one hand, are sufficient to convert into a permanent gas every substance with which we are acquainted; the pressures, on the other hand, apart from the high eight satellites revolving round it. Of these eight, only four-the four discovered by Galileo, in the first days of his possession of a telescope-need be considered; the other four are of the same order of size as the asteroids, and are indeed much smaller than Ceres. But the Galilean satellites are of a higher rank. Europa, the smallest, is in size a twin to the Moon; Callisto, the outermost, is almost exactly the size of Mercury; Io, the innermost, is midway bet\'leen the two in its dimensions. But Ganymede, the largest, is almost comparable with Mars, its diameter being 0.45 that of the Earth instead of the 0.53 of Mars. But the Moon, Mercury, and Mars have all been shown, on the ground of their small size, to be worlds unfit for habitation; the satellites of Jupiter are, therefore, all rejected on the same score. Nor can the greater nearness of their immediate primary compensate for their remoteness from the Sun. It is true that Jupiter presents to Ganymede a disc with more than 200 times the apparent area that the Sun presents to the Earth, but to make up for the falling-off of the solar radiation, each unit of this area should radiate about $1/250^{th}$ as much heat as each unit of the Sun's surface. In other words, the absolute surface temperature of Jupiter should be $1/4^{th}$ that of the Sun, or about 1550^{o} C., and this is higher than can be admitted. The Sun and Jupiter together cannot put Ganymede in as favourable a position as Mars, much less as favourable as the Earth. The case of Jupiter carries with it those of Saturn, Uranus, and Neptune. All three, from their high albedoes and low densities, are still in a vaporous condition; still in some sort, semi-Suns; ,sources of a certain amount of heat, and not recipients merely. The days are yet far distant when a solid crust can form on anyone of them, and the water condense from the steamy atmosphere to form oceans, seas, and rivers. Not till then, if at all, when water as a liquid, water that flows, is present, can life begin to appear and enter on its long course of change.

CHAPTER XI
WHEN THE MAJOR PLANETS COOL

The question has been asked: "It is evident that life cannot exist at the present time on the outer planets, since they are in a highly heated and quasi-solar condition; but when they cool down, as cool they must, and a solid crust is formed, may not a time come when they will be habitable? It seems impossible to think that worlds so beautiful to our eyes and so vast in scale are destined never to be peopled by intelligent beings." It is clearly difficult to answer satisfactorily a question that requires so deep a plunge into the recesses of the unknown future; yet, so far as our knowledge goes,

stretched out parallel to the Sun's equator. A group of spots in its later stages of development is more commonly reduced to a single round, well- defined, dark spot. These groups, when near the edge of the Sun, are usually seen to be accompanied by very bright markings, arranged in long irregular lines, like the foam on an incoming tide. These markings are known as the faculae, from their brightness. In the spectroscope, when the serrated edges of the chromosphere are under observation, every now and then great prominences, or tongues and clouds of flame, are seen to rise up from them, sometimes changing their form and appearance so rapidly that the motion can almost be followed by the eye. An interval of fifteen or twenty minutes has frequently been sufficient to transform, quite beyond recognition, a mass of flame fifty thousand miles in height. Sometimes a prominence of these, or even greater, dimensions has formed, developed, risen to a great distance from the Sun, and completely disappeared within less than half an hour. The velocity of the gas streams in such eruptions often exceeds one hundred miles a second; sometimes, though only rarely, it reaches a speed twice as great. Sunspots do not offer us examples of motions of this order of rapidity, but the areas which they affect are not less astonishing. Many spot groups have been seen to extend over a length of one hundred thousand, or one hundred and fifty thousand miles, and to cover a total area of a thousand million square miles. Indeed, the great group of February, 1905, at its greatest extent, covered an area four times as great as this. Again, in the normal course of the development of a spot group, the different members of the group frequently show a kind of repulsion for each other in the early stages of the group's history, and the usual speed with which they move away from each other is three hundred miles an hour. The spots, the faculae, the prominences, are all, the different ways, of the nature of storms in an atmosphere; that is to say, that, in the great gaseous bulk of the Sun, certain local differences of constitution, temperature, and pressure are marked by these different phenomena. From this point of view it is most significant that, many spots are known to last for more than a month; some have been known to endure for even half a year. The nearest analogy which the Earth supplies to these disturbances may be found in tropical. cyclones, but these are relatively of far smaller area, and only last a few days at the utmost, while a hundred miles an hour is the greatest velocity they ever exhibit, and this, fortunately, only under exceptional circumstances. For a wind of such violence mows down buildings and trees as a scythe the blades of grass; and were tornados moving at a rate of 300 miles an hour as common upon the Earth as spots are upon the Sun, it noticed in dealing with the Moon, or Venus, or Mars, for these and all the planets yet noticed are less in size, surface, volume, and mass than the Earth, and hence possess less inherent heat. It is only now that the greater planets are being considered that the question of a source of heat, other than the Sun, can arise. But the evidence of such heat on Jupiter is not to be disputed. The albedo or reflective index of Jupiter has been put by the late Prof. G. Bond, of Harvard College Observatory, as higher than unity; in other words, that it emits more light than it receives. This is now generally regarded as an excessive estimate, but the albedo of the disc as a whole cannot be put lower than 0.72, or about that of white paper. But many of the "belts" or dark regions are of a dull copper tint, and the polar caps are dusky, so that Bond's estimate must be realized for the most brilliant "zones," as the brighter regions are called; certainly for the whitest of the white spots. No direct evidence of inherent luminosity has been obtained, for the satellites disappear entirely in eclipse. But though their shadows in transit appear very dark, it is clear that they are not absolutely black, since sometimes such a shadow is not distinguishable in darkness from the satellite that casts it; a delicate proof that the background on which it falls has some intrinsic luminosity. Unless there is the counteracting effect of a high temperature, the atmosphere of Jupiter would have a pressure at the surface of 104 lb. to the square inch, and the level of half pressure be attained at a mile and a quarter; the reverse condition to that on Mars would obtain, and the atmosphere of Jupiter would be much denser and much shallower than that of the Earth. Denser it probably is; shallower it cannot be, for the great white spots, each often five or six thousand miles in diameter, that range themselves at times along the equatorial regions till they look like the port- holes of a ship, evidently rise from depths great even as compared with their size. But it is only by intense heat that the effect of the great mass of Jupiter in constricting its atmosphere within shallow depths can be overcome. Again, the extraordinary lightness of the planet, so little above the density of water, points in the same direction. So, not less unmistakably, do the magnitude and rapidity of the atmospheric movements. The clouds and storms of our own atmosphere are worked by solar heat; solar heat it is that draws up the vapours and provides the chief part of the energy manifested in the speed and strength of the air-current. But solar heat can only give 1/27th the amount of that energy at the distance of Jupiter, so that, if they were entirely dependent on solar radiation, the winds of Jupiter should be very feeble. Further, the difference of presentment due to the difference of latitude is a fruitful cause of in- equalities of

high even at the surface to permit any such condensation. The application of the spectroscope to astronomy is not confined to the Sun, but reaches much further. The stars also yield their spectra, and we are compelled to recognize that they also are suns; intensely heated globes of glowing gas, rich in the same elements as those familiar to us on the Earth and known by their spectral lines to be present on the Sun. The stars, therefore, cannot themselves be inhabited worlds any more than the Sun, and at a stroke the whole of the celestial of luminaries within the furthest range of our most powerful telescopes are removed from our present search. Only those members of our solar system that shine by reflecting the light of the Sun can be cool enough for habitation; the true stars cannot be inhabited, for, whatever their quality and order, they are all suns, and must necessarily be in far too highly heated a condition to be the abode of life. Many of them may, perhaps, be a source of light and heat to attendant planets, but there is no single instance in which such a planet has been directly observed; no dark, non-luminous body has ever been actually seen in attendance on a star. Many double or multiple stars are known, but these are all instances in which one sun-like body is revolving round another of the same order.***** We see no body shining by reflected light outside the limits of the solar system. Planets to the various stars may exist in countless numbers, but they are invisible to us, and we cannot discuss conditions where everything is unknown. Enquiry in such a case is useless, and speculation vain. The stars, as revealed to us by the spectroscope are all of the same order as the Sun, but they are not all of the same species.

***** The movements of not a few double stars point to perturbations caused by the attraction of unseen bodies. There are also a number of instances known of "Eclipse" or "Algol-type" variable stars, in which the presence of a dark companion is indicated by the diminution of the light of the star at regular intervals.

Quite a large number of stars, of which Arcturus is one of the best-known examples, show spectra that are essentially the same as that of the Sun, but there are other stars of which the spectra bear little or no semblance to it. Nevertheless, it remains true that, on the whole, stellar spectra bear witness to the presence of just the same elements as we recognize in the Sun, though not always in the same proportions or in the same conditions-hydrogen, calcium, sodium, magnesium, iron, titanium, and many more are recognized in nearly all. It is true that not all the known terrestrial elements have yet been invariably suffused with a pale olive-green colour, which seemed to be associated with great disturbance, and which was rarely seen elsewhere. ...The red belts presented on all occasions the appearance of a passive medium, in which the phenomena of the streamers and other forms. ..were manifested. The phenomena would be exactly reproduced by streamers of cloudy white matter floating in a semi-transparent reddish fluid, some- times submerged and sometimes rising to the surface. ...The dark spots frequently seen on the red belts usually occupied spaces left by sharp turns in the streamers, and they were of the same colour as the belts, but deeper in tint, as if the, fluid medium could be seen to a greater depth."* In other words, Jupiter is a striped or banded planet, the bands lying along the direction of turning. These bands are coloured in varying tints, and the planet rotates very rapidly, for the details in the bands pass quickly from one limb to the other. And not only is the speed of rotation of the whole very rapid-Jupiter turns about its axis in a little less than ten hours, so that a particle at its equator moves through 466 miles in each minute-but the various items that form the bands rotate in different times. They may also alter their ... form and their colour. Jupiter seems, then, to be a planet with a great and rapidly changing atmosphere that extends above a shoreless sea formed of some liquified substance or substances-the whole in a state of flux. But if we turn back to the Table, we see that Jupiter at its mean distance from the Sun is 5.2 times that of the Earth; that is to say, it receives only 1/27th of the light and heat that we receive. But in Chapter VIII, we learnt from Mars that as this receives only 3/7th of the Earth's light and heat, its mean temperature would sink to -30 °C.; the Earth's being 16 °C. Mars is therefore almost always a frozen planet; frozen except on its mere surface when this is exposed to the full rays of the Sun. No sea there would ever be melted to a depth of more than a few inches, even at noonday in midsummer. And yet Mars has at least ten times the advantages of Jupiter. Jupiter, then, must be a frozen planet through and through; no liquid of any sort can exist on its surface; no vapour of any substance can exist in its atmosphere. It must be icebound even at its summer noonday. Yet, from the description given by Prof. Keeler, it is manifestly not so; and another item in the Table emphasizes that it cannot be so. The density of the Sun is 1.4 that of water, Jupiter's is 1.33, showing that but a very small proportion (if any) of its bulk can be solid; the rest must be vaporous, or at least fluid. How then can we reconcile these inconsistencies? It is in the dimensions of Jupiter that we find the answer. The mass of the planet is 317 times that of the Earth; it is

same building materials have been employed, and throughout they retain the same qualities. Hydrogen is seen in the spectra of nearly all stars, and also in those of nebulae. The elemental lines of oxygen are not indeed seen in stellar spectra, but that the element is present is shown by the flutings of titanium oxide which distinguish stars like Antares. Nitrogen and carbon again are not recognized by their elemental lines, but the lines of cyanogen are seen in the spectra of comets and of sunspots, and hydrocarbon flutings in the spectra of comets and red stars; while in a few of the hottest stars even sulphur has recently been identified.*

All the five organo-genetic elements are therefore abundantly diffused through space; the materials for protoplasm, "the albuminous subtance with water," are at hand everywhere. This being so, it is reasonable to infer that if organic life exists elsewhere than on this Earth, and its essential feature, there as here, is the metabolism of nitrogenous carbon compounds in association with protoplasm. But it is objected that "we are not yet able to identify all the lines in solar or stellar spectra; .may not some of these lines be due to elements of which we know nothing here, and may not such new elements form complex and unstable compounds with each other, or with some of those familiar to us, that would take the place of the five organo-generators, and so give rise to a physical basis of life, different from that we know on this Earth?' But the development of Mendeleeff's Periodic Law has shown that the elements are not to be regarded as disconnected entities.

* Proc. R. Soc., LXXX, 50, 1907.

The Law as given in Mendeleeff's own words, runs: "The properties of the elements as well as the forms and properties of their compounds are in periodic dependence on, or (expressing ourselves algebraically) form a periodic function of the atomic weights, of the elements." In other words, they form a series, not only as it regards their atomic weights, but also as it regards their own properties and the forms and properties of their compounds. We are no longer at liberty, as we might have been many years ago, to call into fancied existence new elements having no relation in their properties and compounds to those with which we are acquainted. New elements, no doubt, will be discovered in the future, as in the past; and indeed we be able to discover them and learn their and atomic weights and properties without ever being able to handle them in a terrestrial laboratory. In a series of remarkable papers communicated to the Royal Astronomical Society during the past year (1911-1912), Dr. J.

perihelion, and then recede from him for periods that it takes even thousands of years to complete, But without dwelling on such extreme cases, two of the best known of the periodic comets may be taken as examples of the rest, Encke's is the comet of shortest period, returning in about 3.3 years. At perihelion it is 31 millions of miles from the Sun; one-third the distance of the Earth. It receives, therefore, at this part of its orbit, 9 times as much light and heat as the Earth. But at aphelion it retreats deep into the region of the asteroids, and is much more than four times the mean distance of the Earth, At this part of its orbit it receives but 1/17th as much heat as the Earth. By far the most famous of all the comets is that known by the name of Halley, and its mean period is 76 years. At perihelion it comes within the orbit of Venus; indeed, nearly halfway between that and the orbit of Mercury. At aphelion it recedes to thirty-five times the distance of the Earth, far beyond the orbit of Neptune. The range in its light and heat from the Sun is from 3 times that of the Earth to less than 1/1200th; or, in other words, the supply of heat at one time is nearly 4000 times that at another, and of the 76 years of its period, on1y 80 days are spent within the orbit of the Earth, Comets cannot be homes of life; they are not sufficiently condensed; indeed, they are probably - but loose congeries of small stones. But even if comets were of planetary size it is clear that life could not be supported on them; water could not remain in the liquid state on a world that rushed from one such extreme of temperature to another. Between the orbits of Mars and Jupiter there are scattered an untold number of little planets commonly known as asteroids or minor planets. Minor planets indeed they are, for the one first discovered-Ceres-probably outweighs all the rest, known and unknown, put together, though some- thing like 700 have already been detected, and the list grows at the rate of about one a week. As the Table shows, Ceres is so small that the Earth exceeds it in volume 5000 times; even the Moon is 90 times as large. The mass of Ceres is not known; being so small, its density is probably less than that of the Moon, so that the Earth may easily outweigh it 10,000 times. The unfavourable conditions resulting from smallness of size - that the Moon presents are therefore exaggerated exceedingly in the case of Ceres; its atmosphere must approach in tenuity what we should regard as a vacuum in a terrestrial laboratory, and water as a liquid be entirely unknown. Its distance from the Sun is another hostile factor; for in consequence it receives per unit of surface only 13 per cent of the light and heat that falls on the Earth; its maximum temperature under a zenith Sun will fall far below freezing-point, the minimum on the dark side will approach the absolute zero. With Ceres the whole of

other presents itself as approaching water in suitability for its essential office. If we, ourselves, were able to create a vehicle, could we imagine one more perfectly suited?

CHAPTER V
THE MOON

The Sun and Moon offer to our sight almost exactly the same apparent diameters; to the eye, they look the same size. But as we know the Sun to be 400 times as distant as the Moon, it is necessarily 400 times as large; its surface must exceed that of the Moon by the square of 400, or 160,000; its volume by the cube of 400, or 64,000,000. As the Sun is of low mean density, its mass does not exceed that of the Moon in quite the same high ratio; but it is equal in mass to 27,000,000 moons. Compared with the Sun, the Moon is therefore an insignificant little ball-a mere particle; but as a world for habitation it possesses some advantages over the Sun. The first glance at it in a telescope is sufficient to assure the observer that he is looking at a solid, substantial globe. It is not only substantial, it is rugged; its surface is broken up into mountains, hills, valleys, and plains; the mountains stand out in sensible relief; it looks like a ball of solid silver boldly embossed and chased. So far all is to for the purpose of habitation. Wherever men are, they must have a solid platform on which to stand; they must have a stable terrene whereon their food may grow, and this the Moon could supply. "The Earth's gloom of iron substance " is necessary for man here, and the Moon appears to offer a like stability. Another favourable condition is that we know that the Moon receives from the Sun a sufficient supply of light and heat. Each square yard of its surface receives, on the average, the same amount of light and heat that would fall upon a square yard on the Earth that was presented towards the Sun at the same inclination; and we know from our own experience that- this is sufficient for the maintenance of life. And the Moon is near enough for us to subject her to a searching scrutiny. Every part of the hemisphere turned toward us has been repeatedly examined, measured, and photographed; to that extent our knowledge of its topography is more complete than of the world on which we live. There are no unexplored regions on our side of the Moon. The great photographs taken in recent years at the observatories of Paris and of the University of Chicago have shown thousands of " crater-pits," not more than a mile across; and narrow lines on the Moon's surface have been detected with a breadth less than one-tenth of this. An elevation on the Moon, if it rose up abruptly from an open plain, would make its presence apparent by the shadow which it would cast soon after atmospheric circulation, the extreme range of temperatures, the low temperature at which water will boil. But the heat to which Mercury is exposed far transcends our terrestrial experience. In the mean it receives nearly seven times as much heat from the Sun as the Earth does, but this supply is not maintained uniformly, for Mercury moves round the Sun in a very eccentric orbit, so that when in aphelion it receives, surface for surface, only about four times as much heat as the Earth, but some six weeks later when in perihelion it receives more than eleven times. The great range of temperature due to the thinness of the atmosphere must therefore be further increased by the varying distance of the planet from the Sun. A reference to Prof. Poynting's figures shows that the mean temperature of Mercury must approximate to 194^{o} C., while water will boil at 40^{o} C. or even lower. Here, then, is a condition the exact reverse of Mars. Water as a liquid will be rare on Mercury, not because it is congealed, but because it is evaporated; on the dark side of the planet it may, indeed, pass into ice, but on the side exposed to the Sun it must exist normally as a constituent of the atmosphere. Water in a liquid state, water that flows, must. be almost unknown. But we have good reason to believe that that which is the dark side of Mercury at one time is always dark; that which is exposed to the Sun is always exposed to it. Since Mercury wears no concealing veil of atmosphere, and displays markings that can be identified and followed, a surprising circumstance has come to light. In 1889, Schiaparelli discovered that Mercury, instead of rotating on its axis in about 24 hours like the Earth and Mars, rotates in 88 days; that is to say, it always turns the same face towards the Sun, just as the Moon turns the same face towards the Earth. This fact, confirmed theoretically by Prof. G. H. Darwin in his development of the theory of tidal friction, puts the condition of Mercury in quite a new light. No alternation of day or night refreshes and restores the little world; one hemisphere is for ever exposed to the blasting heat of the Sun, seven times hotter for it than for the Earth; the other hemisphere is for ever exposed to the darkness and cold of outer space, a range from something like 390^{o} C. above freezing-point, to 270^{o} C. below. It is true that between the two hemispheres there is a "debatable land," for, owing to the ellipticity of the orbit, the face turned to the Sun is not exactly the same at all times, and a region about 47^{o} in width on each side of the planet, that is to say, rather more than a quarter of its entire surface, has one day and one night in each period of 88 days, but these more favoured sections can scarcely be considered more habitable than the rest. The conditions of Mercury are so unfavourable for life that, even if this remarkable relation of rotation period to revolution did

striking and varied than would be anticipated. But the question arises whether all the changes that are associated with the progress of the lunar day can be ascribed to this effect. Thus, Prof. W. H. Pickering writes concerning a well-known pair of little craters of about nine miles in diameter, known as Messier and Messier A, situated side by side not far from the centre of the Mare Fecunditatis. When the Sun rises first on them, the eastern one, A, is tri-angular and larger than Messier, which latter is somewhat pear-shaped. About three days after sunrise; they both suddenly turn white, Messier rapidly grows in size, soon surpasses A, and also becomes triangular in shape. Six days after sunrise the craters are again nearly of the same size, owing to the diminution of Messier. The shape of A has become irregular, and differs in different lunations. At nine days after sunrise the craters are exactly alike in size and shape, both now being elliptical, with their major axes lying in a nearly N. and S. direction. Just before sunset A is again the larger, being almost twice the size of Messier:"
***** Some observers explain this cycle of changes as due merely to the peculiar contour of the two objects, the change in the lighting during the lunar day altering their apparent figures. Prof. W. H. Sir Pickering, on the other hand, while recognizing that some portion of the change of shape is probably due to the contour of the ground, conceives that, in order to explain the whole phenomenon, it the is necessary to suppose that a white layer of hoar frost is formed periodically round the two craters and it is also alleged that whereas Madler described the two craters as being exactly alike eighty years ago, Messier A is now distinctly the larger; but it is very doubtful whether Madler's description can be was trusted to this degree of nicety. If it could, this would establish a permanent change in the actual structure of the lunar surface at this point. There are several other cases of the same order of ambiguity. The most celebrated is Linne, a white spot about six miles in diameter on the Mare Serentatis. This object appears to change in size during the progress of the lunar day, and, as with fain Messier, some selenographers consider that it has also suffered an actual permanent change in shape within the last sixty or seventy years. Here again the evidence is not decisive; Neison is by no means convinced that a change has taken place, yet does not think it impossible that Linne may once have been a crater with steep walls which have collapsed of a into its interior through the force of gravity. Another type of suspected change is associated with the neighbourhood of Aristarchus, the brightest formation on the Moon, so bright indeed that William Herschel, observing it when illuminated by earthshine in the dark portion of the moon, thought that he was watching a lunar volcano in eruption. In

we are obliged to see them.

CHAPTER IX
VENUS, MERCURY AND THE ASTEROIDS

Of all the planets, Venus appears, to the un- assisted eye, by far the loveliest. When seen in the early morning before sunrise-its "western elongation"-or after sundown in the evening-its "eastern elongation"-and still more as it attains its greatest brilliancy, it has attracted attention everywhere and in all ages. It then shines with brilliance ten times as great as Jupiter in opposition, and the brightest members of the heavenly host look pale and dim beside it. It is emphatically the morning or the evening star, Lucifer, or Vesper, herald or follower of the Sun; it can even assert itself in the presence of the Lord of Day, for it has often been seen at noonday by watchers who knew where to look; sometimes by the general crowd. But in the telescope Venus appears less satisfying. It is a pretty spectacle indeed to watch the phases of the gleaming little globe of silver, for, like the Moon under varying illumination from the Sun, it undergoes change of apparent shape. But the surface of the planet yields little detail, and that little is illusive and ill-defined. The clear-cut outlines and black shadows of the Moon have no place here, nor do the ruddy plains and blue-grey "seas" of Mars find any analogues. All that can be observed beyond the changes of phase are a few faint, ill-defined patches, where the molten silver of the general surface is slightly dimmed and tarnished, and perhaps one or two spots, not less evasive and difficult to fix, that exceed the rest of the surface in brightness. This very difficulty in making out the markings on Venus is hopeful for our search; it points to a veiling over the planet, a veiling by an atmosphere. And the statistics of the Table show that Venus closely resembles our Earth in size and mass, and therefore probably in atmospheric equipment. If we assume that the atmosphere of any planet is in direct proportion to its mass-and as Venus is so nearly the twin of the Earth there is no reason to expect any great difference between the two in this respect-the atmosphere of Venus would have a pressure of about 11.2 lb. on the square inch, and the level of half pressure would be nearly four miles above the surface. In other words the atmosphere would be both thinner and deeper than that of the Earth, but the difference would not, be important in amount. But Venus is nearer to the Sun than the Earth, and receives nearly double

is no air to carry the vapour that might dim our view. Life is change, and a planet where there is no change, or where that change is very small, can be no home for life. The" stability and insensibility" are indeed required in the platform upon which life is to appear, but there must be the presence of "the passion and the perishing," or life will be unable to find a home. We infer the absence of water and air from the Moon not only from the

***** The Moon, by Philip Fauth, p. 156.

unchanging character of its features and the distinctness with which we see them; we are able to make direct observations. Galileo, the first man to observe the Moon to better advantage than with the naked eye, was not long before he decided that the Moon contained no water, for though Milton, in a well-known passage, makes Galileo discover "Rivers or mountains on her spotty globe," Galileo himself wrote: "I do not believe that the body of the Moon is composed of earth and water." The name of maria was given to the great grey plains of the Moon by Revelius, but this was simply for convenience of nomenclature, not because he actually believed them to be seas. One observation is, in itself, sufficient to prove that the maria are not water surfaces. The Moon's" terminator," that is to say the line dividing the part in sunlight from that in darkness, is clearly irregular when it passes over the great plains; were they actually sea it would be a bright line and perfectly smooth. The grey plains are therefore not expanses of water nor were they in time past. It is obvious that in some remote antiquity their surface was in a fluid condition, but it was the fluidity of molten rock. This is seen by the way in which the maria have invaded, breached, broken down, and submerged many of the circular formations on their margins. Thus the Mare Humorum has swept away half the wall of the rings, Hippalus and Doppelamayer, and far out in the open plain of the Mare Nubium, great circles like Kies, and that immediately north of Flamsteed, stand up in faint relief as of half-submerged rings, Clearly there was a period after the age in which the great ring mountains and the walled plains came into existence, when an invasive flood attacked and partially destroyed a large proportion of the,. And the flood itself evidently became more viscous and les fluid the further it spread from its original center of action, for the ridges and crumpling of the surface indicate that the material found more and more difficulty in its flow. We have evidence just as direct that there is no atmosphere. This is very strikingly shown when the Moon, in its monthly progress among the stars, passes before one of them and occludes it. Such an occultation is instantaneous, and I particularly impressive when alleged uniformity and breadth of the canals. Prof. Lowell repeatedly insists that the canals are of even breadth from end to end, and spring into existence at once throughout their whole length. This statement is in itself a proof that the canals cannot be what he supposes them to be. An irrigation system could not have these characteristics; the region fertilized would take time to develop; we should see the canal extending itself gradually across the continent, and its breadth would not be uniform from end to end, but the region fertilized would grow narrower with increase of distance from the fountainhead of the canal. Under what conditions can we see straight lines, perfectly uniform from end to end, spring into existence, in their entirety, without going through any stages of growth? When the lines are not actual images, but are suggested by markings perceived, but not perfectly defined. In 1902 and 1903, in conjunction with Mr. Evans, the headmaster of Greenwich Hospital School, I tried a number of experiments on this point, with the aid of about two hundred of the boys of the school. They had several qualifications in respect of these experiments; they were keen-sighted, well drilled; accustomed to do what they were told without asking questions; and they knew nothing whatsoever of astronomy, certainly nothing about Mars. A diagram was hung up, based upon some drawing or other of the planet made by Schiaparelli, Lowell or other Martian observer, but the canals were not inserted; only a few dots or irregular markings were put in here and there. And the boys were arranged at different distances from the diagram and told to draw exactly what they saw. Those nearest the diagram were able to detect the little irregular markings and represented them under their true forms. Those at the back of the room could not see anything of them, and only represented the broadest features of the diagram, the continents and seas. Those in the middle of the room were too far off to define the minute markings, but were near enough for those markings to produce some impression upon them and that impression always was of a network of straight lines, sometimes with dots at the points of meeting, Advancing from a distance toward the diagram the process of development became quite clear, At the back of the room no straight lines were seen; as the observer came slowly forward, first one straight line would appear completely, then another, and so on, until all the chief canals drawn by Schiaparelli and Lowell in the region represented had come into evidence in their proper places, Advancing still further, the canals disappeared, and the little irregular markings which had given rise to them were perceived in their true forms, These experiments at the Greenwich Hospital School were merely the repetition of similar ones that I had myself made privately

its atmosphere. A larger proportion, therefore, of the solar rays are employed in heating the soil of the Moon than in heating that of the Earth, and in this connection the effect of an important difference between the two worlds must be noted, The Earth rotates on its axis in 23 hours 56 minutes 4 seconds, the mean length of its rotation as referred to the Sun being 24 hours. The rotation of the Moon, on the other hand, takes 27 days 7 hours 43 minutes to accomplish, giving a mean rotation, as referred to the Sun, of 29 days 12 hours 44 minutes. The lunar surface is therefore exposed uninterruptedly to the solar scorching for very nearly fifteen of our days at a time, and it is, in turn, exposed to the intense cold of outer space for an equal period. As the surface absorbs heat so readily, it must radiate it as quickly; hence radiation must go on with great rapidity during the long lunar night. Lord Rosse and Prof. Very have both obtained measures of the change in the lunar heat radiation during the progress of a total eclipse of the Moon, with the result that the heat disappeared almost completely, though not quite at the same time as the light. Prof. Langley succeeded in obtaining from the Moon, far down in the long wave lengths of the infra-red, a heat spectrum which was only partly due to reflection from the Sun; part coming from the lunar soil itself, which, having absorbed heat from the Sun, radiated it out again almost immediately. In 1898, Prof. Very, following up Langley's line of work, concluded that the temperature of the lunar soil must range through about 350^o Centigrade, considerably exceeding 100^o at the height of the lunar day, and falling to about the temperature of liquid air during the lunar night. So wide a range of temperature must be fatal to living organisms, particularly when the range is repeated at short, regular intervals of time. But this range of temperature comes directly from the length of the Moon's rotation period; for the longer the day of the Moon, the higher the temperature which may be attained init; the longer the night, the greater the cold which will in turn be experienced. We learn, therefore, that the time of rotation of a planet is an important factor in its habitability.

CHAPTER VI
THE CANALS OF MARS

Both of the two worlds best placed for our study are thus, for different reasons, ruled out of court as worlds for habitation. The Sun by its vastness, its intolerable heat and the violence of its changes, has to be rejected on the one hand, while the Moon, so small, and therefore so rigid, unchanging and bare, is rejected on the other. Of the other heavenly bodies, the planet Mars is the one that we see to best advantage. Two other planets, Eros and Venus, at times come least total excitement in order to produce an appreciable impression, and therefore the smallest appreciable impression produces the effect of a straight line. It is sufficient, then, for us to suppose that the surface of Mars is dotted over with minute irregular markings, with a tendency to aggregate in certain directions, such as would naturally arise in the process of the cooling of a planet when the outer crust was contracting above an unyielding nucleus. If these markings are fairly near each other it is not necessary, in order to produce the effect of "canals," that they should be individually large enough to be seen. They may be of any conceivable shape, provided that they are separately below the limit of defined vision, and are sufficiently sparsely scattered. In this case the eye inevitably sums up the details (which it recognizes but cannot resolve) into lines essentially" canal-like" in character. Wherever there is a small aggregation of these minute markings, an impression will be - given of a circular spot, or, to use Prof. Lowell's nomenclature, an "oasis." If the aggregation be greater still and more extended, we shall have a shaded area -a "sea." The above remarks apply to observation with the unaided eye, but the same principle applies yet more strongly to telescopic vision. No star is near enough or sufficiently large to give the least impression of a true disc; its diameter is indistinguishable; it is for us a mathematical point, "without parts or magnitude." But the image of a star formed by a telescope is not a point but a minute disc, surrounded by a series of diffraction rings. This disc is "spurious," for the greater the aperture of the telescope the smaller the apparent disc. That which holds good for a bright point like a star holds good for every individual point of a planetary surface when viewed through the telescope; that is to say, each point is represented by a minute disc; all lines and outlines therefore are slightly blurred, so that minute irregularities are inevitably smoothed out. When we come to photographs, the process is carried to a third stage. The image is formed by the telescope, subject to all the limitations of telescopic images, and is received on a plate essentially granular in structure, and is finally examined by the eye. The granular structure of the plate acts as the third factor in concealing irregularities and simplifying details; a third factor in producing the two simplest types of form -the straight line and the circular dot. Prof. Lowell describes the canals as like lines drawn with pen, ink and ruler, but not a few of our best observers have advanced much beyond r this stage. Even as far back as 1884, some of the canals were losing their strict rectilinear appearance to Schiaparelli, and the observers of the planet who have been best favoured by the power of the telescope at their disposal, by the atmospheric conditions under which they worked,

William Herschel, who, during the oppositions of 1777, 1779, 1781, and 1783, determined the inclination of the axis of Mars to the plane of its orbit, measured its polar and equatorial diameters, and ascertained the amount of the polar flattening. He paid also special attention to two bright white spots upon the planet, and he, showed that these formed round the planet's poles and increased in size as the winter of each several hemisphere drew on and diminished again with the advance of summer, behaving therefore as do the snow caps of our own polar' regions. The next stage in the development of our knowledge of Mars must be ascribed to the two German astronomers, Beer and Madler, who made a series of drawings in the years 1830, 1832 and 1837, by means of a telescope of 4 inches aperture, from which they were able to construct a chart of the entire globe. This chart may be considered classic, for the features which it represents have been observed afresh at each succeeding opposition. Mars, therefore, possesses a permanent topography, and some of the markings in question can be identified, not only in the rough sketches made by Sir William Herschel, but even in those made by Hooke and Cassini as far back as the year 1666. In the forty years that followed, the planet was studied by many of the most skilled observers, particularly by Mr. J. N. Lockyer in 1862, and the Rev. W. R. Dawes in 1864. In 1877, the late Mr. N. E. Green, drawing- master to Queen Victoria, and a distinguished painter in water colours, made a series of sketches of the planet from a station in the island of Madeira 2000 feet above sea-level. When the opposition was over, Mr. Green collected together a large number of drawings, and formed a chart of the planet, much richer in detail than any that had preceded it, and from his skill, experience and training as an artist he reproduced the appearance of the planet with a fidelity that had never been equalled before and has never been surpassed since. At this time it was generally assumed that Mars was a miniature of our own world. The brighter districts of its surface were supposed to be continents, the darker, seas. As Sir William Herschel had already pointed out long before, the little world evidently had its seasons, its axis being inclined to the plane of its orbit at much the same angle as is the case with the Earth; it had its polar caps, presumably of ice and snow; its day was but very little longer than that of the Earth; and the only important difference seemed to be that it had a longer year, and was a little further off the Sun. But the general conclusion was that it was so like the Earth in its conditions that we had practically found out all that there was to know; all that seemed to be reserved for future research was that a few minor details of the surface might be filled in as the power of our telescopes was increased. But fortunately for one. If a future development in the power of telescopes should equal the advance made from the 4-inch of Beer and Madler, to the 33-inch which Antoniadi used in 1909, is it reasonable to suppose that Prof. Lowell's oases will refuse to yield to such improvement, and will all still show them- selves as uniform spots, precisely circular in outline? It is clear that Beer and Madler would have been mistaken if they had argued that the apparently perfect circularity of the two oases which they observed proved them to be artificial, because the increase in telescopic power has since shown us that neither is circular. The obvious reason why they appeared so round to Beer and Madler was that they were too small to be defined in their instruments; their minor irregularities were therefore invisible, and their apparent circularity covered detail of an altogether different form. Beer and Madler only drew two such spots; Lowell shows about two hundred. Beer and Madler's two spots seemed to them exactly alike; these two spots as we see them to-day have no resemblance to each other. Prof. Lowell's two hundred oases, with few exceptions, seem all of the same character; is it possible to suppose, if telescopes develop in the future as they have done in the past, that the two hundred oases will preserve their uniformity of appearance any more than the Lacus Solis and the head of the Sinus Sabreus? If a novice begins to work upon Mars with a small telescope, he will draw the Lacus Solis and the Sinus Sabreus as two round, uniform spots, and as he gains experience, and his instrumental power is increased, he will begin to detect detail in them, and draw them as Dawes and Schiaparelli and others have shown them later. It is no question of planetary change; it is a question of experience and of "seeing." There is a much simpler explanation of the regularity of the canals and oases than to suppose that an industrious population of geometers have dug them out or planted them; it is connected with the nature of vision. A telegraph wire seen against a background of a bright cloud can be discerned at an amazing distance-in fact, at 200,000 times the breadth of the wire; a distance at which the wire subtends a breadth of a second of arc. For average normal sight the perception of the wire will be quite unmistakable, but at the same time it would be quite untrue to say that the perception of the wire was of the nature of defined vision, as would be seen at once if small objects of irregular shape were threaded on the wire; these would have to be many times the breadth of the wire in order to be detected. Again, if instead of a wire of very great length extending right across the field of view of both eyes, a short, black line be drawn on a white ground, it will be found that as the length of the line is diminished below a certain point so its

conspicuous had been delineated by other astronomers before any rumour of Schiaparelli's work had come abroad, and as Mars came under observation again and again at successive oppositions, the number of those who were able to verify Schiaparelli's discoveries increased. It has now long been known that the great Italian astronomer was not the victim of a mere optical illusion; there were actual markings on the planet Mars where he had represented them; markings, which, when seen under like conditions and with equal instrumental equipment, did present the appearance of straight, narrow lines. The "canals of Mars " are not mere figments of the imagination, but have a real objective basis. As this controversy has passed away, another and a very different one has arisen out of an un- fortunate mistranslation of the term chosen by Schiaparelli to indicate these linear streaks. In, conformity with the type of nomenclature adopted by previous areographers who had divided Mars into "seas," "continents," "islands," "isthmuses," " straits" and the like, Schiaparelli had called the narrow lines he detected "canali," that is to say" channels," but without intending to convey the idea of artificial construction. Indeed, he himself was careful to point out that these designations " were not intended to prejudge the nature of the spot, and were nothing but an artifice for helping the memory and for -shortening descriptions." And he added, "We speak in the same way of the lunar seas, although we well know that there are no true seas on the Moon." But " canali" was unhappily rendered in English as "canals," instead of "channels." " Channel " would have left the nature of the marking an open question, but, in English, "canal" means an artificial waterway. Here then the question as to whether or no Mars is inhabited comes definitely before us. Have we sufficient grounds for believing that the "canals " are artificial constructions, or may they be merely natural formations? In 1894, Mr. Percival Lowell founded at Flagstaff, Arizona, U.S.A., a well-equipped observatory for the special study of Mars, and he has continued his scrutiny of the planet from that time to the present, with the most unrelaxing perseverance. The chief results that he has obtained have been the detection of many new "canals "; the discovery of a number of dark, round dots, termed by him "oases," at the junctions of the "canals"; and the demonstration that the "canals " and certain of the dusky regions are subject to strictly seasonal change, as really as the polar caps themselves. In addition, he has formed the conclusion, which he has supported with much ingenuity and skill, that the regularity of the " canals " and " oases, quite precludes the possibility of their being natural formations. Hence there has arisen the second controversy: that on the nature of the "canals"; for Mr. Lowell considers that their fined to some hardy forms of a low type. At a distance of forty millions of miles it is not easy to discriminate between the darkness of sheets of water and the darkness of stretches of vegetation. Some of the so-called "seas" may possibly be really of the latter class, but that there must be expanses of water on the planet is clear, for if there were no water surfaces there would be no evaporation; and if there were no evaporation from whence could come the supply of moisture that builds up the winter pole cap? The great American astronomer, Prof. Newcomb, gave in Harper's Weekly for July 25, 1908, an admirable summary of the verdict of science as to the character of the meteorology of Mars. "The most careful calculation shows that if there are any considerable bodies of water on our neighbouring planet they exist in the form of ice, and can never be liquid to a depth of more than one or two inches, and that only within the torrid zone and during a few hours each day. ...There is no evidence that snow like ours ever forms around the poles of Mars. It does not seem possible that any considerable fall of such snow could ever take place, nor is there any necessity of supposing actual snow or ice to account for the white caps. At a temperature vastly below any ever felt in Siberia, the smallest particles of moisture will be condensed into what we call hoar frost, and will glisten with as much whiteness as actual snow. ...Thus we have a kind of Martian meteorological changes, very slight indeed and seemingly very different from those of our earth, but yet following similar lines on their small scale. For snowfall substitute frostfall; instead of feet or inches say fractions of a millimetre, and instead of storms or wind substitute little motions of an air thinner than that on the top of the Himalayas, and we shall have a general description of Martian meteorology." What we know of Mars, then, shows us a planet, icebound every night, but with a day temperature somewhat above freezing-point. As we see it, we look upon its warmest regions, and the rapidity with which it is cleared of ice, snow, and cloud shows the atmosphere to be rare and the moisture little in amount and readily evaporated.. The seas are probably shallow depressions, filled with ice to the bottom, but melted as to their surfaces by day. From the variety of tints noted in the seas, and the recurrent changes in their outlines, they are composed of congeries of shallow pools, fed by small sluggish streams; great ocean basins into which great rivers discharge themselves are quite unknown.

CHAPTER VIII
THE ILLUSIONS OF MARS

The two preceding chapters have led to two opposing, two

the three books mentioned, he deals directly with "Proofs of Life on Mars:' The presence of vegetation may be inferred from seasonal changes of tint, just as an observer on the Moon might with the naked eye watch effects on the Earth. But though "vegetable life could thus reveal itself- directly, animal life could not. Not by its body but by its mind would it be known. Across the gulf of space it could be recognized only by the imprint it had made on the face of Mars. "Confronting the observer are lines and spots that but impress him the more, as his study goes on, with their non-natural look. So uncommonly regular are they, and on such a scale as to raise suspicions whether they can be by nature regularly produced" (pg 188). "…Unnatural regularity, the observations showed, betrays itself in everything to do with the lines: in their surprising straightness, their amazing uniformity throughout, their exceeding tenuity, and their immense length" (pg 189). "As a planet ages, its surface water grows scarce. Its oceans in time dry up, its rivers cease to flow, its lakes evaporate (pg 203). ...Now, in the struggle for existence, water must be got. ... Its procuring depends on the intelligence of the organism that stand in need of it. ... As a planet ages, any organism upon it will share in its development. They must evolve with it, indeed, or perish. At first they change only, as environment offers opportunity, in a lowly, unconscious way. But, as brain develops, they rise superior to such occasioning. ...The last stage in the expression of life upon a planet's surface must be that just antecedent to its dying of thirst. ...With an intelligent population this inevitable end would be long foreseen. ...Both polar caps would be pressed into service in order to utilize the whole available supply and also to accommodate most easily the inhabitants of each hemisphere" (pp. 204-11). " That intelligence should thus mutely communicate its existence to us across the far reaches of space, itself remaining hid, appeals to all that is highest and most far-reaching in man himself. More satisfactory than strange this; for in no other way could the habitation of the planet have been revealed. It simply shows again the supremacy of mind. ...Thus, not only do the observations we have scanned lead us to the conclusion that Mars at this moment is inhabited, but they land us at the further one that these denizens are of an order whose acquaintance was worth the making "(p. 215). For the moment, let us leave Prof. Lowell's argument as he puts it. Whether we accept it or not, it remains that it is a marvellous achievement of the optician's skill and the observer's devotion that from a planet so small and so distant as Mars any evidence should be forthcoming at all that could bear upon the question of the existence of intelligent organisms upon its surface. But it is of the utmost to be liberated as the rain falls. The oceanic currents have the same effect, and how great the modification which they introduce may be seen by comparing the climates of Labrador and Scotland. There appear to be no great oceans on Mars. The difference of 28° which we find on the Earth between the equator and the edge of the Arctic Circle is a difference which remains after the convection currents of air and sea have done much to reduce the temperature of the equator and to raise that of high latitudes. If we suppose that their effect has been to reduce this difference to one half of what it would have been were each latitude isolated from the rest, we shall not be far wrong, and we should get a range of 56° as the true equivalent difference between the mean temperatures of Singapore and Archangel; i.e. of the Earth and Mars; and Mars would stand at -40° C. The closeness with which this figure agrees with that reached by Prof. Poynting suggests that it is a fair approximation to the correct figure. The size of Mars taught us that we have in it a planet with an atmosphere of but one half the density of that prevailing on the top of our highest mountain; the distance of Mars from the Sun showed us that it must have a mean temperature close to that of freezing mercury. What chance would there be for life on a world the average condition of which would correspond to that of a terrestrial mountaintop, ten miles high and in the heart of the polar regions? But Mars in the telescope does not look like a cold planet. As we look at it, and note its bright colour, the small extent of the white caps presumed to be snow, and the high latitudes in which the dark markings-presumed to be water or vegetation-are seen, it seems difficult to suppose that the mean temperature of the planet is lower than that of the Earth. Thus on the wonderful photographs taken by Prof. Barnard in 1909, the Nilosyrtis with the Protonilus is seen as a dark canal. Now the Protonilus is in North Lat. 42°, and on the date of observation -September 28, 1909- the winter solstice of the northern hemisphere of Mars was just past. There I would be nothing unusual for the ground to be covered with snow and the water to be frozen in a corresponding latitude if in a continental situation on the Earth. Then, again, in the summer, the white polar caps of Mars diminish to a far greater extent than the snow and ice caps of the Earth; indeed, one of the Martian caps has been known to disappear completely. Yet, as the accompanying diagram will show, something of this kind is precisely what we ought to expect to see (**Figure 1**). The diagram has been constructed in the following manner; A curve of mean temperatures has been laid down for every 10° of latitude on the Earth, derived as far as possible from accepted isothermals in continental countries in the northern hemisphere. From this curve

relates to its size and mass. As the foregoing Table shows, it comes between the Moon and the Earth in these respects. The figures show at a glance that Mars ranks in its dimensions between the Moon and the Earth and that on the whole, it is more like to the Moon than it is to the Earth. But in what way would this affect Mars as a suitable home for life? In many ways; and amongst these the distribution of its atmosphere and the sluggishness of its atmospheric circulation are not the least important. It was mentioned in Chapter III that at a height of about three and a third miles the barometer will stand at 15 inches, or half its mean height at sea level, showing that one half the atmosphere has been passed through. Mont Blanc, the highest mountain in Europe, is under 3 miles in height, so that it is not possible, in Europe, to climb to the level of half-pressure; Mt. Everest, the highest mountain in the world, is not quite six miles high, so that no part of the solid substance of our planet reaches up to the level of the quarter pressure. On a very few occasions daring aeronauts have soared into the empyrean higher than the summits of even our loftiest mountains, but the excursion has been a dangerous one, and they have with difficulty brought their life back from so rare and cold, so inhospitable a region. When Gay-Lussac, in 1804, attained a height of 23,000 feet above sea level, the thermometer, which on the ground read 31°C., sank to 9° below zero, and the rare atmosphere ,vas so dry that paper crumpled up as if it had been placed near the fire, and his pulse rose to 120 pulsations a minute instead of his normal 66. When Mr. Glaisher and Mr. Coxwell made their celebrated ascent between 1 and 2 o'clock on the afternoon of September 5, 1861, they found that at a height of 21,000 feet the temperature sank to –10.4°; at 26,000 feet to -15.2°; and at 39,000 feet the temperature was down to -16.0°C. At this height the rarefaction of the air was so great and the cold so intense that Mr. Glaisher fainted, and Mr, Coxwell's hands being rendered numb and usless, by the cold, he was only able to bring about their descent in time by pulling the string of the safety valve with his teeth. Yet when they attained this height they were far above all cloud or mist, and the Sun's rays fell full upon them. The Sun's rays had all the force that they had at the surface of the Earth, but in the rare atmosphere of seven miles above the Earth, the radiation from, every particle not in direct sunlight was so great that while the right hand, exposed to the Sun, might burn, the left hand, protected from his direct rays, might freeze. But gravity at the surface of Mars is much feebler than at the surface of the Earth, and in order to, reach the level of half-pressure a Martian mountaineer would have to climb, not three and a third miles, but eight and three-quarter miles; that is to say, the distance to the Sun, Mars receives per unit of surface only about three-sevenths of the light and heat of that received by the Earth. The inclination of the axis of Mars is almost the same as that of the Earth, so that the general character of the seasons is not very different on the two planets, and the torrid, temperate, and frigid zones have almost the same proportions. The length of the day is also nearly the same for both, the Martian day being slightly longer; but the most serious factor is the greater distance of Mars, and the consequent diminution in the light and heat received from the Sun. The light and heat received by the Earth are not so excessive that we could be content to see them diminished, even by 5 per cent, but for Mars they are diminished by 57 per cent. How can we Judge the effect of so important a difference? The mean temperature of our Earth is supposed to be about 60° F., or 16° C. Three-sevenths of this would give us 7° C. as the mean temperature of Mars, which would signify a planet not impossible for life. But the zero of the Centigrade scale is not the absolute zero; it only marks the freezing-point of water. The absolute zero is computed to be -273° on the Centigrade scale; the temperature of the Earth on the absolute scale therefore should be taken as 289°, and three-sevenths of this would give 124° of absolute temperature. But this is 149° below freezing-point, and no life could exist on a planet under such conditions. But the mean temperature of Mars cannot be computed quite so easily. The hotter a body is the more rapidly it radiates heat; the cooler it is the slower its radiation. According to Stefan's Law, the radiation varies for a perfect radiator with the 4th power of the absolute temperature; so that if Mars were at 124° abs., while the Earth were at 289° abs., the Earth would be radiating its heat nearly 30 times faster than Mars. The heat income of Mars would therefore be in a much higher proportion than its expenditure; and necessarily its heat capital would increase until income and expenditure balanced. Prof. Poynting has made the temperature of the planets under the 4th power Law of radiation the subject of an interesting enquiry, and the figures which he has obtained for Mars and other planets are included in the Table. The equatorial and average temperatures are given under the assumption that Mars possesses an atmosphere as efficient as our own in equalizing the temperature of the whole planet. If, on the other hand, its atmosphere has no such regulating power, then under the zenith Sun the upper limit of the temperature of a portion of its surface reflecting one-eighth would be, as shown in the Table, 64 °C. This would imply that the temperature on the dark side of the planet was very nearly at absolute zero. If we regard Mars as resembling our Moon, and take the Moon's effective e average temperature as 297 °

For we must remember that, though our own atmosphere is a hindrance to our observing, yet the atmosphere of the planet into which we are looking is a greater hindrance still. Like the lace curtains of the window of a house, it is a much greater obstacle to looking inward than to looking outward, and as the perfect distinctness with which we see the Moon is a proof that it is practically without an atmosphere, so the great detail visible on Mars bears unmistakable testimony to the slightness of the atmospheric veil around that planet. And when we turn again to the statistics of Mars, we see that this must inevitably be the case. Of two planets, one heavier than the other, it is not possible to suppose that the lighter should secure the greater proportional amount of atmosphere, With planets, as with persons, it is the most powerful that gets the lion's share: "to him that hath it is given, and from him that hath not is taken away even that which he seemeth to have." But if we assume that Mars has acquired an atmosphere proportional to its mass, then we see from the Table that this must be a little less than $1/9^{th}$ of that of the Earth; exactly 0.107. It is distributed over a smaller surface, 0.285. Consequently the amount of air above each square inch of Martian surface is 0.107 x 0.285 =0.38. But since the force of gravity at the surface of Mars is less than on the Earth, this column of air will only weigh 0.38 X 0.38 =0.145; or one-seventh of the column of air resting on a square inch of the Earth's surface. The pressure at the surface of Mars will therefore be 2.1 lb.; and the aneroid barometer would read 4.3 inches, (In order to express the diminished pressure of the Martian atmosphere, it is necessary to refer it to the aneroid barometer, The mercury in a mercurial barometer, or the water in a water barometer would lose in weight in consequence of the diminished force of gravity in the same proportion as the air would, and the mercurial barometer would read 11.4 inches.) But a pressure of 2.1 lb. on the square inch is far less than that experienced by Coxwell and Glaisher in their great ascent; it is about one-half the pressure that is experienced on the top of the very highest terrestrial mountains, But the habitable regions of the Earth do not extend even so far upward as to the level of a pressure of 7.3 lb. on the square inch; that is, of half the terrestrial surface pressure. Plant life dies out before we reach that point, and though birds or men may occasionally attain greater heights, they cannot domicile there, and are, indeed, only able thus to ascend in virtue of nourishment which they have procured in more favoured regions. If we could suppose the conditions of the whole Earth changed to correspond with those prevailing at the summit of Mt. Everest, or even at the summit of Mont Blanc, it is clear that the life now present on this planet would