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## 525TH ORDINARY GENERAL MEETING.

### HELD IN THE ROOMS OF THE INSTITUTE ON MONDAY, JANUARY 22ND, 1912, AT 4.30 P.M.

### MR. E. J. SEWELL, MEMBER OF COUNCIL, PRESIDED.

The Minutes of the last Meeting were read and signed, and the SECRETARY announced the following elections:—

MEMBER: Rev. Evan H. Hopkins.

ASSOCIATES: Herman R. Wyatt, Esq., Vernon Roberts, Esq., Miss Sophia M. Nugent, Mrs. C. S. Hogg, Miss Grace D. Gardiner.

The CHAIRMAN in calling upon Mr. MAUNDER to read his paper said: It would be ridiculous for me to propose to introduce Mr. Maunder to any meeting at the Victoria Institute. He is so well known to us all as an active member of the Council and as an untiring and interesting lecturer for the Institute that any introduction is quite superfluous.

The subject on which he is to read a paper is in itself very interesting. But we are accustomed to seeing it dealt with in newspapers and magazines by writers who only half-know what they are talking about and who, consequently, very often much misunderstand the information which they pass on in their articles. It is, therefore, an intellectual treat to have the subject dealt with by a writer who not only thoroughly knows his subject but, as many audiences can testify, has the art of making what he says thoroughly intelligible to people who are unacquainted, or only moderately acquainted, with the technicalities of astronomy and astro-physics.

On subjects such as the conditions of existence on planetary bodies altogether inaccessible to direct observation it is imperative that we should distinguish between (1) known and established facts, (2) inferences of high probability, based on established facts, but still made subject to various assumptions, and (3) speculations as to facts which may possibly be the result of highly hypothetical conditions. Most of those who deal with this subject are unable to keep these three categories distinct, and stumble in the half-light of imperfect knowledge. Mr. Maunder walks with a sure step in the light of clear and definite knowledge, and we are therefore fortunate in having him for our guide.

The following paper was then read by E. WALTER MAUNDER, ESQ., F.R.A.S. :—

## *THE CONDITIONS OF HABITABILITY OF A PLANET; with Special Reference to the Planet Mars.*

THE first thought which men had concerning the heavenly bodies was an obvious one: they were lights. There was a greater light to rule the day, a lesser light to rule the night, and there were the stars also.

But with the acceptance of the Copernican theory, this world on which we live, while losing its pride of place as the centre of the universe, from another point of view received a promotion, in that itself it became a heavenly body of the same order as some of those that shine down upon us. And, as the earth is an inhabited world, the question naturally arises "May not these bright lights of heaven also be, like it, inhabited worlds?" There is a strong and natural desire to obtain an affirmative answer to the question; all men would greatly delight to be able to recognize the presence of races similar to our own upon other worlds in the depths of space.

What do we mean by an "inhabited" world? We know quite well what we mean by an "inhabited" island. When an explorer in his voyage lights upon a land hitherto unknown, no richness of vegetation, no fullness and complexity of animal life will warrant him in describing it as inhabited. He can only give it that title if he should find men there. Similarly, if we speak of a planet as being habitable, we mean that it is suitable for the presence of beings that we could recognize as being essentially of the same order as ourselves, possessing an intelligent spirit lodged in an organic body. Animals without intelligence could not be dignified by the title of "inhabitant," nor could disembodied intelligences, such as men have fabled to live in rocks, or streams, or trees—fairies, nymphs and elves and the like—be accurately described by the same term. We may readily imagine that in outward form the inhabitants of another world might differ very greatly from ourselves, but, like us, they must be possessed of intelligence and self-consciousness, and these qualities must be lodged in and expressed by a living, material body. Our inquiry is a physical one; it is the necessities of the living body that must guide us in it; a world unsuited for living organisms is not, in our sense, a habitable world.

What constitutes a living organism? It is almost impossible to give a comprehensive and satisfactory definition, yet we all know some of the chief characteristics of an organism. In the first place it is a machine. Like man-made machines it is a storehouse of energy, but it differs from artificial machines in that, of itself and by itself, it is continually drawing non-living matter into itself, converting it into an integral part of the organism, and so endowing it with the qualities of life, and it derives from this non-living matter fresh energy for the carrying on of the work of the machine. The living organism, therefore, is continually changing its substance, while it remains as a whole essentially the same. As Professor S. J. Allen has remarked: "The most prominent and perhaps the fundamental phenomenon of life is what may be described as the *energy traffic*, or the function of *trading in energy*. The chief physical function of living matter seems to consist in absorbing energy, storing it in a higher potential state, and afterwards partially expending it in the kinetic or active form."

Here is the wonder and mystery of life, the power of the living organism to assimilate dead matter, to give it life, and bring it into the law and unity of the organism itself. But it cannot do this indiscriminately; it is not able thus to convert every dead material; it is restricted, narrowly restricted, in its action.

First of all, living organisms are not built up out of every element; four elements must always be present and be predominant; the four being hydrogen, oxygen, nitrogen, and carbon. The compounds which these four elements form with each other in living organisms are most complex and varied, and they also admit to combination, but in smaller proportions, a number of the other elements, of which we may take sulphur as an example.

This fact disposes at once of the vague plea which is sometimes raised, "Is it not possible that there may be life upon other worlds under physical conditions totally different from those which prevail here?" We cannot think it, for the evidence of the spectroscope has shown us that the same elements that are familiar to us here are present, not only in our sun, but in the most distant stars. And more than that, the elements have the same properties there as here. For the evidence of the spectrum of a body is evidence of its essential structure, far more searching than any chemical analysis could possibly give; it reveals to us the qualities of its ultimate molecules.

The same elements therefore exist throughout space, and exist with the same qualities. Nor are we able to call into imagined existence other elements of which we know nothing with properties quite unrelated to those of the known elements. For the Periodic Law has shown us that the elements do not exist as isolated phenomena, to which we could in imagination add indefinitely in any direction, but that they are strictly related to each other in all their properties. If, therefore, organic life on another world could be built up of elements other than the four which form its chief basis here, we should have the same phenomenon occurring within our own experience. We may therefore dismiss, as a wholly chimerical hypothesis, the suggestion that the conditions of life as we find them here may be abrogated elsewhere.

What are the conditions of habitability here on this world? They have never been more happily stated than by Ruskin in his *Modern Painters*.

"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 itself the nitrogen from the atmosphere. The food for the plant is largely brought to it by water, and it assimilates it by the help of water. Life on a planet therefore turns upon the presence of water, the great neutral liquid and general solvent, the compound of the two most abundant elements, hydrogen and oxygen. There is no other compound of like properties and simplicity of constitution that could take its place, or that the elements could supply in such abundance. We cannot imagine a world wherein bisulphide of carbon or hydrochloric acid or any other such compound could discharge the functions which water fulfils here. It is, therefore, upon the question of the presence of water that the question of the habitability of a given world chiefly turns. In the physical sense man is "born of water," and any world fitted for his habitation must "stand out of the water and in the water."

Where shall we find such another world? There were two bodies whose surfaces men could study to some extent, even before the invention of the telescope—the sun and the moon. But we are able now to determine the temperature of the sun with some approach to precision, and we know that not only is it far too hot for the presence of vegetation, but it is so hot that oxygen and hydrogen would usually refuse to combine there. The components of the molecules of water would be driven asunder; water would be dissociated. And as with the sun so with all the stars, for they, in various measures and degrees, are all suns. The moon also is without the leaf and the cloud; its surface has been drawn, photographed and measured over every square mile, until the side visible to us has been more thoroughly surveyed than our earth, but it shows us only bare unchanging rock. A man placed there could draw no nutriment from the atmosphere around him, or the soil beneath; no vapour would ever soften the hardness of the heaven above, no leaf the hardness of the rock below.

But what of planets? There may be planets circling round the stars, or there may not be; we have no means of knowing, and we cannot discuss that about which we are totally ignorant. Our survey, therefore, is confined to the planets of the solar system and we turn naturally to Mars, the one that is next beyond us in distance from the sun, because its position enables it to be easily observed from time to time, and its surface is the one that we know best.

But Mars at its average distance is 140,000,000 miles from us; 34,000,000 miles even at its nearest approach. The mere mention of distances so great, so far beyond our power to appreciate, seems at once to put it out of the question that Mars should be able to offer us any evidence, one way or the other, as to whether it is inhabited by intelligent beings. That we should be able to gather any evidence at all, for or against, is a remarkable achievement.

It is more remarkable still that an able and experienced astronomer should have convinced himself that he has obtained evidence of the actual handiwork upon Mars of highly intelligent and capable beings. This discovery—if discovery it be—is asserted by Mr. Percival Lowell, a wealthy American, who for the last eighteen years has been studying the surface of Mars with the most admirable diligence and skill. According to him, the surface of the planet is covered by a network of very fine lines, looking like the meshes of a spider's web. These lines, popularly known as "canals," are, as Mr. Lowell describes them, so narrow, hard, regular and straight that he considers we are shut up to believe them to be artificial constructions, the work of very intelligent engineers. The points, too, where the "canals" intersect are often marked by dots, usually known as "oases," which are just as regular in their way, being, according to Mr. Lowell, truly circular. And he claims that the object of these two types of structure is quite clear. Five parts out of seven of the surface of our own globe are occupied by our oceans, but on Mars there are no great oceans, and at best only two or three small seas. The store of water on Mars has run low, and Mr. Lowell's theory is that the inhabitants have constructed vast irrigation works, by which the water from one polar cap or the other is brought, as it melts, to lower latitudes. The long, dark lines seen on the planet are not, according to him, the actual "canals" themselves. but the straths of vegetation springing up along their banks. Where several "canals" meet, there a circular area of considerable size is brought under cultivation, and these are the "oases." Clearly such vast engineering works, extending, as they do, to every portion of the planet, could not be carried out without the ordered co-operation of its entire population. Accepting the argument that the regularity of the "canals" and "oases" proves that they are artificial, we reach the conclusion not only that there are intelligent beings on Mars, but that they must have achieved a complete political unity, and have developed intellectual powers and a command over the forces of nature which far outstrip anything that we as yet have been able to accomplish here.

The study of the surface of Mars goes back almost to the time of the invention of the telescope, the earliest drawing extant having been made in the year 1636. In 1666, Robert Hooke, the Gresham Professor of Astronomy, and Secretary to the Royal Society, detected several dark spots on the planet, and in the same year Cassini discovered that Mars rotated upon it axis in a period of about twenty-four hours forty minutes. The next great advance was made by Sir 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 the snow does in 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 Mädler, who made a series of drawings in the years 1830, 1832, and 1837, by means of a telescope of four 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. The surface of Mars therefore possesses permanent features, and some of the markings in question can be identified not only in the rough sketches of Sir William Herschel, but even in those of the year 1666, made by Hooke and Cassini. In the forty years that followed, the planet was studied by many of the most skilled observers, and in 1877 the late Mr. N. E. Green, Drawing Master to Queen Victoria, and a painter in water-colours with a most delicate appreciation of colouring, made a series of sketches of the planet from a station in the island of Madeira, 2,000 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 not 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; there were occasional traces of cloud; 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 general 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 progress this sense of satisfaction was rudely disturbed. As Mars, in its progress round the sun, receded from the earth, or rather as the earth moved away from it, the astronomers who had observed so diligently during the autumn of 1877 turned their attention to other objects, but one of them, Schiaparelli, the most distinguished astronomer on the continent of Europe, still continued to watch the planet, and as the result of his labours he published some months later the first of a magnificent series of Memoirs, bringing to light what appeared to be a new feature. His drawings not only showed the "lands" and "seas," that is to say the bright and dark areas, that Green and his predecessors had drawn, but also a number of fine, narrow, dark lines, crossing the "lands" in every direction. These narrow lines are the markings which have been so celebrated, I might say so notorious, as the "canals of Mars." The English word "canal" gives the idea of an artificial watercourse, an idea which Schiaparelli himself had no intention of creating; he had called them *canali* or "channels," and it is quite possible that the controversy as to their nature, which has been carried on for so many years, would never have arisen but for the unfortunate mistranslation into English of the *canali* as "canals."

Yet the controversy itself has not been unfortunate, for it has focussed attention upon Mars in a way that perhaps nothing else could have done, and since 1877 the most powerful telescopes of the great public observatories of the world have been turned upon the planet, and the most skilful and experienced astronomers have not been ashamed to devote their time to it.

There is no need to attempt to review the immense mass of observations that have been accumulated in the last thirty-five years. We may take as representative of the two parties in the controversy Mr. Lowell himself, who has observed Mars with such perseverance for the last eighteen years, on the one side, and on the other, M. Antoniadi, an architect by training and an astronomer by genius, who has even a longer record to show.

In the opposition of 1909, Mr. Lowell was observing Mars from his observatory at Flagstaff, Arizona, a site carefully chosen by himself for the good definition obtained there, while M. Antoniadi had the use of the great 33-inch refractor of the Meudon Observatory, near Paris. The former showed the planet as covered with a perfect network of "canals," which he describes as "narrow regular lines of even width throughout, running with geometric precision from definite points to another point where an oasis is located." These canals are drawn as following the arcs of great circles, and sometimes extend almost half round the planet, disregarding all inequalities of surface, and Mr. Lowell speaks of them as being so straight that in a drawing they have to be put in by the aid of a ruler, a freehand line not being straight or uniform enough. M. Antoniadi, on the other hand, though he shows "canals" of a kind, shows them as streaks, that is to say, they have not the hardness, the narrowness, or the uniformity of Mr. Lowell's representations. They are not mere geometrical lines, but have characteristics of their own; there is no trace of any geometrical network, looking like the figure of a proposition in Euclid, and M. Antoniadi is quite clear that such network does not exist. Yet his drawings show an immensity of fine detail, much of which escaped the scrutiny of Mr. Lowell.

Within the last few years it has been found possible to enlist the services of photography in this connection. The difficulties of doing this can only be appreciated by those who have actually attempted it. First of all, the size of the image of the planet depends upon the focal length of the telescope, and at a good opposition the diameter of the image of Mars formed by a mirror or object glass is just one ten-thousandth part of that focal length. In other words, a telescope one hundred inches long, that is 8 feet 4 inches, would give an image only one-hundredth of an inch in diameter, a mere pinpoint. If, however, we desire the image to be only onefifth of an inch in diameter, the telescope would have to be 167 feet in length. At Mount Wilson a telescope has actually been constructed with an equivalent focal length of 150 feet; if this were mounted like an ordinary telescope, it would be impossible to give it the necessary rigidity, and any wind would set up tremors in it which would be fatal to the chance of securing good photographs. But by firmly fixing the telescope and reflecting the light from the planet into it, from a moving mirror, this difficulty has been overcome. At the Yerkes Observatory and at Mr. Lowell's smaller telescopes have been used and the image of Mars has been enlarged afterwards. But though a wonderful success has attended these efforts of Mr. Lowell and of Professors Barnard and Hale, the photographs have not settled the controversy. Mr. Lowell finds "canals" on his photographs, though it must be added that in appearance they are more like M. Antoniadi's representations than Mr. Lowell's own drawings. Professor Barnard's photographs, which appear to be the best that have yet been secured, show, on the other hand, nothing that is canaliform, but they reproduce most closely the beautiful paintings made by the late Mr. Green, thirty-five years ago.

The actuality of the "geometrical network" is, therefore, still in dispute; is there anything about the planet that is not in dispute?

Two facts about the planet had been ascertained long before the invention of the telescope; its distance from the sun as compared with that of the earth was known to be more than half as much again. This implies that it receives from the sun only three-sevenths the amount of light and heat, surface for surface, that the earth does. The length of its year was also known; it is much longer than that of the earth, being only six weeks short of two full terrestrial years; expressed in days, it is 687 as compared with our 365¼ days.

Since the invention of the telescope the distance of Mars from the sun has been measured, not only relatively, but in miles, and the size and weight of the planet have been determined. The latter was inferred from the movements of the two tiny satellites discovered in 1877. We know that Mars is but little more than half the earth in diameter; in volume it is only about one-seventh; and in mass only one-ninth that of the earth. Its density, therefore, is about five-sevenths of the earth, and the attraction of gravitation at its surface is not much more than one-third as much as it is here. On the earth a falling weight will pass through sixteen feet in the first second;

the same object on Mars would only pass through six feet in the same time; consequently, all movements on Mars that are the effect of gravitation are much slower than they are here, and this implies that its atmospheric circulation must be sluggish. The late R. A. Proctor, unequalled in his day as a popular writer on astronomy, made one of his few mistakes when he described Mars as a planet swept by hurricanes. The less the attractive power of the planet the more languid must the movements of its atmosphere be; we know with certainty that there are no hurricanes on Mars.

The feeble action of gravity has another effect. On the earth if we ascend some three and a third miles, say about as high as the top of Mont Blanc, we find that the barometer reads just half of what it does at the sea level; half the atmosphere has been passed through. At double that height the pressure would be halved again; it would be only one-quarter of that at sea level. On Mars the level of half pressure will be at nearly nine miles from the surface, and of quarter pressure at nearly eighteen miles. This relation we may briefly express by saying that the barometric gradient is much steeper for the earth than for Mars, and it follows that however thin and rare the atmosphere may be at the surface of Mars, yet at only a few miles height the pressure must be the same for the two planets, and above that height the pressure for Mars would be the greater.

It is quite clear that Mars has not much atmosphere; its surface markings are seen far too distinctly for it to be possible to suppose that we view them through anything like the amount of air that exists above the earth; indeed it is very doubtful whether an observer on the planet Venus could make out anything of our geography through the veil that our atmosphere spreads round us. It is generally supposed that the atmospheric pressure at the surface of Mars may be about one-seventh of that on the earth, equivalent to the sort of atmosphere that we should find about nine miles high above the earth. This would be about the atmospheric density that Mars might claim if atmospheres were dealt out to planets in proportion to their masses. But it appears probable that with planets as with people, the strongest get the lion's share; to those that have it is given, and from those which have not, even that which they seem to have is taken away. The above estimate, therefore, must be taken as the highest possible, probably much higher than the fact; for a little planet like Mars cannot have the power of acquiring or retaining an atmosphere possessed by so much heavier a globe as the earth.

These are the two chief factors regulating the condition of a planet; the amount of light and heat received by it, and the density and distribution of its atmosphere. Within the limits of the solar system the first depends upon its distance from the sun; the second upon the size and density of the planet itself.

There is a simple way by which we may take a first step towards appreciating the result of the greater distance of Mars. If we take the earth at one of the equinoxes we shall find that as much light and heat from the sun falls upon three square yards at the equator as falls upon seven in latitude 64½°. This difference is, of course, due to the angle on which the higher latitude is presented to the sun, and we find that while the mean temperature at the equator is about 80 degrees Fahr. that of latitude of 64½° is quite 50 degrees lower. As the mean temperature of the earth as a whole is about 60 degrees, we should from this way of looking at the problem take the mean temperature of Mars as about 10 degrees, that is to say, 22 degrees below freezing point. So far then Mars would seem to be as much worse off than the earth, as a place within the Arctic Circle is worse off than the equator, but we have to add the further drawback that, owing to the thinness of the atmosphere of Mars, we should have to select within the Arctic Circle the top of a mountain ten miles high to compare with a station on the sea level at the equator.

But we have omitted as yet a number of considerations all of which tend in the same direction, and all against the habitability of the planet. Five-sevenths of the surface of the earth is covered with water, and water is the great equaliser of temperature. The atmospheric circulation of the earth, too, is quick and efficient, so that our equatorial regions are much cooler, our polar regions much warmer than they would be if the air and water of the earth were stagnant. It is probable that the difference in temperature between the equator and latitude 64½° would be quite doubled if it were not for the equalising influences of our atmosphere and seas, and that we ought to put the mean temperature of Mars as 100 degrees below that of the earth. Professor Poynting, by another method, has reached the same figure, and puts it as 40 degrees below zero, the freezing point of mercury.

Hardly less important than the mean temperature of a planet is the range of temperature. At Greenwich the mean maximum day temperature for the middle of July is about 75 degrees, the mean minimum night temperature for the middle of January is about 33 degrees, a range of 42 degrees. This range is not that between the very highest and lowest temperatures ever recorded, but the average range between the hottest part of the day in summer and the coldest part of the night in winter. Britain is however an island, and the surrounding ocean tempers our climate and contracts the range of temperature very greatly. A continental climate in the same latitude would show a range about twice as great.

This range of temperature is, on the average, smallest at the equator, greatest at the poles; the length of the day and night being invariable at the equator, while at the poles there is but one day and one night in the whole year. The range therefore increases with the latitude. On Mars, where the year is nearly twice the length of ours, the range from equator to pole must be much greater than on the earth; the more so that the absence of oceans and the sluggishness of the atmospheric circulation would leave unmodified the full effect of a polar day and a polar night each almost as long as a complete terrestrial year.

The range in any particular latitude would also be greater than on the earth. We know that during the night the earth radiates into space the heat which it has received from the sun on the previous day, and the rarer and drier the air, the more rapid the fall of temperature. But the Martian air is so thin that during the day it offers no hindrance to the heating effect of the sun's rays upon the soil, and during the night little or no hindrance to radiation; it cannot play the part fulfilled by the earth's atmosphere of imparting heat that it has gathered during the day to the soil during the night. The conclusion therefore reached by the late Professor Newcomb is generally accepted by astronomers, that "during the night of Mars, even in the equatorial regions, the surface of the planet probably falls to a lower temperature than any we ever experience on our globe. If any water exists it must not only be frozen but the temperature of the ice must be far below the freezing point." During the night of the polar regions, the temperature of Mars must closely approach the absolute zero.

But though this is the case, and the mean temperature of Mars even in the equatorial regions is below the freezing point of water, yet, owing to the wide range of temperature, due to the rarity of the atmosphere, it is probable that the maximum temperature at noonday in summer time for any particular latitude does not differ very greatly from that experienced in similar latitudes here. And it is just those regions of the planet which are enjoying noontide in summer which are most favourably presented for our inspection. We see that part of Mars which is at its best.

But, as we have seen, the habitability of a world turns upon the presence and abundance of the compound water in the liquid state. Here water melts at 32 degrees and boils at 212 degrees; through a range of 180 degrees it is in the liquid state. And the mean temperature of our planet, and of all latitudes outside the polar circle, is above the freezing point and far below the boiling point. Water with us, therefore, is normally a liquid. On Mars the boiling point can only be about 80 degrees above freezing point, so that the range within which water can exist as a liquid is very small. But the mean temperature of the planet as a whole, and of every latitude in particular, is much below the freezing point; the normal condition of water there is that of ice, and it is impossible for it to fulfil its great function of enabling organic life to receive nutriment. The noonday temperature may indeed rise high above the freezing point; may even reach the boiling point; but this can only suffice to melt a thin film of the surface ice. As Professor Newcomb puts it; "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."

Since the atmosphere is so thin and so little water is at any time above the freezing point, there can at no time be any great depositions of snow or rain. The polar caps, therefore, cannot be vast accumulations of snow, but at the best a thin deposit of hoar frost. The winters on Mars are seasons of what we should call "black frost"; intense cold with but a very slight precipitation of water vapour.

It is doubtful, therefore, if there can be organic life of any kind; certainly, no life so highly organized as to deserve the title of "inhabitant." But it is conceivable that there may be some low form of plant, or perhaps even of animal life, capable of coming into activity, maturing and reproducing itself within the warmer hours of a Martian day, and of passing the night in the form of spores. During the iron nights of Mars, even in the tropics, it is not possible to conceive of life existing except in embryo.

And since there is no water to flow, there can be no water-courses, natural or artificial. How is it then that Mr. Lowell and his supporters see and draw this network of lines that looks so artificial? And why is there this discordance between his observations and those of other astronomers at least as skilful and experienced, and with equipment certainly not inferior?

The "Ancient Mariner," in Coleridge's poem, describing the approach of the phantom ship to the "Wedding Guest," says:

> "At first it seemed a little speck,
> And then it seemed a mist,
> It neared and neared, and took at last
> A certain shape, I wist.
> A speck, a mist, a shape."

There could scarcely be a neater way of stating the solution of the problem. When the phantom ship was first detected on the horizon it was too far off to give any idea of form or outline. It was unmistakable that something was there, but the Ancient Mariner could see nothing but a "speck," a round dot; it was too far off to show any detail; the details were all averaged out, and it formed a minute circular spot.

And then it neared, and it was clear that it had details, but what they were the Mariner could not say; it was an ill-defined, shapeless object, "a mist." And again it neared, and then it began to take a "certain shape"; he could recognize the hull, the mast, the spars.

In 1830, the two German astronomers, Beer and Mädler, observing Mars with a telescope of 4 inches aperture, frequently drew two round spots on the planet, exactly the same size and exactly the same shape. Thirty-four years afterwards those spots were drawn by Sir Norman Lockyer with a telescope of 8 inches aperture, but neither of them was round, and they bore no resemblance to each other. A few years later Schiaparelli drew them with a telescope of 18 inches aperture, and both spots were then full of minute detail, and more unlike each other than ever. In 1909, M. Antoniadi observed both regions with a telescope of 33 inches aperture and added yet more detail and further increased their unlikeness. Now these changes in the representation of the planet are not due to any change on the planet itself. An observer coming fresh to its study and having a telescope of only 4 inches aperture, will see exactly what Beer and Mädler did under the same conditions—two round dots exactly alike. But if he carefully train himself, and increase the size of his telescope, then, granted he possesses the eyesight and skill of the astronomers I have mentioned, he will give us in succession views that practically correspond with those of Lockyer, Schiaparelli and Antoniadi. The increase in telescopic power has produced a change equivalent to the planet having "neared and neared."

A telegraph wire against the background of a dull sky can be perceived with certainty at an amazing distance, the limit being reached when the wire subtends a second of arc, or in other words when its distance from the observer is two hundred thousand times the thickness of the wire. But though this is quite unmistakable perception, it is not a defined image that is formed. If a bead be put upon the telegraph wire, the bead must be more than thirty times the breadth of the wire to be perceived, and some sixty or seventy times the breadth of the wire before it could be fully defined, so that the observer could distinguish between a bead that was square, round or any other shape, the area of its cross-section being supposed to be the same in each case. But between the limits of one second of arc and sixty seconds of arc, all minute objects, whatever their shape or discontinuity, must take on, in the observer's eye, the two simplest possible geometrical forms, the straight line and the round dot. Here, and not in any gigantic engineering works, is the explanation of the artificiality of the markings on Mars as Mr. Lowell sees them; their artificiality disappears under better seeing with more powerful telescopes.

The existence of water in the liquid state is the chief condition for habitability of a planet; and this we have seen depends upon the size and density of the planet, on the one hand, and its distance from the sun, on the other. Applying the criterion to the planet Mercury, we find that on the average it receives six and a half times as much heat from the sun as the earth does, but from its small size, its atmosphere must be rarer even than that of Mars. The range in temperature from day to night must be extreme, and water can usually only exist as vapour on the side turned to the sun, and as ice on the side turned from it. But there is little doubt that Mercury always turns the same face to the sun, even as the moon turns the same face to the earth, and this condition alone is sufficient of itself to render Mercury uninhabitable.

In the case of Venus we have a world not very much smaller than our own. The force of gravity is about seven-eighths that on the earth, and the atmospheric density probably about three-quarters. These are not important differences, and though Venus receives almost twice as much light and heat per unit of surface, it is possible that the immense amount of cloud with which its atmosphere is filled may make a sufficient screen. The probability is that ice is comparatively rare on Venus, but that its atmosphere is heavily charged with water vapour, and that its climate may not greatly differ on the average from those of certain moist climates within the torrid zone of the earth.

But the cloudy atmosphere of Venus renders it practically impossible for astronomers to be sure that they have ever seen the permanent markings of its surface, and one great question remains without any certain answer as yet. This is whether Venus, like Mercury, rotates in the same time as it revolves round the sun, or like the earth in about twenty-four hours. In the former case one hemisphere would be perpetually exposed to unendurable heat and the other to unendurable cold, and Venus would be as uninhabitable as Mercury. Yet Schiaparelli and many of our best observers are convinced that this is the condition that actually prevails. Personally I doubt if the evidence is as yet sufficient to warrant us in drawing an assured conclusion, and I am inclined to think that Venus may be rotating in much the same period as the earth. If this be so, then so far as we know, Venus may be a habitable world. Whether it is actually inhabited is a matter entirely beyond our knowledge.

The outer planets need not detain us. The spectroscope shows us distinctly that Jupiter, Saturn, Uranus, and Neptune all have a considerable amount of native heat, and our observations of Jupiter make it clear that it is still in a condition of constant commotion. Of all these four planets it is improbable that a solid crust has yet begun to form, or water to deposit in the liquid state. They may be better described as small, undeveloped suns than as great, highly developed earths. As for their satellites, though several are larger than the moon, they are all smaller than Mars, and therefore cannot come up to the standard required of a habitable world.

So in our own system we have found that there is one planet, our earth, that is inhabited, and one other that may perchance be habitable; the others may with certainty all be ruled out of court.

We have learnt more. In any system where there are planets revolving round a central sun, the range of distance from that central sun, within which a world must revolve to be habitable, is very restricted, and even within that range of distance the size and density required for that world is very restricted also. The probability, therefore, in any particular case is against a given system containing a habitable world. But systems of two suns or of more, as so many of the stellar systems are, seem quite unfitted to sustain life on their attendant planets. The conditions which would result would be far too unstable and irregular for the nurture and maintenance of living organisms.

Under the Ptolemaic theory the earth was regarded as the centre of the universe. The work of Copernicus deprived it of this pride of place, but exalted it to the rank of a heavenly body. There it seemed to be one of the smallest, most insignificant of its compeers. But I think if we have reasoned aright this afternoon we see that it has a claim to a higher distinction than size or brightness can possibly give it; it is almost certain that it is unique amongst the heavenly bodies that are visible to us, and amongst those that are unseen and unknown there can only be a small proportion, at best, so well favoured. It is the home of life, carefully fitted and prepared for that purpose by its position and its size.

That it has been built upon this scale, that it has been given this place, are not these tokens of purpose and design? And though it be little amongst the worlds, a little member of a comparatively little system, can we doubt what that design and purpose was? The Wisdom of God Who was with Him "when He prepared the heavens, when He set a compass upon the face of the depths, when He established the clouds above, when He strengthened the fountains of the deep, when He gave to the sea His decree that the waters should not pass His commandment, when He appointed the foundations of the earth," desired that, as "the Word made flesh," He might "rejoice in the habitable part of His earth, and have His delights with the sons of men."

## DISCUSSION.

The CHAIRMAN said: As regards the very much debated point of the markings on Mars, which have been called by the question-begging name of "canals," Mr. Maunder's proof that the name is due to a mistranslation of Schiaparelli's Italian word "canali" is only another instance of the influence of names over thought.

It is impossible to doubt that much of the speculation as to the nature of these markings would either never have come into existence, or would have taken an entirely different line, if they had been called simply "markings" instead of "canals."

As he tells us, the measurement of these markings shows them to be many miles in width, and thousands of miles in length; the explanation that the sharp edges of the markings show them to be channels of artificial construction must therefore be abandoned, and has been abandoned. As Mr. Maunder tells us they are now explained as "straths of vegetation springing up along the banks" of such channels. But this second explanation of the markings seems to me plainly inconsistent with the observed facts. These are that the edges of the markings are (1) sharp, and (2) parallel. But anyone who has seen, in India, cultivation carried on along the banks of channels by means of the water contained in them must have observed that the edges of such cultivation are not sharp, but very ill-defined, and are never parallel. The reasons are plain: there is always water enough for keeping the crop alive close to the bank, but as you go further back from the bank the supply of water diminishes, and it more and more frequently happens that the cultivation at the outer edges has water enough to begin with and therefore starts to grow, but as the season goes on and the water supply falls, the growth at the other edges withers and dies for want of water. In the second place, unless the supply of water at the head of the channel is absolutely uniform from year to year, the strip of cultivation is wider in a year of abundant supply and narrower in a year when the supply is smaller. But the supply of water produced by melting snow-caps at the poles of Mars is very unlikely to be absolutely uniform from year to year, and if the markings were due to cultivation (or vegetation) produced by such melting snow, we ought to see the markings vary in width from year to year. This has never been observed.

Finally, the edges of such cultivation (or vegetation) are never parallel. The reason is quite plain. Near the source of supply, at the head of the channel, the water is abundant, and owing to the fall of the ground along the banks can be carried by the necessary subsidiary channels to a great distance. As you go lower down the channel, the drawing-off of much of the water has greatly diminished the supply to start with, and the decrease in level of the point from which the subsidiary channels start greatly diminishes the distance to which the water can be got to flow along them. The consequence must be (and, as every observer can testify, actually is) that the cultivation (or vegetation) along the banks of a channel tapers down from a considerable width near the head (or source of supply) to a very narrow strip at the end of the channel where the water has all been used up above. And again, for the reason mentioned before, the length of such a strip of cultivation will vary from year to year. In a year of abundant supply the water will suffice for cultivation further down the banks of the channel than in a year of short supply, so that such a strip of cultivation will shrink, in length as well as in width, from year to year.

This also is not in accordance with the observed behaviour of the "canals" of Mars.

I think, therefore, that the explanation of these markings as a strip of cultivation (or vegetation) due to the channel water does not at all fit the observed facts.

Mr. MARTIN ROUSE said: With illustrations as ample and convincing as they were beautiful and with the very clearest logic Mr. Maunder has proved that men and animals with organization and natural functions like those we know upon the Earth cannot exist in Mars. And yet the objection arises, for what purpose have Mars and other planets been provided with satellites and other devices which must supplement the light that they receive from the sun, and perhaps equalize the heat also, and which appear to do so all the more as their distance from the sun is greater. Understanding that Mercury had a cloudier atmosphere than Venus (though to-day's lecture has rendered me a little doubtful of this), I have seen a complete and beautiful gradation thus: next to the sun comes Mercury with a very cloudy atmosphere, then Venus with a clearer atmosphere but no moon, then the Earth with a still clearer atmosphere (as we learn to-day) and with one moon, then further out Mars with a thin atmosphere (as we learn) and two moons, then far, far out Jupiter with eight moons, and then Saturn with ten moons and a vast luminous ring besides. As for Uranus and Neptune they are probably too far away and minute in appearances for astronomers to have yet discovered how many satellites or rings they may have.

Surely this supplementation of light and probably of heat also cannot have occurred by mere chance; and if the planets are not already habitable may they not have been intended to become so at a time yet future?

Mr. J. T. MATTHEWS said: I came to this meeting hoping that Mr. Maunder would tell us something about life upon other worlds, and I have been much disappointed that he has rather taken the other line, and argued that there are very few, if any, inhabited worlds other than our own. Surely all the millions of stars which the telescope shows us were not created without some purpose; may they not have planets revolving round them that we cannot see and of which we knew nothing? And of the planets in the solar system, may there not be forms of life quite unlike those with which we are familiar that would flourish under such conditions that they offer? Why should we think that water is the only liquid that can support life?

A MEMBER asked: Might not life be possible on Mars near the edge of the polar caps since, when the ice is melting, there would be abundance of water there?

Mr. SCHWARTZ said: Mr. Maunder has given us an interesting paper but I fear that he has taken a rather prejudiced view of the question. Mr. Maunder says on the first page that all men would greatly delight to be able to recognize the presence of races similar to our own upon other worlds; I rather think myself that the reverse is the case. Then, again, I think Mr. Maunder was quite unwarranted in assuming that we know all the elements that exist. Up to a very few years ago we knew nothing of helium beyond the bright line which it showed in the solar chromosphere; now it has been discovered on the Earth. Nearly one-third of the dark lines of the solar spectrum are not yet assigned to any element known to us on the Earth, and several terrestrial elements have not yet been identified in the sun.

Mr. D. HOWARD said: Mr. Maunder's paper is specially interesting as an example of accurate scientific thought applied to a question generally discussed only from a popular point of view. He has shown us exactly what the conditions must be on Mars and they certainly are incompatible with organic life.

The history of the canals is a very curious one and shows the difficulty of accurate observation even for skilled observers. I am afraid we must still be content to doubt what the markings on Mars are and still more what they are caused by, but if highly organized life is impossible on Mars they cannot be the result of the labours of Martians.

Let us always beware of "must be's." "There must be inhabitants of the planets, or if not what use are they."

That they are of use there is no doubt, but study of facts and not imagination is the only way to find out even partially what that is.

And beware of Final Causes as a basis of argument; Lord Bacon well described them as "Unfruitful Virgins."

Mr. MAUNDER, in replying, said: I am exceedingly indebted to the Meeting for the very generous reception which has been given to my paper. My purpose throughout has been to confine myself to the region of observed facts and not to enter upon vague, general and unsupported speculations. Mr. Rouse asked if the fact that the number of satellites appeared to increase as we went outwards from the sun did not look as if the outer planets were intended to be inhabited in the future, if they were not inhabited now? In reply to this it should be borne in mind that our moon was the only satellite in the solar system that was of any serious service as a light-giver. The moons of Mars would not together afford one-fourth the light, or those of Jupiter one-tenth, to their respective primaries that the moon gives to the Earth; and these satellites usually suffer total eclipse when they are at the full. It hardly looks, therefore, as if they have been designed for the purpose of supplying the deficiency of sunlight. I greatly sympathize with Mr. Howard's wise advice that we should beware of making assumptions as to the purpose of any particular structure. It reminds me very much of what Galileo wrote in his Dialogue of the "Third Day," the Dialogue which brought his condemnation. He puts into the mouth of Saviati the words, "Methinks we arrogate too much to ourselves, Simplicio, when we assume that the care of us alone is the adequate and sufficient work beyond which the Divine Wisdom and Power do nothing and dispose of nothing." And may we not look at the question from another point of view? We know that many millions of acorns fall every year, but only a very few grow up into oaks, so if, in the gradual evolution of the solar system one planet and one planet alone has been rendered fit to bear life, can we in any sense say that the material of the solar system has been wasted? Mr. Schwartz thought that I was prejudiced when I said that there was a strong and natural desire amongst men to be able to recognize the presence of similar races in other worlds; and he denied that such a desire existed. I think, however, he showed pretty clearly that he himself felt this desire, and that his real objection to my paper was that I showed that there were few facts to satisfy that desire. Mr. Matthews asked whether there might not be to many of the stars planets that we cannot see and know nothing about, and whether there might not be life upon these. Perhaps so, but as we know nothing about them we cannot discuss the conditions of life there. It was again inquired whether some liquid other than water might not form the basis of life on some other worlds. But we find water admirably fitted for its purpose on this world; and we know of no other liquid that could take its place. If some other liquid could better fulfil the functions performed by water we might reasonably ask why that liquid has not fulfilled that purpose here. Such an assumption would imply, moreover, a faulty design in the creation of the Earth. It is probable that at one portion of the year on Mars, the edge of the ice-cap is more plentifully supplied with water than any other part of the planet, but for a period longer than an entire terrestrial year that region is in total darkness and exposed to the cold of space. It is far less likely to be inhabited than the equatorial regions.

Mr. BISHOP asked: Would you tell us whether you think the other planets may be habitable in the future?

Mr. MAUNDER: That question, of course, leads us far into the unknown, but the great difficulty in the case of the outer planets is that they receive so little heat from the sun at the present time, and no way by which that heat can be greatly increased in the future is obvious to us at the present. My desire in pointing out how stringent were the conditions for life as we see them to be here, was not to call in question purpose and design in the formation of other worlds, but to emphasize the evidence that we have of purpose and design in the formation of this world.

Communication from Rev. A. IRVING, D.Sc., B.A.:—

Being unable to attend the Meeting on January 22nd, I beg to offer one or two remarks upon this very able paper. I greatly appreciate this closely reasoned paper from an expert in Astronomical Science. It is to be hoped that it may be the prelude to a more sane and sober way of dealing with matters of which we have no positive knowledge; and I think we may go entirely with the author in his conclusions as to the limits of possibility of the "habitability" (as he has defined the word) of either the innermost planet, Mercury, or the four great outer planets of our solar system, which seem to record phases of planetary development, through which (in its "pre-oceanic stage") our Earth has already passed, owing to its much smaller mass, and therefore the more rapid dissipation of its heat-energy into the "entropy" of the universe, as Clausius uses that term.

There is one point on which Mr. Maunder has not touched at any length, namely, the probable disappearance of much of the quondam hydrosphere of Mars into the lithosphere, such as Professor Federico Sacco, of Turin University, foreshadows for our future Earth, in his most interesting and instructive essay, *L'orogénie de la Terre,* which does not seem so widely known as it should be to our English astronomers and geologists.

"Life," we must recollect, is known to us on this Earth only *in its manifestations;* and we are in blank ignorance of what it is *per se;* an ignorance of which we feel the more profoundly conscious since the appearance of Professor Bergson's monumental work, *Creative Evolution.* I observe that Mr. Maunder does not attempt to dogmatize as to the limits of possibility to "Creative and Directive Power" in that direction; but in the sense in which he has defined the term "habitability," we can, I think, follow him. We do well, however, to recollect that "Creative Evolution" has the whole *duration* of eternity as well as limitless space for its operation.

There is just one little point which seems to me open to criticism in the paper, when on p. 79 the author speaks of a "man-made machine" as a "storehouse of energy." I think we can hardly say that. A contrivance it is (from the simple lever to the steam-engine or aeroplane)—a contrivance directed to certain ends for *accumulating and directing energy* (thus converting "energy" into force); but we can hardly say that the energy is stored in any permanent sense, even in the electric accumulator. We are confronted here, again, with the fundamental distinction between *organism* (in which the energy acts from within, under the vital directive action) and an *inorganic structure,* which cannot supply its own energy, even though the materials in which that energy is potentially stored may be ready to hand, as in the fuel of the steam engine, or the mineral elements of the cells of an electric battery.

It may seem ungracious to offer even this small criticism on a paper in which generally everything is so well put, and especially in the two last paragraphs, in which the author seems to be working towards a philosophical centre, from which we may be able to see the teachings of Science and Revelation in one common perspective.

Communication from SYDNEY T. KLEIN, Esq. F.L.S., etc.:—

The Institution is to be congratulated on having such an expert as Mr. Maunder to tell us the latest phase of the old controversy as to the existence of life upon the planets; there is no astronomer living who has done more in the way of popularizing the Science of Astronomy than Mr. Maunder has done, especially in his connection with the British Astronomical Association; he is indeed a worthy successor of Richard A. Proctor, and his present paper will be highly appreciated by our members. I have been much interested in the paper and especially his remarks on the planet Mars.

The writer of the paper seems to have restricted himself to the question whether the planets are inhabited *now*, he does not touch upon the larger question whether they may have been inhabited in the past or may in the future be the abode of sentient beings similar to ourselves; now this is rather an important point, especially when the argument tends, as it does in the paper, to suggest that one particular world only, namely the Earth, has been prepared by *design* to be the home of man. The planets of the solar system are *all* in different and distinct stages of what may be called growth in preparation for life, such giant and remote planets as Jupiter, Saturn, Uranus, and Neptune have not yet reached or are only just arriving at the stage of consolidation, a stage which the Earth went through probably fifty million years ago when the moon had its birth; whereas, on the other hand, Mars, Mercury and the moon, having small masses, have progressed faster and are probably in a stage well in advance of the Earth; whilst Venus, of practically the same mass as the Earth, although about one-fourth nearer to the sun, has so dense an atmosphere that her physical conditions are probably very like our own and her organic life similar to ours.

With regard to the so-called "canals" in Mars, I think Mr. Maunder was the first to point out that if you place a number of black dots on a white card and look at it from a long distance, the eye at once forms lines of those dots, and this is probably the true explanation of what Mr. Lowell claims he saw, and that it was upon these pseudo-perceptions that he made his wonderful drawings; there were certainly no such canals shown on the photographs he brought over and which many of us examined very minutely without finding any trace of his network of canals, and as pointed out by Mr. Maunder, the larger the telescopes used the less did the markings have the appearance of straight lines; the controversy certainly took a humorous turn worthy of Punch, when the advocates for the canal theory actually propounded the extraordinary theory that "many of the telescopes were too large to show such small markings."

Mr. Maunder truly points out that under certain conditions of temperature, as are found in the earlier stages of the formation of a world, the basis of living matter, as we know it, in plant and animal structures, namely protoplasm, could not exist, but he also states that among other worlds in the universe there can only be a small proportion, at best, so well favoured as our Earth for sustaining life; now we find by means of the spectroscope that each of the atoms comprising that protoplasm, namely, oxygen, hydrogen, carbon and nitrogen, are identically the same throughout the whole universe, whether we observe them here in our laboratories or when situated at the very limit of our perception, through the greatest telescopes; we also know that though each atom is continuously pulsating and clashing with others billions of times per second, they show absolutely no signs of wear or diminution in activity in a million years, for we can examine side by side two sets of say hydrogen atoms, one of which is a million years older than the other; the atoms we examine here are, in time, a million years in advance of those we examine through our astro-spectroscope, as we are seeing these latter atoms only as they were a million years ago, and yet wherever we turn to in space we find this hydrogen atom and all other atoms identical to those not only in the sun, but in our surroundings on this little Earth; we also see the same *forces* at work in the far off nebulæ as we are experiencing in this little corner. Does not this wonderful proof of unity of design throughout the whole visible universe force upon us the conviction that round each of the myriads of other stars in our star cluster, of which our sun is one, and probably round the suns in countless other star clusters, are planets in the course of preparation for sustaining life, life probably, as Mr. Maunder points out, based upon protoplasm as we know it, but possibly under conditions absolutely beyond conception from our present restricted outlook.