ESSAYS IN ASTRONOMY

The Bookpage 2002

The Rotation and Physical Constitution of the Planet Mercury and the Planet Mars

by Giovanni Virginio Schiaparelli

AMONG the older planets no one is so difficult to observe as Mercury; and none presents so many obstacles to the investigation of its orbit as well as to the study of its physical nature. With respect to the orbit it is enough to say that Mercury is the only planet whose motions it has been declared to be impossible up to the present time to subject to the laws of universal gravitation; and the theory of whose orbit, though elaborated by the sagacious mind of a Leverrier, still presents notable discrepancies with observations. As to its physical nature, very little is known, and of that little it may be said that nearly all of it rests upon observations now a century old, made at Lilienthal by the famous Schroeter. The telescopic examination of this planet is, in fact, most difficult. So close is its orbit to the sun that Mercury never appears in the sky far enough away from that great luminary to admit of its examination in complete darkness-at least not in our latitudes. Observations which are made in the period of twilight, before rising or after the setting of the sun, are rarely successful, because under such circumstances the planet is always near to the horizon, and so subject to disturbances and unequal refraction in the lowest atmospheric strata, as to present for the most part in the telescope that uncertain and flaming aspect which strikes the naked eye as a bright scintillation; for that very reason the ancients called it Stilbon, which means the scintillating. Observations fulfillment of a duty. I will first speak of the rotation of the planet, which I have found to be very different from what has been believed up to the present time, on the faith of the few and insufficient observations made a hundred years ago with imperfect telescopes. The manner and chief peculiarities of this rotation, which it has taken me many years of observation to establish, may be described in few words, by saying that Mercury revolves around the sun in a manner similar to that in which the moon revolves around the earth. As the moon describes its orbit around the earth, showing to us always very nearly the same face and the same spots, so Mercury in its orbit around the sun constantly presents to that great luminary very nearly the same hemisphere of its surface. I have said almost the same hemisphere, and not exactly the same hemisphere. Mercury, in fact, like the moon, presents the phenomenon of libration. Observing the full moon with a small telescope at very different epochs, we shall find that, in general, the same spots occupy the central region of its disk; but, studying more minutely these central spots, and the relations of their distances from the eastern border of the moon, and from the western border, we shall soon ascertain (as did Galileo, now two hundred and fifty years ago, for the first time) that they oscillate by sensible amounts, now toward the right hand and again toward the left. This phenomenon is named the libration in longitude, and arises chiefly because the point toward which the moon perpetually and almost exactly directs one of its diameters is not the centre of the earth, neither is it the centre of the lunar elliptical orbit, but that one of the two foci of that orbit which is not occupied by the earth.1. This point is called by astronomers the upper focus. To anyone stationed at this point the moon would therefore show always the same aspect. To us, who are, instead, on the average forty-two thousand kilometres distant from the point, the moon shows itself in slightly different aspects at different times, turning toward us now more of its eastern regions, now more of its western. Exactly similar is the way in which Mercury presents itself to the sun during the various phases of its revolution about that body. One of the diameters of the planet is constantly directed not toward that focus of its elliptical orbit which is occupied by the sun, but toward the other

8. Popular lecture delivered on February 7, 1854, at Konigsberg, on the occasion of Kant commemoration.

9. "Mechanical Energies of the Solar System." Note, p. 351.

twenty-four hours, an observer on Mercury would see the sun describe an arc of forty-seven degrees, with an alternating motion to and fro, upon the celestial vault; and this arc would remain always in the same position with respect to the horizon of the observer. A complete cycle of such double oscillations of the sun would last almost exactly eighty-eight terrestrial days; and according as the arc of the solar oscillatory motion aforesaid is all above the spectator's horizon, or all below that horizon, or partly above and partly below it, there would be different appearances and a different distribution of heat and of light. Accordingly, in those regions of Mercury where the arc of solar oscillation remains entirely below the local horizon, the sun will never be seen, and there will be continual darkness. In such regions, which occupy nearly three eighths of all the planet, the dense and eternal night can never be abated except by occasional sources of light, such as refraction and atmospheric twilights, by polar auroras, or similar phenomena, to which may be added the faint light afforded by the stars and planets. Another region of Mercury which also comprises three eighths of the whole surface will have the entire arc of solar oscillation above the horizon, and it will be continually exposed to the rays of the sun, with- out any variation other than that of their greater or less obliquity during the various phases of the period of eighty-eight days: for such a region no night will be possible. And, lastly there are other regions, comprising in all a fourth part of the whole planet, for which the arc of the apparent oscillation of the sun is in part above the horizon, and part below. For these places alone alternations of light and darkness will be possible. In these privileged regions the entire period of eighty-eight terrestrial days will be divided into two intervals: one all light, the other all darkness; the duration of each will be equal at certain places; in others, instead, light or darkness will prevail in greater or less degree, according to the position of the place upon the surface of Mercury, and according as a larger or smaller portion of the arc before described remains above its horizon. Upon a planet where affairs are so ordered the possibility of organic life depends upon the existence of an atmosphere capable of distributing the solar heat over different regions so as to modify the extraordinary excesses of heat and of

increase very much toward his centre, and therefore a considerably greater amount of heat than that must be supposed to have been generated if his whole mass was formed by the coalition of comparatively small bodies. On the other hand, we do not know how much heat may have been dissipated by resistance and minor impacts before the final conglomeration; but there is reason to believe that even the most rapid conglomeration that we can conceive to have probably taken place could only leave the finished globe with about half the entire heat due to the amount of potential energy of mutual gravitation exhausted. We may, therefore, accept, as a lowest estimate for the sun's initial heat, 10,000,000 times a year's supply at the present rate, but 50,000,000 or 100,000,000 as possible, In consequence of the sun's greater density in his central parts. The considerations adduced above, in this paper, regarding the sun's possible specific heat, rate of cooling, and superficial temperature, render it probable that he must have been very sensibly warmer 1,000,000 years ago than now; and, consequently, if he has existed as a luminary for 10,000,000 or 20,000,000 years, he must have radiated away considerably more than the corresponding number of times the present yearly amount of loss. It seems, therefore, on the whole most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the future, we may say, with equal certainty, that inhabitants of the earth can not continue to enjoy the light and heat essential to their life for many million years longer unless sources now unknown to us are prepared in the great storehouse of creation.

1. See "On a Universal Tendency in Nature to the Dissipation of Mechanical Energy," "Proceedings of the Royal Society of Edinburgh," April 19, 1852; or the "Philosophical Magazine," October, 1852; also "Mathematical and Physical Papers," vol. i, art. 59.

Canals on Mars

Comet of Cheseaux's 1744 - Comet of 1811

Donati's Comet Sept. 29, 1858 - Comet of July 2nd 1861 identical appearance to a person viewing them from the depths of celestial space. Concerning the nature of the surface of Mercury very little can be ascertained from the observations so far made. Thus we have to note that three eighths of its surface re- main inaccessible to the solar rays, and hence to our vision also; and there is very little hope of ever knowing anything about it with certainty. But, nevertheless, it will be easy to reach precise and certain knowledge of the portion visible to us. The dark spots, even when they are not obscured by atmospheric condensation in the manner mentioned above, appear always under the form of bands of extremely light shadings, which under ordinary circum- stances can only be observed with much difficulty and great attention. Upon more favourable occasions these shadings have a warm brown tint like sepia, which nevertheless is never greatly different from the general colour of the planet. This is usually of a light rose tint, tending toward a copper colour. It is most difficult to give a satisfactory graphic representation of such vague and diffused forms or bands specially from the want of fixity of the edges which always leaves room for a certain choice. Such indeterminate edges, however, I have reason to believe, in most cases are mere appearances arising from insufficient optical power of the instrument; because the more beautiful is the image and the more perfect the vision, the more manifest is the tendency of the shadings to dissolve into a number of minute particles. And there is no doubt that by using a more powerful telescope all would appear re- solved into minuter forms; exactly as with a simple opera-glass we may see those irregular and indistinct masses of shading which every one can see with the naked eye upon the moon resolved into much smaller parts. Considering the difficulty of making a proper study of the dark spots of Mercury, it is not easy to express a well- founded opinion on their nature. They might simply depend upon the diverse material and structure of the solid superficial strata, as we know to be the case with the moon. But if anyone, taking into account the fact that there exists an atmosphere upon Mercury capable of condensation and perhaps also of precipitation, should hold the opinion that there was something in those dark spots analogous to our seas, I do not think that a

if the whole is fluid. That is to say, the temperatures, at different distances from the centre, must be approximately those which any portion of the substance, if carried from the centre to the surface, would acquire by expansion without loss or gain of heat.

III. THE ORIGIN AND TOTAL AMOUNT OF THE SUN'S HEAT.

-The sun being, for reasons referred to above, assumed to be an incandescent liquid now losing heat, the question naturally occurs, How did this heat originate? It is certain that it can not have existed in the sun through an infinity of past time, since, as long as it has so existed, it must have been suffering dissipation, and the finiteness of the sun precludes the supposition of an infinite primitive store of heat in his body. The sun must, therefore, either have been created as an active source of heat at some time of not immeasurable , antiquity, by an overruling decree; or the heat which he has already radiated away, and that which he still possesses, must have been acquired by a natural process, following permanently established laws. Without pronouncing the former supposition to be essentially incredible, we may safely say that it is in the highest degree improbable, if we can show the latter to be not contradictory to known physical laws. And we do show this and more, by merely pointing to certain actions going on before us at present, which, if sufficiently abundant at some past time, must have given the sun heat enough to account for all we know of his past radiation and present temperature, It is not necessary at present to enter at length on details regarding the meteoric theory, which appears to have been first proposed in a definite form by Mayer, and afterward independently by Waterston; or regarding the modified hypothesis of meteoric vortices, which the writer of the present article showed to be necessary, in order that the length of the year, as known for the last 2,000 years, may not have been sensibly disturbed by the accessions which the sun's mass must have had during that period, if the heat radiated away has been always compensated by heat generated by meteoric influx, For reasons mentioned in the first part of the present article, we may now the fourth it is absolutely proved by the observations of Auwers and Engelmann. The same fact had been discovered by William Herschel in the case of Japetus, the eighth and most distant satellite of Saturn. That which would seem to be the general rule for the satellites is therefore, as exemplified in the case of Mercury, the exception among the planets. Such an exception, however, seems not without cause, and it is probably connected with the fact of Mercury's great proximity to the sun, and perhaps also with the other fact that Mercury is without satellites. In my opinion, it depends also upon the way in which Mercury was generated at the time when the solar system took its present form. The singularity of Mercury constitutes, therefore, a new document to add to those which must be considered in the study of the solar and planetary cosmogony.

A discourse delivered at the meeting of the Royal Academy of the Lincei, December 8, 1889, in the presence of the King and Queen of Italy. Translated by SARA CARR UPTON.

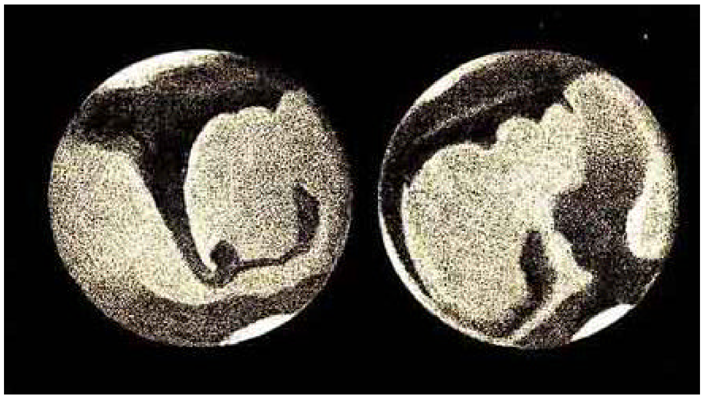
1. That is, taking no account of the slight inclination of the lunar equator with respect to the plane of its orbit, and supposing the moon's motion in this orbit to be the so-called simple elliptic motion, in which the perturbations of the true anomaly are disregarded as well as certain terms that are of the order of the square of the eccentricity.

THE PLANET MARS

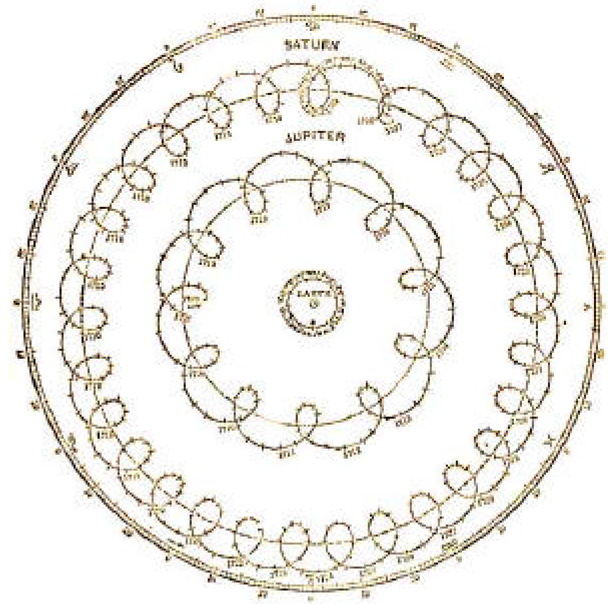
MANY of the first astronomers who studied Mars with the telescope had noted on the outline of its disk two brilliant white spots of rounded form and of variable size. In process of time it was observed that while the ordinary spots upon Mars were displaced rapidly in consequence of its daily rotation, changing in a few hours both their position and their perspective, the two white spots remained sensibly

tenth per cent of the diameter would be more or less than the equivalent of 20,000 years' heat; but we may regard it as most probably not many times more or less than this amount. Now, it is in the highest degree improbable that mechanical energy can in any case increase in a body contracting in virtue of cooling. It is certain that it really does diminish very notably in every case hitherto experimented on. It must be supposed, therefore, that the sun always radiates away in heat something more than the Joule-equivalent of the work done on his contracting mass, by mutual gravitation of its parts. Hence, in contracting by one tenth per cent in his diameter, or three tenths per cent in his bulk, the sun must give out something either more, or not greatly less, than 20,000 years' heat; and thus, even without historical evidence as to the constancy of his diameter, it seems safe to conclude that no such contraction as that calculated above (one per cent in 860 years) can have taken place in reality. It seems, on the contrary, probable that, at the present rate of radiation, a contraction of one tenth per cent in the sun's diameter could not take place in much less than 20,000. years, and scarcely possible that it could take place in less than 8,600 years. If, then, the .mean specific heat of the sun's mass, in its actual condition, is not more than ten times that of water, the expansibility in volume must be less than 1/4000 per 100^0 C. (that is to say, less than 1/10 of that of solid glass), which seems Improbable. But although from this consideration we are led to regard it as possible that the sun's specific heat is considerably more than ten times that of water (and, therefore, that his mass cools considerably less than 100^0 C. in 700 years, a conclusion which, indeed, we could scarcely avoid on simply geological grounds), the physical principles we now rest on fall to give us any reason for supposing that the sun's specific heat is more than 10,000 times that of water, because we can not say that his expansibility in volume is probably more than 1/400 per 1^0 C. , And there IS, on other grounds, very' strong reason for believing that the specific heat is really much less than 10,000. For it is almost certain that the sun's mean temperature is even now as high as 14,0000 C,; and the greatest quantity of heat that we can explain, with any probability, to have been by natural causes ever acquired by the sun these icy fields present themselves to us at a glance that occur during the summer of our own arctic regions, according to the descriptions of explorers. The southern snow, however, presents this peculiarity: The centre of its irregularly rounded figure does not coincide exactly with the pole, but is situated at another point, which is nearly always the same, and is distant from the pole about 300 kilometres (180 miles) in the direction of the Mare Erythraeum. From this we conclude that when the area of the snow is reduced to its smallest extent the south pole of Mars is uncovered, and therefore, perhaps, the problem of reaching it upon this planet is easier than upon the earth. The southern snow is in the midst of a huge dark spot, which with its branches occupies nearly one third of the whole surface of Mars, and is supposed to represent its principal ocean. Hence the analogy with our arctic and antarctic snows may be said to be complete, and especially so with the antarctic one. The mass of the northern snow cap of Mars is, on the other hand, centred almost exactly upon its pole. It is located in a region of yellow colour, which we are accustomed to consider as representing the continent of the planet. From this arises a singular phenomenon which has no analogy upon the earth. At the melting of the snows accumulated at that pole during the long night of ten months and more the liquid mass produced in that operation is diffused around the circumference of the snowy region, converting a large zone of surrounding land into a temporary sea and filling all the lower regions. This produces a gigantic inundation, which has led some observers to suppose the existence of another ocean in those parts, but which does not really exist in that place, at least as a permanent sea. We see then (the last opportunity was in 1884) the white spot of the snow surrounded by a dark zone, which follows its perimeter in its progressive diminution, upon a circumference ever more and more narrow. The outer part of this zone branches out into dark lines, which occupy all the surrounding region, and seem to be distributary canals by which the liquid mass may return to its natural position. This produces in these regions very extensive lakes, such as that designated upon the map by the name of Lacus Hyperboreus; the neighbouring interior sea called Mare Acidalium becomes more black and more conspicuous.

produce any appreciable portion of the heat radiated away, it must be supposed to come from matter circulating round the sun, within very short distances of his surface. The density of this meteoric cloud would have to be supposed so great that comets could scarcely have escaped as comets actually have escaped, showing no discoverable effects of resistance, after passing his surface within a distance equal to 1/8 of his radius. All things considered, there seems little probability in the hypothesis that solar radiation is at present compensated, to any appreciable degree, by heat generated by meteors falling in; and, as it can be shown that no chemical theory is tenable, 3. it must be concluded as most probable that the sun is at present merely an incandescent liquid mass cooling. How much he cools from year to year becomes therefore a question of very serious import, but it is one which we are at present quite unable to answer. It is true we have data on which we might plausibly found a probable estimate, and from which we might deduce, with at first sight seemingly well-founded confidence, limits, not very wide, within which the present true rate of the sun's cooling must lie. For we know, from the independent but concordant investigations of Herschel and Pouillet, that the sun radiates every year from his whole surface about 6×10^{30} (six million million million million million) times as much heat as is sufficient to raise the temperature of one pound of water by 1^0C. We also have exce1lent reason for believing that the sun's substance is very much like the earth's. Stokes's principles of solar and stellar chemistry have been for many years explained in the University of Glasgow, and it has been taught as a first result that sodium does certainly exist in the sun's atmosphere, and in the atmospheres of many of the stars, but that it is not discoverable in others. The recent application of these principles in the splendid researches of Bunsen and Kirchhof (who made an independent discovery of Stokes's theory) has demonstrated with equal certainty that there are iron and manganese, and several of our other known metals, in the sun. The specific heat of each of these substances is less than the specific heat of water, which indeed exceeds that of every other known terrestrial body, solid or liquid. It might, therefore, at first sight seem probable that the mean specific



Markings on Mars – ca 1890



Early Model of the Solar System

regions appear at times surrounding the north pole and reaching to 50^o and 55^o of latitude. They are, perhaps, transitory snows, similar to those which are observed in our latitudes. But also in the torrid zone of Mars are seen some very small white spots more or less persistent; among others one was seen by me in three consecutive oppositions (1877-1882) at the point indicated upon our chart by longitude 268^o and latitude 16^o north. Perhaps we may be permitted to imagine in this place the existence of a mountain capable of supporting extensive ice fields. The existence of such a mountain has also been suggested by some recent observers upon other grounds. As has been stated, the polar snows of Mars prove in an incontrovertible manner that this planet, like the earth, is surrounded by an atmosphere capable of transporting vapour from one place to another. These snows are, in fact, precipitations of vapour, condensed by the cold and carried with it successively. How carried with it if not by atmospheric movement? The existence of an atmosphere charged with vapour has been confirmed also by spectroscopic observations, principally those of Vogel, according to which this atmosphere must be of a composition differing little from our own, and, above all, very rich in aqueous vapour. This is a fact of the highest importance, because from it we can rightly affirm with much probability that to water and to no other liquid is due the seas of Mars and its polar snows. When this conclusion is assured beyond all doubt, another one may be derived from it of not less importance - that the temperature of the Arean climate, notwithstanding the greater distance of that planet from the sun, is of the same order as the temperature of the terrestrial one. Because, if it were true, as has been supposed by some investigators, that the temperature of Mars was on the average very low (from 50^o to 60^o below zero), it would not be possible for water vapour to be an important element in the atmosphere of that planet, nor could water be an important factor in its physical changes, but would give place to carbonic acid, or to some other liquid whose freezing point was much lower. The elements of the meteorology of Mars seem, then, to have a close analogy to those of the earth. But there are not lacking, as might be expected, causes of dissimilarity. From circumstances of the smallest

THE AGE OF THE SUN'S HEAT

by SIR WILLIAM THOMSON
(LORD KELVIN)

THE second great law of thermodynamics involves a certain principle of irreversible action in Nature. It is thus shown that, although mechanical energy is indestructible, there is a universal tendency to its dissipation, which produces gradual augmentation and diffusion of heat, cessation of motion, and exhaustion of potential energy through the material universe.[1] The result would inevitably be a state of universal rest and death, if the universe were finite and left to obey existing laws. But it is impossible to conceive a limit to the extent of matter in the universe; and therefore science points rather to an endless progress, through an endless space, of action involving the transformation of potential energy into palpable motion and thence into heat, than to a single finite mechanism, running down like a clock, and stopping forever. It is also impossible to conceive either the beginning or the continuance of life, without an overruling creative power; and, therefore, no conclusions of dynamical science regarding the future condition of the earth can be held to give dispiriting views as to the destiny of the race of intelligent beings by which it is at present inhabited. The object proposed in the present article is an application of these general principles to the discovery of probable limits to the periods of time, past and future, during which the sun can be reckoned on as a source of heat and light. The subject will be discussed under three heads:

I. The secular cooling of the sun.
II. The present temperature of the sun.
III. The origin and total amount of the sun's heat.

whitish spots, changing their position and their form rarely extending over a very wide area.. They frequent by preference a few regions, such as the Islands of the Mare Australe, and on the continents the regions designated on the map with the names of Elysium and Tempe. Their brilliancy generally diminishes and disappears at the meridian hour of the place, and is re-enforced in the morning and evening with very marked variations. It is possible that they may be layers of cloud, because the upper portions of terrestrial clouds where they are illuminated by the sun appear white. But various observations lead us to think that we are dealing rather with a thin veil of fog instead of a true nimbus cloud, carrying storms and rain. Indeed, it may be merely a temporary condensation of vapour under the form of dew or hoar frost. Accordingly, as far as we may be permitted to argue from the observed facts, the climate of Mars must resemble that of a clear day upon a high mountain. By day a very strong solar radiation, hardly mitigated at all by mist or vapour; by night a copious radiation from the soil toward celestial space, and because of that a very marked refrigeration. Hence a climate of extremes, and great changes of temperature from day to night, and from one season to an- other. And as on the earth at altitudes of 5,000 and 6,000 metres (17,000 to 20,000 feet) the vapour of the atmosphere is condensed only into the solid form, producing those whitish masses of suspended crystals which we call cirrus clouds, so in the atmosphere of Mars it would be rarely possible (or would even be impossible) to find collections of cloud capable of producing rain of any consequence. The variation of the temperature from one season to another would be notably increased by their long duration, and thus we can understand the great freezing and melting of the snow, which is renewed in turn at the poles at each complete revolution of the planet around the sun. As our chart demonstrates, in its general topography Mars does not present any analogy with the earth. A third of its surface is occupied by the great Mare Australe, which is strewn with many islands, and the continents are cut up by gulfs and ramifications of various forms. To the general water system belongs an entire series of small internal seas, of which the Hadriacum and the Tyrrhenum communicate with it by wide mouths,

their orbits tended to support his hypothesis. It has, however, since been discarded by nearly all the highest authorities in astronomy, to the regret, no doubt, of those whom the idea of any celestial catastrophe seems to fascinate, whether it be the possible collision of two suns, the destruction of the earth by a comet, or the blowing of a planet into pieces by its own inherent forces. Even if such an event could have occurred, and have produced the minor planets, it' must have been at an exceedingly remote epoch; otherwise, by the laws of mechanics every fragment would have continued, once in each of its subsequent revolutions round the sun, to pass again and again through the point of explosion. Millions of years would have been required to enable the mutual perturbing attractions of the fragments upon each other so to change their orbits as to have effaced all trace of the point where the catastrophe took place. Apart, however, from this, and apart from the fact that it is difficult to conceive how the orbits could have been spread over seven eighths of the vast interval which separates those of Mars and Jupiter, apart also from the great extension of the region in which they move which is involved in the newly found orbit of Eros, another argument against the hypothesis seems to be conclusive. It appears impossible to conceive of such an amount of explosive energy in any globe as should not only hurl away a number of ejected portions in the directions and with the velocities which would produce such widely differing or- bits, but such as should break up and suitably project the whole mass of the globe, leaving no fragment of any importance unprojected. A cannon-ball, as Proctor has remarked in his "Old and New Astronomy," "might be driven by a certain charge of gunpowder to a distance of two or three miles, but a thousand times that charge would not scatter the fragments of the cannon (if the ball had been tightly driven in) over a similar distance all round the place of explosion. Nothing known about our earth's interior, nothing which we can infer about the interior of any other planet formed by processes such as we recognise in the development of the solar system as at present understood, suggests the possibility that a millionth part of the force necessary to shatter a planet, as Olbers's theory requires, can ever be generated or accumulated within the continents, and are sometimes clothed in brown (even black in certain cases), and assume the appearance of seas, while in other cases their colour is intermediate in tint, and leaves us in doubt t to which class of regions they may belong. Thus all the It islands scattered through the Mare Australe and the Mare Erythraeum belong to this category; so too the long peninsula called Deucalionis Regio and Pyrrhre Regio, and in the vicinity of the Mare Acidalium the regions designated by the names of Baltia and Nerigos. The most natural idea, and the one to which we should be led by analogy, is to suppose these regions to represent huge swamps, in which the variation in depth of the water produces the diversity of colours. Yellow would predominate in those parts where the depth of the liquid layer was reduced to little or nothing, and brown, more or less dark, in those places where the water was sufficiently deep to absorb more light and to render the bottom more or less invisible. That the water of the sea, or any other deep and transparent water, seen from above, appears more dark the greater the depth of the liquid stratum, and that the land in comparison with it appears bright under the solar illumination, is known and confirmed by certain physical reasons. The traveller in the Alps often has occasion to convince himself of it, seeing from the summits the deep lakes with which the region is strewn extending under his feet as black as ink, while in contrast with them even the blackest rocks illumined by the sunlight appeared brilliant. 1. Not without reason, then, have we hitherto attributed to the dark spots of Mars the part of seas, and that of continents to the reddish areas which occupy nearly two thirds of all the planet, and we shall find later other reasons which confirm this method of reasoning. The continents form in the northern hemisphere a nearly continuous mass, the only important exception being the great lake called the Mare Acidalium, of which the extent may vary according to the time, and which is connected in some way with the inundations which we have said were produced by the melting of the snow surrounding the north pole. To the system of the Mare Acidalium undoubtedly belong the temporary lake called Lacus Hyperboreus and the Lacus Niliacus. This last is ordinarily separated from the Mare Acidalium by means of an isthmus or regular dam, of which

has hitherto been secured. It is very fortunate that Eros, when at its nearest approach to the sun, is also almost in the plane of the earth's orbit. If the earth is at the same time in the corresponding part of its own orbit, the planet's approximation to the earth is consequently in nowise hindered by its being elevated above, or depressed below, the earth's orbit. But the two are only simultaneously in these positions once in about every thirty years, and it is very unfortunate that an exceedingly favourable concurrence of such positions occurred in January, 1894, so that the next occasion will not be until January, 1924. In the latter part, however, of 1900, and in the beginning of 1901, the earth and Eros will come within about 31,000,000 miles, and this, their nearest approach to one another before the year 1924, will enable observations of much importance to be made, which ought to suffice for a decided improvement in the accuracy of our present estimate of the distance of the sun. A few further statements with reference to this very remarkable planet may be of interest. Its mean distance from the sun is 5,500,000 miles less than that of Mars. That distance ranks, therefore, not with those of all the other little planets as between that of Mars and that of Jupiter, but as between the earth's and that of Mars. Owing, how- ever, to the ovalness of its orbit, it passes in one part of its circuit about 11,000,000 miles beyond the maximum distance of Mars, which is, nevertheless, a comparatively slight excess. Its period of revolution around the sun is 643 days, that of Mars being 687. There is no fear of its ever colliding with Mars, because the two orbits, where they would otherwise intersect, are separated by an interval of about 21,000,000 miles, owing to the difference of their tilts, or inclinations to the ecliptic. Besides its great usefulness for the purpose already explained, the perturbations of its motion by the earth's at- traction will afford another indirect and theoretically very interesting method of determining the distance of the sun, by its enabling a comparison to be made between the masses of the earth and the sun. The perturbations of the motion of Eros by Mars will, in addition, be very valuable to astronomers. Certain recondite effects of its proximity in reference to the moon may also prove to be important. The great alterations in its distance from the earth at different times will afford most cases happen apparently capriciously, or at least according to laws not sufficiently simple for us to be able to unravel. Often one or more become indistinct, or even wholly invisible, while others in their vicinity increase to the point of becoming conspicuous even in telescopes of moderate power. The first of our maps shows all those that have been seen in a long series of observations. This does not at all correspond to the appearance of Mars at any g1ven period, because generally only a few are visible at once. 2. Every canal (for now we shall so call them) opens its ends either into a sea, or into a lake, or into another canal, or else into the intersection of several other canals. None of them have yet been seen cut off in the middle of the continent, remaining without beginning or without end. This fact is of the highest importance. The canals may intersect among themselves at all possible angles, but by preference they converge toward the small spots to which we have given the name of lakes. For example, seven are seen to converge in Lacus Phoenicis, eight in Trivium Charontis, six in Lunae Lacus, and six in Ismenius Lacus. The normal appearance of a canal is that of a nearly uniform stripe, black, or at least of a dark colour, similar to that of the seas, in which the regularity of its general course does not exclude small variations in its breadth and small sinuosities in its two sides. Often it happens that such a dark line opening out upon the sea is enlarged into the form of a trumpet, forming a huge bay, similar to the estuaries of certain terrestrial streams. The Margaritifer Sinus, the Aonius Sinus, the Aurorae Sinus, and the two horns of the Sabaeus Sinus are thus formed, at the mouths of one or more canals, opening into the Mare Erythraeum or into the Mare Australe. The largest example of such a gulf is the Syrtis Major, formed by the vast mouth of the Nilosyrtis, so called. This gulf is not less that 1,800 kilometres (1,100 miles) in breadth, and attains nearly the same depth in a longitudinal direction. Its surface is little less than that of the Bay of Bengal. In this case we see clearly the dark surface of the sea continued without apparent interruption into that of the canal. Inasmuch as the surfaces called seas are truly a liquid expanse, we can not doubt that the canals are a simple prolongation of them, crossing the yellow areas or continents. Of the remainder, that the

But the glare of the sun's light, the ill-defined edge of the sun's disk, and the atmosphere of Venus itself, combine to deprive such observations of the necessary accuracy. Apart from some other methods, involving long periods of time and highly complicated theoretical investigations in their use, attention was therefore next given to an attempt to obtain the distance of the planet Mars when it makes its nearest approaches to the earth. It was, however, found to be difficult to measure the exact position of the centre of its disk. Whereupon it was suggested that some of the nearer minor planets, although they would be farther from the earth, and their distance from it proportionately more difficult to determine, might more than compensate for this disadvantage by the great accuracy with which the positions of their starlike telescopic images might be observed. And this was found to be the case. The most accurate value of the sun's distance known at the present time is believed to be that which has been skillfully deduced In this way from observations of certain of the nearer minor planets by Dr. Gill, H. M. Astronomer at the Cape of Good Hope. The new planet, Eros, is of the utmost value for such observations, because the accuracy of the result which they afford is proportionate to the nearness to the earth of the planet that is observed. The method of calculation employed depends upon the ratio of the planet's distance to the distance between two observers simultaneously looking at it from two widely separated points upon the earth's surface, or to the distance through which an observer may himself be moved, by the rotation of the earth upon its axis, between two observations made, the one soon after sunset, and the other shortly before sunrise. The movements of the earth and the planet in their orbits in the interval (as also if in the first case the two observations made are not exactly simultaneous) can be allowed for, and will not affect the final result. An observer may be moved between such an evening and early-morning observation when this latter (termed the diurnal) method is employed, provided he be near to the equator, to a position which may be separated by about 7,000 miles, supposed- to be measured in a straight line drawn through the earth, from his previous place. The effect would be the same in low or is even entirely dried up. Then, in place of the canals there remains either nothing or at most stripes of yellowish colour differing little from the surrounding background. Sometimes they take on a nebulous appearance, for which at present it is not possible to assign a reason. At other times true enlargements are produced, expanding to 100, 200, or more kilometres (60 to 120 miles) in breadth, and this sometimes happens for canals very far from the north pole, according to laws which are unknown. This occurred in Hydaspes in 1864, in Simois in 1879, in Ackeron in 1884, and in Triton in 1888. The diligent and minute study of the transformations of each canal may lead later to a knowledge of the causes of these effects. But the most surprising phenomenon pertaining to the canals of Mars is their gemination, which seems to occur principally in the months which precede and in those which follow the great northern inundation-at about the times of the equinoxes. In consequence of a rapid process, which certainly lasts at most a few days, or even perhaps only a few hours, and of which it has not yet been possible to determine the particulars with certainty, a given canal changes its appearance and is found transformed through all its length into two lines or uniform stripes more or less parallel to one another, and which run straight and equal with the exact geometrical precision of the two rails of a railroad. But this exact course is the only point of resemblance with the rails, because in dimensions there is no comparison possible, as it is easy to imagine. The two lines follow very nearly the direction of the original canal and end m the place where it ended. One of these is often superposed as exactly as possible upon the former line, the other being drawn anew; but in this case the original line loses all the small irregularities and curvature that it may have originally possessed. But it also happens that both the lines may occupy opposite sides of the former canal and be located upon entirely new ground. The distance between the two lines differs in different geminations and varies from 600 kilometres (360 miles) and more down to the smallest limit at which two lines may appear separated in large visual telescopes-less than an interval of 50 kilometres (30 miles). The breadth of the stripes themselves may range from the limit of visibility, which we may suppose to be 30 kilometres (18

dots (the effect of the rotatory motion of the earth having been duly compensated); the planet left its trail in a little straight line drawn by it in the direction of its motion. In the next year Max Wolf found thirteen more, and in the same year Charlois ten, by this new method. And since the early part of 1892, out of one hundred discoveries or such planets, only three or four have been made by the old method of eye observation. Once more, however, the great abundance of these photographic discoveries of planet after planet began to make astronomers despair of the possibility of so keeping count of their orbits and positions as to be able to determine whether the little trails, of which several were sometimes found upon the same photographic plate, indicated the presence of planets previously seen or hitherto unknown. It would, indeed, have been quite impossible to do so had it not been for the unremitting industry of German computers, as evidenced year by year in the " Berliner Jahrbuch." These little bodies were even termed astronomical nuisances. But one of them-the 433d-has at last proved to be a great astronomical treasure. It has proved that it would have been most unwise to have neglected any of these minute portions of our solar system. Some-e. g., Hilda (No. 153), Thule (No. 279), and one which is still unnamed (No. 361)-approach so near to the orbit of Jupiter that they will be of much use in the accurate determination of that great planet's mass. Others are of especial interest in the comparison of their very oval orbits with those of certain periodic comets. But by far the most important are those whose orbits lie nearest to that of the earth. Only three or four, however, such as Aethra (No. 132), Brucia (No. 323), and Ingeborg (No. 391), have hitherto been found which approach the earth, even to a very moderate extent, within the distance of that part of the somewhat oval orbit of Mars in which he is at his farthest from the sun; and they do so only in a small portion of their orbits. But in the case of Eros we meet with something utterly different and unexpected. A new planet has been discovered whose average distance from the sun is less than that of Mars; a planet which at times comes within a distance from the earth not much more than one third of the nearest distance within which Mars ever approaches it. On the 13th of August, 1898, Herr Witt exposed a photographic why it is that it was not seen before 1882. In the ten years that have transpired since that time it has been seen and described at eight or ten observatories. Nevertheless, some still deny that these phenomena are real, and tax with illusion (or even imposture) those who declare that they have observed it. Their singular aspect, and their being drawn with absolute geometrical precision, as if they were the work of rule or compass, have led some to see in them the work of intelligent beings, inhabitants of the planet. I am very [. careful not to combat this supposition, which includes . nothing impossible. (Io mi guardero bene dal combattere questa supposizione, la quale nulla include d' impossibile.) But it will be noticed that in any case the gemination can not be a work of permanent character, it being certain that in a given instance it may change its appearance and dimensions from one season to another. If we should assume such a work, a certain variability would not be excluded from it; for example, extensive agricultural labour and irrigation upon a large scale. Let us add, further, that the intervention of intelligent beings might explain the geometrical appearance of the gemination, but it is not at all necessary for such a purpose. The geometry of Nature is manifested in many other facts from which are excluded the idea of any artificial labour whatever. The perfect spheroids of the heavenly bodies and the ,ring of Saturn were not constructed in a turning lathe, and not with com- passes has Iris described within the clouds her beautiful and regular arch. And what shall we say of the infinite variety of those exquisite and regular polyhedrons in which the world of crystals is so rich? In the organic world, also is not that geometry most wonderful which presides over the distribution of the foliage upon certain plants, which orders the nearly symmetrical, starlike figures of the flowers of the field, as well as of the animals of the sea, and which produces in the shell such an exquisite conical spiral that excels the most beautiful masterpieces of Gothic architecture? In all these objects the geometrical form is the simple and necessary consequence of the principles and laws which govern the physical and physiological world. That these principles and these laws are but an indication of a higher intelligent Power we may admit, but this has nothing to do

home of life. In theorizing on this point we have no past experience or history to guide us. We shall see as we go on to discuss the stellar systems that we have at least one case, perhaps more than one, of a body sunlike in dimensions, which has either ceased to give light or never gave it. It is only in exceptional cases that we have any means of recognising the existence of such bodies; they may be very numerous. Neither can we tell whether the other innumerable brilliant suns scattered through space have attendant planets like our own. But it would be strange if they had not. If any considerable proportion of them have, evidently the chance that there are other habitable worlds in the universe becomes very great.

A lecture delivered before the Catholic University of America.

THE NEW PLANET, EROS

by EDMUND LEDGER

ON the 13th of August, 1898, a little planet was discovered at the Urania Observatory of Berlin by Herr G. Witt, to which he has since given the name of Eros. Its discovery has been the great astronomical sensation of the past twelve months, because its orbit passes out of the zone in which all the other small planets move into a very remarkable proximity to the earth a proximity which will cause Eros to be of the highest value in connection with some of the most arbitrary all explanations of this sort and constitutes the gravest obstacle to the acquisition of well-founded notions. All that we may hope is that with time the uncertainty of the problem will gradually diminish, demonstrating if not what the geminations are, at least what they can not be. We may also confide a little in what Galileo called "the courtesy of Nature," thanks to which a ray of light from an unexpected source will sometimes illuminate an investigation at first believed inaccessible to our speculations, and of which we have a beautiful example in celestial chemistry. Let us therefore hope and study.

From “Natura ed Arte”. February 15, 1893. Translated by WILLIAM H. PICKERING.

1. This observation of the dark colour which deep water exhibits when seen from above is found already noted by the first author of antique memory, for in the "Iliad " (verses 770, 771 of book v) it is described how" the sentinel from the high sentry box extends his glance over the wine-coloured sea." In the version of Monti the adjective indicating the colour is lost.

2. In a footnote the author refers to a drawing of Mars made by himself, September 15, 1892, and says: ". ..At the top of the disk the Mare Erythraeum and the Mare Australe appear divided by a great curved peninsula, shaped like a sickle, producing an unusual appearance in the area called Deucalionis Regio, which was prolonged that year so as to reach the islands of Noachis and Argyre. This region forms with them a continuous whole, but with faint traces of separation occurring here and there in a length of nearly six thousand kilometres (four thousand miles). Its colour, much less brilliant than that of the continents, was a mixture of their yellow with the brownish gray of the neighbouring seas." The interesting feature of this note is the remark that it was an unusual appearance,

Mars, the most habitable in appearance of them all. As a rule, of course, the smaller a planet is, other things being equal, the more rapidly it will cool from its originally incandescent state; Mars then should be older-that is, have passed through more of its successive changes-than we. It looks so, besides. The seas seem to be drying up, the air thinning away. On the other hand, the great superior planets, Jupiter, Saturn, Uranus, and Neptune are young, and have the best part of their life before them. What portion of the total life of a planet is that in which it becomes habitable by beings like ourselves we can not very well determine. If we accept the estimates of geology, the time that the human race has been here is a very small part of our world's history. But how much longer this earth would naturally remain a possible residence for us we can not say with accuracy. It would seem probable, however, that the period in which all the necessary conditions of life would simultaneously exist cab hardly be a very considerable part of the whole. The in- habitants of a planet in the stage of decadence from its most perfect state could, no doubt, on the principle of the "survival of the fittest," accommodate themselves to their more unfavourable circumstances for a good while; but the time would come when the struggle would have to be abandoned. If it is true that- the period of habitability by the high organisms is a small part of a planet's life, obviously the chance is small for any planet in particular of its being in that period now or at any particular time. We must say that it probably is not, unless we have, as in the case of Mars, some positive indications that it is. So far as we can trust such positive indications, Venus and Mercury are approaching that part of their life that the earth is in at present; the earth seems at one time to have had the very dense and vaporous atmosphere that apparently surrounds them now. To sum up now, briefly, the results to which our examination has led us: In the first place, our observations should probably be modified by the very plausible theory, now generally adopted, that all the bodies of our system, sun and planets, have passed and are passing through a series of changes, beginning with a state of great heat and expansion, in which and for a long time no life is possible on their surfaces, and in a great part of which indeed, as in the case of the sun at present, they can hardly be the naked eye, undergoes great variations, because the distance of the planet from the earth (an element upon which his apparent lustre almost wholly depends) is not the same at each successive opposition. Thus it happens that when Mars is near the earth and sun (or in perigee and perihelion) which occurs once in four synodical revolutions, equivalent to above eight and a half years, he shines with remarkable intensity, and sometimes rivals the brilliancy of Jupiter. It is, however, only at epochs of about fifteen years that the planet is observed shining with his maximum lustre, and very well situated for examination in a telescope. In 1845, 1862, and in 1877, Mars was seen under peculiarly favourable circumstances, and in 1892 the conditions will recur again. At his apparition in 1719 he shone with such striking grandeur as to cause great alarm among the peasantry of France, who discerned all sorts of ill-omens in the fiery-red light he cast upon them. This planet was justly celebrated during the historic period on account of his imposing appearance in the heavens. Figures 1. and 2. The Markings on Mars. To the Jews he was familiarly known under a title analogous to "blazing," and the Greeks gave him a similar appellation in -- . Yet Mars is not comparable with Venus in point of brilliancy, and is very seldom as conspicuous as Jupiter. At his last favourable appearance in 1877 (which was one of the most noteworthy on record, being signalised by the discovery of his two satellites), the planet could be well compared with Jupiter visible at the same period in the evening sky, but there could be no doubt that the jovian planet surpassed his rival. We can, however, readily understand that in past ages Mars, with his intense blood-red lustre, would be certain to attract much notice, and instil dread into the popular mind. By means of the telescope astronomers have been enabled to distinguish varieties of light and shade upon the surface of Mars. There are certain permanent markings of irregular outline invariably visible every time the planet becomes conveniently placed for observation. That these lineaments are something more than mere atmospheric appearances is evident beyond doubt by their constancy. No matter how great the difference of time at which they are examined, they are seen to retain the same forms, in fact, the same identical features are manifested again and again, though, of course,

the earth, in spite of its greater distance from the sun. As to Venus and Mercury, we can hardly form any decided opinion. They seem to be surrounded by dense, cloudy atmospheres, which may tend, in a great measure, " to keep off the intense heat of the sun. A rather singular thing has lately been observed, or at least thought to be observed, by Schiaparelli, with regard to Mercury-that is, that some markings on it seem to indicate that its period of rotation round its axis is the same as that of its revolution round the sun; or, in other words, that it acts as our moon does, keeping always the same face toward the centre round which it revolves. This would seem to be borne out by the white spot on the black disk of the planet, which has been reported by various observers as regularly visible at the time of its transits across the sun's face. If this white spot is a real object, it would seem that it is always turned away from the sun. If this can be accepted, it would be, of course, to some extent, an argument against the habitability of Mercury, as its inhabitants would be deprived of the vicissitude of day and night, and the side turned constantly toward the sun would probably, in spite of everything, become uncomfortably warm. Now that we have-though quite hurriedly-completed our consideration of the planets as to their suitableness for habitation, what answer shall we give to the question with which we started? Before giving it, another reflection must be made, which will brighten the prospect a good deal for those who would fain believe all these magnificent orbs to be the abode of life like ours. It is this: Will it not suffice to satisfy the minds of those who can not believe that these great globes, similar in so many respects to ours, can be tenantless, to hold that they are habited for a portion, though not for the whole, of their history? For myself, I do not feel the craving for the plurality of worlds, as it is called, which seems to be general. I must confess that I have never been able, personally, to feel the force of the argument which strikes most minds so powerfully, that these habitations could not have been made by their Creator except to be actually inhabited. The mere size and mass of an object seem to me to amount to little. Jupiter itself, or Saturn, with its beautiful ring and satellite system, simply as a mass of matter or a mechanical construction, is a far less noble creation of God than a single human water. The brighter regions of the surface are orange-coloured; the darker spaces, which vary a good deal in depth of shading, are greenish, possessing the aspect of a fluid by which the sun's rays are absorbed. Hence, it is to be inferred that the latter parts represent seas and the former land. If this is so there is considerably more land than water in Mars. The form and distribution of his chief features have been carefully mapped, and that they might be conveniently referred to, have received distinctive titles, so that we are enabled to refer to them with the same aptitude as we may refer to the features of the earth on a terrestrial globe. The names of eminent astronomers have been selected as the most suitable titles to the Martian continents and seas, and we are getting familiar with "Dawes Ocean," "Kaiser Sea," "Madler Continent," and the other conspicuous parts of his surface. But the most remarkable details revealed by our telescopes consist of two white markings, one at each pole. A number of observations of these singular appearances lead to the supposition that they are masses of snow or ice accumulated in the polar regions of the planet. This theory of their origin is strikingly supported by observation, for it has been found that under the sun's powerful action, in the summer months of Mars, the polar snows diminish in extent, while during the progress of winter they again become augmented. In fact, the variations assigned to these objects occur at such periods and in such positions as accord exactly with the accepted theory of their nature, They were first seen and figured as early as 1704, but they had probably been detected at a much anterior date, for such prominent objects could not long evade the scrutiny of the telescope. A very singular though well-attested foot in connection with them is that they are not exactly opposite to each other. This apparent anomaly is not readily explained, though it has been suggested that on Mars, as on the earth, the poles of cold do not correspond with the poles of rotation. The southern snow region, as observed and delineated on September 8th, 1877, at 12.30 p.m., is shown in Fig. 3. The two white spots on the western side have been named the Mitchel Mountains, the inference being that they are the snow-crowned summits of lofty elevations situated just outside the polar snow-space. Fig. 3. South Pole of Mars. In the views of the latter

speaking. I think few, if any, astronomers believe them to be habitable in their present condition; for, though the case is more doubtful for Uranus and Neptune, still they have, in their general features, so much resemblance to Jupiter and Saturn, that it is usually presumed that they are in the same state. But no one could pretend to be certain with regard to the matter. Before we leave this portion of our system, however, we lust not omit a part of it which is eminently worth considering with reference to the present question. I mean the numerous satellites, which are such a striking feature in it. Let us consider specially those of Jupiter, about which we know the most. The four moons of Jupiter are all quite considerable bodies, ranging in size from that of our moon to that of the planet Mars. There is plenty of room on them for a very large population; the surface of the largest does not fall far short of that of the land part of our own globe. There is no reason why they should not be in the same general physical state as the earth is; we have already seen that, as far as light and neat are concerned, they may be considered as amply provided; perhaps, indeed, even better than we; for the great planet itself, round which they circulate, would probably serve as a much better luminary by night than our own moon, and may very probably contribute not a little to keeping them comfortably warm, if it is indeed still in a melted and glowing condition. We may well believe that it is indeed a second sun to them, and if the satellites of Jupiter keep, like our own moon, the same side always turned toward the primary planet, that favoured side would enjoy a continual warmth, which might indeed be excessive. Similar remarks may, of course, be made of all the other satellites which we find in this great region, revolving round Saturn, Uranus, and Neptune. Much has been said of the splendour of the Saturnian sky as seen from the planet itself, with the great ring arching over the heavens and the satellites circling along it. It is far more likely that, if this splendour is seen at all, it is from the satellites, from which, especially from Japetus, the most remote, whose orbit lies outside of the plane of the ring, a most magnificent view of the noble planet, with its rings and the other satellites, could be had. Saturn from Japetus would look as it does to us with a magnifying power of about three hundred and fifty notable fact that the colour never affects the snow masses at the poles, which invariably present a dazzling whiteness. But it would appear that there are no clouds of any intensity and extent upon the surface of Mars, because his chief markings are always easily identified Certainly, in the equatorial region of the planet no really dense clouds have ever made themselves evident. The opacity of our terrestrial atmosphere is such, that remarkable differences must be observable in our appearance as viewed from Mars. Tracts of land will be utterly hidden from view, and the constantly varying forms of cloud phenomena will be interesting to witness and difficult to account for. Above the surface of Mars, however, there are no cloud masses to obliterate the outline of his land and sea, though an atmosphere and its modifications are necessary to the existence of the snow patches and other features supposed to be common to his globe. But there is evidence to show that occasionally certain parts of the planet are rendered faint, and, indeed, a few instances are recorded in which the features were entirely obscured, On September 29th, 1877, at 9h. Mr. Green, at Madeira, saw the outline of the De la Rue Ocean on Mars hidden by cloud on the planet. On September 18th there were manifest signs of the breaking up of the snow-zone around the south pole, and its great indistinctness at this epoch was especially noted by several observers. And in 1877 and 1862 portions of Dawes Ocean were sometimes hidden by a light not constantly hanging over that region of the surface. Occasionally, too, white patches have been glimpsed on the margin of the disc chiefly on the eastern side, and as these objects remained upon the limb the inference is, that they were exterior to the surface and originated by masses of cumulus clouds or mists upon the planet. But to be thus observable their volume must be very considerable, and far beyond the extent and character of what we have been led to understand of the atmosphere of Mars, It was by means of the spots observed on this planet that his period of rotation became an element easy of determination. On the morning of February 6th, 1666, the astronomer Cassini, surveying Mars through a telescope sixteen feet long, was astonished to behold two dusky spots on his disc. He looked for them again on subsequent nights, and his diligence was rewarded by their re-appearance. Noting their

vision in detail; but still an inhabitant of Neptune might have a good deal larger pupil than ours in proportion to the size of his eye than ours. And then, again, there is no reason why the retina itself should not be made much more sensitive to light than ours; and here we have an increase which has no limit, so far as we can tell. It would be an injury to us to have our optic nerve more sensitive; the strong sunlight to which we are exposed would hurt us. But there is no reason why the Neptunians should not have what would be a benefit to them. The whole question, then, of light in the solar system is one of little consequence; eyes could easily in any planet be such as to suit the exigencies of the case. With regard to heat, the question is a little more difficult, but not very much. If we should assume that the 500° Fahrenheit by which our temperature here is raised above that of space are simply due to our distance from the sun, and that Neptune could only have one nine-hundredth part of that, of course the temperature there would practically be that of space itself, or 460° below the Fahrenheit zero. But we know that, in fact, the genial warmth of the earth is in a great measure due to its atmospheric garment or blanket; and we can not be at all sure that an atmosphere may not exist on Neptune which may make the absorption so much greater than the radiation that an equality between the two would not be reached before the planet had accumulated from its scanty solar supply enough to make its temperature equal to ours. And, besides, there is no certainty that these great outer planets may not still retain a great deal of their own intrinsic heat; that they may yet be warm enough, even on the surface, to act as a source of heat to their inhabitants. Indeed, the danger here is rather that they are too hot than too cold. Yes, that is the trouble with all the great outer planets, with Jupiter and Saturn, as well as Uranus and Neptune, as we shall shortly see. As far as atmosphere is concerned, the spectroscope would indicate rather a dense one on both Uranus and Neptune, and of the same character on each. Uranus shows belts on its surface similar to those seen on Jupiter; but we can not be sure that this indicates a similar constitution in the two planets. On the whole, we may say that there is quite what we may call a probability that Uranus and Neptune are in a habitable condition; the probability is, that object in view: These failures brought discouragement. Evidently an increase in telescopic power was needed, or what was of equal importance, a very favourable position of Mars must be awaited, before the discovery of his moons could be looked upon as feasible. Now it was known that in 1877 the planet would be singularly well placed for such observations, and Professor Hall, of the Naval Observatory at Washington, having a very fine refracting telescope of twenty-six inches aperture under his direction, resolved to make renewed search for the suspected satellites, though at the very outset he confessed to a want of confidence as to success. Looking at the mass of negative results obtained by skilful astronomers in the past (especially by Sir W. Herschel in 1783, and D'Arrest in 1862 or 1864) he had little hope of the realisation of his desires. Nevertheless, the search was begun early in August, 1877, and several small stars of the ordinary character were seen near the planet. On August 10th, Professor Hall commenced to look in the region close around Mars, and enveloped in the glare of his light, but nothing was found. The next night observations were resumed, and he ultimately detected a very faint object, which afterwards turned out to be a satellite of the planet, but before he could secure a note of its position, a fog gathered up from the Potomac River and over-spread the sky; but on August 16th the satellite was recovered again, and on the ensuing night, while watching and waiting for its re-appearance, another yet fainter satellite was discovered, and the true character of the two objects being placed beyond doubt by further diligent observation, the facts of the discovery were announced to the scientific world. The names selected for the new bodies were Deimos (Terror) for the outer satellite, and Phobos (Fear) for the inner satellite. They are remarkably close to the planet, and revolve in very short periodic times. Thus Deimos is 14,500 miles distant from the centre of Mars, and revolves around him in 30 hours 18 minutes; and Phobos, at a distance of 5,800 miles, revolves in 7 hours 39 minutes. The latter moon was at first a complete puzzle to its discoverer, for it would appear on different sides of its primary during the same night, and at first he thought there were two or three inner moons. To settle the matter, he followed this moon throughout the whole nights of

know that such a place as this empty space is not " habitable." From the consideration of the sun we will pass to that of the next most conspicuous object to us in the planetary system-that is to say, the moon. I have already expressed in a previous lecture the views generally entertained by astronomers about the moon. It is pretty certain that the side of it which we see offers nothing in the way of a convenience of life except mere standing-room. There is hardly a doubt that its surface consists simply of bare rock, unvaried by water, soil, or any kind of vegetation; that if there be any atmosphere upon it, it is so excessively rarefied as to be, for purposes of life, practically equivalent to none. As to the other side, of course, we can say nothing positively. It may perhaps in some way be different from this. But taking the ordinary and (to say the least) very probable view as to the method of formation of the planetary, masses, by cooling from a liquid condition, it is hard to see how there could possibly be any considerable difference of shape or of density between the half of the lunar sphere which is turned toward us and that which is turned. And unless there be such a difference, the other side must be as destitute of atmosphere as this; and if of atmosphere, of water as well; for the water or other fluid, if existing in any quantity, would form an atmosphere, if none previously existed. The moon then hardly seems to present the condition required for what we should call a habitable planet; though it fails in a very different way from the sun. The moon is dead; the sun is too much alive. The moon may have been habitable and inhabited once; the sun may be in the future. So far, our survey has not been very encouraging. But we have not yet considered the planets properly so called. In considering them from this point of view, let us proceed in the contrary order to that which we followed in describing them in detail. Let us start at the outer limit, with the great twin planets, as we may call them, on account of their great similarity, widely separated in space as they are-namely, Uranus and Neptune. These would perhaps generally be imagined as very cheerless habitations for intelligent beings, on account of their distance from the sun, and the comparatively small amount of light and heat which that great central fire sends to them, if that which the earth receives be taken as the standard. Particularly round numbers, about 139,000,000 miles. Owing to the eccentricity of the planet's orbit, the distance varies between 152,000,000 and 126,000,000 miles. In Fig. 6, if s represents the position of the sun, and E 1, E 2, E 3, and E 4 the earth's orbit, then M 1, M 2, M 3, M 4, is the relative distance of Mars. At m the planet is in perihelion, and at m' in aphelion. Now when the planet is near perihelion at the time of opposition, his distance from the earth is at the minimum, and he becomes visible under very favourable conditions. His apparent diameter then subtends an angle of about 23 seconds of arc, whereas if the planet comes into opposition at m' when in aphelion, the diameter is only 13 seconds, so that it is easy to understand why the successive apparitions of Mars are not all equally favourable, and why at certain epochs special efforts are made to obtain telescopic observations of his features. Fig. 6. orbit of the Earth and Mars. There is no other planet of the solar system which offers so close an analogy to the earth as Mars. The telescope reveals to us the figures of broad tracts of land, and expanses of sea upon his surface. The durations of his day and night almost coincide with our own. His exterior experiences the alternating changes of the seasons. His nights are illumined by two satellites, which present all the phenomena of our own moon, and more frequently, owing to their greater velocity. An atmosphere probably surrounds the planet, in fact, the existence of air is indispensable to his other features. Hence the inference that Mars is a habitable globe appears a very obvious and fair conclusion, and it would be inconsistent to imagine that this planet, provided apparently with all the requisite natural facilities to render life a necessary and desirable feature of his surface, is a sphere of desolation, a mass of inert matter, which, though conforming to the laws of gravitation, is otherwise serving no useful end, as the abode and sustenance of animate creatures. It is far more in accordance with analogy and rational speculation to conclude that Mars is the centre of life and activity, and that his surface is teeming with living beings. It cannot be that the sun wastes his radiant warmth upon a bleak and barren globe accompanied by two satellites that were merely devised to lighten the solitary aspect of his sea and landscape! Nor can the sequence of his seasons, or the pleasant

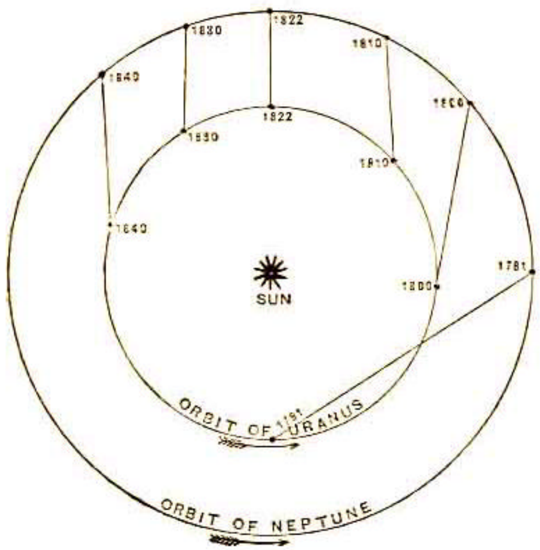
to see an object the size of a man on any of the planetary orbs, we must first be able to see such an object on the moon. Is it possible to obtain a magnifying power sufficient for this? It is possible, we answer, to have such a magnifying power; but the difficulty is to avail ourselves of such a power when we have got it. The great and turbulent sea of atmosphere which lies above us is a seemingly insuperable difficulty. To some extent, of course, we can get free from this by placing our telescope on some high mountain; but there is no mountain high enough to place us altogether out of the atmosphere, and if there were one, we could not live or carry a telescope there. At the highest point at which observations would be possible, which probably would be a good deal below the summit of the Himalayas, enough air still would remain above us to prevent our using a power high enough to discern men like ourselves on the face of our satellite. The tremulousness and waviness produced in the telescopic image by the air, which is, of course, increased the more we magnify, would hopelessly obscure outlines so delicate as those here concerned, and make of such small points a simple invisible blur. Even for the moon, then, the direct discovery of animal life by increased optical power would seem to be a dream which will never be realized. The difficulty, of course, is immensely increased for any other celestial object. No other planet comes nearer to us than about one hundred times the moon's distance; and, moreover, in examining them, we should have to contend with the confusion of outlines coming from their atmospheres as well as from our own. We may then as well give up hope of trying to answer the question, "Are the planets inhabited?" as one which never will be solved for us in this world by any natural means; and fall back on another, on which science, certainly, can give us some light-namely, "Are they habitable; are the physical conditions such in them, so far as we can ascertain, that the life of man or of any highly organized animal could there subsist?" Now, I say the "planets "; for it seems to me that we may as well put the great central body of our system, the sun itself, out of the question. I think it is pretty clear that the surface at least of this enormous globe is in such a state as to make it absolutely impossible for us to of the planet, may be scrutinised with great distinctness. Telescopes may reveal living creatures on either orb, for employing a. power of 1,000 diameters, the objects common to the surface may be examined at an apparent distance of only four miles, from which might be detected all the more prominent features and characteristics. The outlines of buildings or trees may be discerned, and even the recognition of living beings will be possible at this distance. If the planet and its nearest satellite are both inhabited, then the mutual employment of telescopic power must result in mutual recognition, and that would doubtless lead to the adoption of a method of signalling, by which means a constant communication might possibly be going on between the two orbs. But these points are purely matters of speculation. The earliest recorded observation of Mars found in ancient history, is that quoted by Ptolemy in his Almagest, wherein the date is given as the 52nd after the death of Alexander the Great, and the 476th of Nabonassar's era; on the morning of the 21st of the month Athir, the planet was observed slightly above, but very approximate to the star .8 of Scorpio. The dates correspond to the year B.C. 272, January 17th, at 18hrs. on the meridian of Alexandria. There was an occultation of Jupiter by Mars witnessed early in 1591, but that was just before the invention of the telescope, and the phenomenon may have been a very near appulse only of the two bodies. In any case the occultation must have been a partial one, because the apparent diameter of Jupiter almost invariably exceeds that of Mars, and the occurrence ought more correctly to be described as a "transit of Mars across Jupiter," as suggested by Chambers. It was unfortunate that at the epoch of this occurrence, the telescope had not come into use, for some important observations might possibly have been obtained as to the atmosphere of Mars. Oppositions of Mars afford a method (quite independently of transits of Venus) of deriving the value of the solar parallax, and hence the sun's distance. That this element should be very exactly determined, is of extreme importance, inasmuch as it affects other celestial measurements. The Astronomer Royal called attention twenty years ago to the fact that the opposition of Mars in 1877 would offer an

eminently favourable occasion for observing Mars with a view to finding the sun's distance. This had been ascertained at 92,400,000 miles from a parallax of 8".8455 obtained from the transit of Venus in 1874 by the British observers, and Mr. Gill finds from a preliminary discussion of his recent observations of Mars at the island of Ascension, a parallax of 8".78. 3.

1. Reproduced here by the kind permission of the Editor of the Astronomical Register.

2. The outer satellite was seen as early as September 22nd, in the large reflecting telescope of Mr. A. A. Common at Baling. In October he found it plainly visible.

3. More than 200 years ago, namely, in 1672, Flamsteed endeavoured to obtain the solar parallax by observations of Mars, and succeeded approximately in determining it as less than 10". The French soon after declared that they had found the same, for they had witnessed Mars occult the star Aquarii on October 1st., 1672, and the measures taken by three observers, enabled the late M. le Verrier to re-discuss the observations, and derive the solar parallax as 8".866.



Positions of Uranus and Neptune 1781 to 1840

Drawing of the Moon – ca 1919