

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

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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 by night being therefore impossible, and twilight observations being rarely successful, no other way remains but to make the attempt in full daylight, in the continual presence of the sun, and through an atmosphere constantly illuminated. Certain trials made in 1881 persuaded me that it would be possible not only to see the markings on Mercury in full daylight, but also to obtain a series of sufficiently connected and continuous observations of these spots. In the beginning of 1882 I determined to make a regular study of the planet; and in the eight following years I have had the telescope directed upon Mercury several hundreds of times, usually to little purpose, and with the loss of much time; sometimes on

account of atmospheric disturbance, which during the day is often very great (especially in the summer months); and again on account of insufficient transparency of the air. Nevertheless, by employing the necessary patience, I succeeded in seeing the spots on the planet with greater or less precision on more than one hundred and fifty occasions, and also in making at such times some rather satisfactory drawings. For this purpose I used at first the smaller telescope of our observatory, made by Merz, which was often found to be inadequate for observations so difficult as these. But in the mean time the new great equatorial refractor had been installed in the observatory of Milan. It may be called the most perfect work which has yet come from the workshops of Munich. By its aid I was enabled to pursue the work with greater success, and to attain more complete and more certain results. And in regard to this refractor I can not recall without lively emotions of gratitude the warm interest shown by your Majesties, now eleven years ago, when it was a question of providing that noble instrument for the Milan Observatory. Nor is it possible for me to forget the generous eagerness with which this academy, and Quintius Sella of glorious memory at the head of it, supported the proposition with an authoritative vote, and the large majority by which it was honoured in both branches of Parliament; The new facts concerning the planet Mercury which this telescope has revealed, I consider as the most important and most precious results, which have been so far obtained by its aid; so that to give the first account of these new things at this time and in this place seems to me the 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 focus-toward the upper focus. Now, these two foci being distant from each other not less than one fifth of the whole diameter of the orbit of Mercury, the libration of the planet is very great; and that point of Mercury which receives the solar rays vertically is projected on the surface of the planet, and oscillates along its equator in an arc which has an amplitude of forty-seven degrees-that is, more than an eighth of the whole circumference of the equator itself. The complete period of going and returning is equal to the time employed by Mercury in moving around its orbit- that is, almost eighty-eight terrestrial days. Mercury, therefore, is continually oriented to the sun as a magnetic needle to a piece of iron; but it does not point thither so constantly as not to permit of a certain oscillatory motion of the planet eastward and westward, similar to the moon's oscillation with respect to the earth. This oscillatory motion is of the greatest importance in respect to the physical condition of the planet. Let us suppose for a moment that this motion did not exist in fact, and that Mercury always presented the same hemisphere to the light and

heat of the sun, the other hemisphere remaining wrapped in perpetual night. That point of the planet's surface which lies at the central pole of the illuminated hemisphere would eternally have the sun vertically above it; all other places upon Mercury which are reached by the sun's rays would always see the sun above the same point of the horizon, at the same altitude, without any apparent motion or sensible change of place whatever. Therefore such places would have no alternation of day and night, and no vicissitude of seasons. Remaining thus perpetually in presence of the sun, with the stars always invisible, Mercury having no moon, it is difficult to understand how the dwellers in the regions of perpetual day could make any determinations of time (or have any chronology). Upon Mercury things are nearly in this case, but not entirely so. The oscillating motion to which we have seen the body of the planet is subjected with respect to the sun would be attributed by an observer on the planet to the sun itself, just as we are used to attribute to the sun the diurnal motion of rotation which actually belongs to the earth. While, therefore, to us the sun seems to revolve continually from east to west, and thus determines the period of night and day to be 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, without 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 cold. The presence of such an atmosphere upon Mercury was conjectured by Schroeter a century ago; in my observations I find more evident indications of it, which concur in making the probability of its existence almost a certainty. One of the first proofs springs from the continually observed fact that the markings on the planet, visible for the most part when they are found in the central regions of the disk, are less visible or even disappear as they approach its circular borders. I have been able to convince myself that this does not occur simply from the greater obliquity of the line of sight due to perspective, but from the fact that in that perimetral position there is actually a greater hindrance to the vision, and this seems to be due to nothing else but the greater length of the path which the visual rays coming from the non-central spot must pass through in the atmosphere of Mercury to reach the eye. And from this I conclude that the atmosphere of Mercury is less transparent than that of Mars, and that it more nearly resembles, in that regard, that of the earth. In addition to this, the circular border of the planet, where the spots become less visible, always appears more luminous than the rest of the disk. It is often irregularly luminous, in certain parts more so, in others less; and sometimes along this edge rather brilliant white areas may be seen which remain visible for several consecutive days, but which nevertheless are, in general, changeable, now in one portion and now in another. I attribute this fact to condensations in the interior of the

atmosphere of Mercury, which must reflect the solar rays outward toward celestial space, and more strongly as they become more opaque. Such white areas are also often seen in the more central parts of the disk, but in that case they are not so brilliant as upon the border. But there is still more. The dark spots of the planet, although permanent in form and arrangement, are not always equally apparent, but are sometimes more intense and sometimes more faint; and it also happens that some of these markings occasionally become entirely invisible. This I can not attribute to any more obvious cause than to atmospheric condensations similar to our terrestrial clouds, which prevent more or less completely any view of the true surface of Mercury in any portion. The clouded regions of the earth must present an absolutely 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 remain 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 circumstances 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 resolved 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 conclusive argument to the contrary could be advanced. And as those spots are not grouped in great masses, but are dispersed about in areas and zones of no great width, much ramified, and alternated with clear spaces with some uniformity, it might be concluded that no vast oceans and great continents exist upon Mercury, but that the liquid and solid areas mingle with each other in reciprocal ways and with frequent vicissitudes, thus giving rise to a condition of things very different from that which exists upon the earth, and one which perhaps we might envy. At any rate, we have in the case of Mercury (as in Mars), a world which is sufficiently diverse from our own; which receives light and heat from the sun, not only in a greater amount but in a different manner than the earth; and where life, if so be life exists there, finds conditions so different from those to which we are accustomed that we can scarcely imagine them. The perpetual presence of the sun almost vertically above certain regions, and its perpetual absence from other regions, appears to us to be something intolerable. But we must recollect that such a contrast should produce an atmospheric circulation which is at the same time stronger, more rapid, and more regular than that which sows the elements of life on the earth; and ' that on this account it may come about that an equilibrium of temperature is produced quite as complete as ours, and possibly even more so. Mercury is conspicuously distinguished from the other planets by the manner of its revolution around the sun, turning always the same face toward it. All the other planets (at least so far as is ascertained in the cases which it has been possible to determine) revolve rapidly around their axes in the space of a few hours. Mercury's manner of revolution, however, which is unique among the planets, seems, on the other hand, quite usual for the satellites; such at least is true in all the cases where it has been possible to

investigate the rotation motion of a satellite. That our own satellite has always in the memory of man shown to the earth the same hemisphere, is certain also from historical testimony, because Dante speaks of "Cain and the Thorns, " and among the smaller works of Plutarch there is one entitled "Of the Face to be seen In the Disk of the Moon." That the satellites of Jupiter show always the same face to their chief planet is probable as to the first three, and for 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.

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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 motionless at their posts. It was concluded rightly from this that they must occupy the poles of rotation of the planet, or at least must be found very near to them. Consequently they were given the name of polar caps or spots. And not without reason is it conjectured that these represent upon Mars that immense mass of snow and ice which still today prevents navigators from reaching the poles of the earth. We are led to this conclusion not only by the analogy of aspect and of place, but also by another important observation. As things stand, it is manifest that if the above-mentioned white polar spots of Mars represent snow and ice they should continue to decrease in size with the approach of summer in those places and increase during the winter. Now this very fact is observed in the most evident manner. In the second half of the year 1892 the southern polar cap was in full view; during that interval, and especially in the months of July and August, its rapid diminution from week to week was very evident to those observing with common telescopes. This snow (for we may well call it so), which in the beginning reached as far as latitude 70° , and formed a cap of over 2,000 kilometres (1,200 miles) in diameter, progressively diminished, so that two or three months later little more of it remained than an area of perhaps 300 kilometres (180 miles) at the most, and still less was seen in the last days of 1892. In these months the southern hemisphere of Mars had its summer, the summer solstice occurring upon October 13th. Correspondingly the mass of snow surrounding the northern pole should have increased; but this fact was not observable, since that pole was situated in the hemisphere of Mars which was opposite to that facing the earth. The melting of the northern snow was seen in its turn in the years 1882, 1884, and 1886. These observations of the alternate increase and decrease of the polar snows are easily made even with telescopes of moderate power, but they become much more interesting and instructive when we can follow assiduously the changes in their more minute particulars, using larger instruments. The snowy regions are then seen to be successively notched at their edges; black holes and huge fissures are formed in their interiors; great isolated pieces many miles in extent stand out from the principal mass and, dissolving, disappear a little later. In short, the same divisions and movements of 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 tributary 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. And it is to be remembered as a very probable thing that the flowing of this melted snow is the cause which determines principally the hydrographic state of the planet and the variations that are periodically observed in its aspect. Something similar would not be seen upon the earth if one of our poles came to be located suddenly in the centre of Asia or of Africa. As things stand at present, we may find a

miniature image of these conditions in the flooding that is observed in our streams at the melting of the Alpine snows. Travellers in the arctic regions have frequent occasion to observe how the state of the polar ice at the beginning of the summer, and even at the beginning of July, is always very unfavourable to their progress. The best season for exploration is in the month of August, and September is the month in which the trouble from the ice is the least. Thus in September our Alps are usually more practicable than at any other season. And the reason for it is clear- the melting of the snow requires time; a high temperature is not sufficient; it is necessary that it should continue, and its effect will be so much the greater, as it is the more prolonged. Thus, if we could slow down the course of our season so that each month should last sixty days instead of thirty, in the summer, in such a lengthened condition, the melting of the ice would progress much further, and perhaps it would not be an exaggeration to say that the " polar cap at the end of the warm season would be entirely destroyed. But one can not doubt, in any case, that the fixed portion of such a cap would be reduced to much smaller size than we see it to-day. Now, this is exactly what happens on Mars. The long year, nearly double our own, permits the ice to accumulate during the polar night of ten or twelve months, so as to descend in the form of a continuous layer as far as parallel 70° , or even farther. But in the day which follows, of twelve or ten months, the sun has time to melt all, or nearly all, of the snow of recent formation, reducing it to such a small area that it seems to us no more than a very white point. And perhaps this snow is entirely destroyed; but of this there is at present no satisfactory observation. Other white spots of a transitory character and of a less regular arrangement are formed in the southern hemisphere upon the islands near the pole, and also in the opposite hemisphere whitish regions appear at times surrounding the north pole and reaching to 50° and 55° 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° and latitude 16° 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° to 60° 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 moment Nature brings forth an infinite variety in its operations. Of the greatest influence must be different arrangement of the seas and the continents upon Mars and upon the earth, regarding which a glance at the map will say more than would be possible in many words. We have already emphasized the fact of the extraordinary periodical flood, which at every revolution of Mars inundates the northern polar region at the melting of the snow. Let us now add that this inundation is spread out to a great distance by means of a network of canals, perhaps constituting the principal mechanism (if not the only one) by which water (and with it organic life) may be diffused over the arid surface of the planet. Because on Mars it rains very rarely, or perhaps even it does not rain at all. And this is the proof. Let us carry ourselves

in imagination into celestial space, to a point so distant from the earth that we may embrace it all at a single glance. He would be greatly in error who had expected to see reproduced there upon a great scale the image of our continents with their gulfs and islands and with the seas that surround them which are seen upon our artificial globes. Then without doubt the known forms or part of them would be seen to appear under a vaporous veil, but a great part (perhaps one half) of the surface would be rendered invisible by the immense fields of cloud, continually varying in density, in form, and in extent. Such a hindrance, most frequent and continuous in the polar regions, would still impede nearly half the time the view of the temperate zones, distributing itself in capricious and ever-varying configurations. The seas of the torrid zone would be seen to be arranged in long parallel layers, corresponding to the zone of equatorial and tropical calms. For an observer placed upon the moon the study of our geography would not be so simple an undertaking as one might at first imagine. There is nothing of this sort in Mars. In every climate and under every zone its atmosphere is nearly perpetually clear and sufficiently transparent to permit one to recognise at any moment whatever the contours of the seas and continents and, more than that, even the minor configurations. Not, indeed, that vapours of a certain degree of opacity are lacking, but they offer very little impediment to the study of the topography of the planet. Here and there we see appear from time to time a few 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 another. 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, while the Cimmerium, the Sirenum, and the Solis Lacus are connected with it only by means of narrow canals. We shall notice in the first four a parallel arrangement, which certainly is not accidental, as also not without reason is the corresponding position of the peninsulas of Ausonia, Hesperia, and Atlantis. The colour of the seas of Mars is generally brown, mixed with gray, but not always of equal intensity in all places, nor is it the same in the same place at all times. From an absolute black it may descend to a light gray or to an ash colour. Such a diversity of colours may have its origin in various causes, and is not without analogy also upon the earth, where it is noted that the seas of the warm zone are usually much darker than those nearer the pole. The water of the Baltic, for example, has a light, muddy colour that is not observed in the Mediterranean. And thus in the seas of Mars we see the colour become darker when the sun approaches their zenith, and summer begins to rule in that region. All of the remainder of the planet, as far as the north pole, is occupied by the mass of the continents, in which, save in a few areas of relatively small extent, an orange colour predominates, which sometimes reaches a dark-red tint, and in others descends to yellow and

white. The variety in this colouring is in part of meteorological origin, in part it may depend on the diverse nature of the soil, but in its real cause it is not as yet possible to frame any very well grounded hypothesis. Nevertheless, the cause of this predominance of the red and yellow tints upon the surface of ancient Pyrois is well known. Some have thought to attribute this colouring to the atmosphere of Mars, through which the surface of the planet might be seen coloured, as any terrestrial object becomes red when seen through red glass. But many facts are opposed to this idea, among others that the polar snows appear always of the purest white, although the rays of light derived from them traverse twice the atmosphere of Mars under great obliquity. We must then conclude that the Aerean continents appear red and yellow because they are so in fact. Besides these dark and light regions, which we have described as seas and continents, and of whose nature there is at present scarcely left any room for doubt, some others exist, truly of small extent, of an amphibious nature, which sometimes appear yellowish like 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 to which class of regions they may belong. Thus all the 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 the continuity was only seen to be broken once for a short time in 1888. Other smaller dark spots are found here and there in the continental area which we may designate as lakes, but they are certainly not permanent lakes like ours, but are variable in appearance and size according to the seasons, to the point of wholly disappearing under certain circumstances. Ismenius Lacus, Lunae Lacus, Trivium Charontis, and Propontis are the most conspicuous and durable ones. There are also smaller ones, such as Lacus Moeris and Fons Juventae, which at their maximum size do not exceed 100 to 150 kilometres (60 to 90 miles) in diameter, and are among the most difficult objects upon the planet. All the vast extent of the continents is furrowed upon every side by a network of numerous lines or fine stripes of a more or less pronounced dark colour, whose aspect is very variable. These traverse the planet for long distances in regular lines that do not at all resemble the winding courses of our streams. Some of the shorter ones do not reach 500 kilometres (300 miles), others, on the other hand, extend for many thousands, occupying a quarter or some- times even a third of a circumference of the planet. Some of these are very easy to see, especially that one which is near the extreme left-hand limit of our map, and is designated by the name of Nilosyrtris. Others in turn are extremely difficult, and resemble the finest thread of spider's web drawn across the disk. They are subject also to great variations in their breadth, which may reach 200 or even 300 kilometres (120 to 180 miles) for the Nilosyrtris, while some are scarcely 30 kilometres (18 miles)

broad. These lines or stripes are the famous canals of Mars, of which so much has been said. As far as we have been able to observe them hitherto, they are certainly fixed configurations upon the planet. The Nilosyrtis has been seen in that place for nearly one hundred years, and some of the others for at least thirty years. Their length and arrangement are constant, or vary only between very narrow limits. Each of them always begins and ends between the same regions. But their appearance and their degree of visibility vary greatly, for all of them, from one opposition to another, and even from one week to another, and these variations do not take place simultaneously and according to the same laws for all, but in 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 given 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 than 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 lines called canals are truly great furrows or depressions in the surface of the planet, destined for the passage of the liquid mass and constituting for it a true hydrographic system, is demonstrated by the phenomena which are observed during the melting of the northern snows. We have already remarked that at the time of melting they appeared surrounded by a dark zone, forming a species of temporary sea. At that time the canals of the surrounding region become blacker and wider, increasing to the point of converting at a certain time all of the yellow region comprised between the edge of the snow and the parallel of 60° north latitude into numerous islands of small extent. Such a state of things does not cease until the snow, reduced to its minimum area, ceases to melt. Then the breadth of the canals diminishes, the temporary sea disappears, and the yellow region again returns to its former area. The different phases of these vast phenomena are renewed at each return of the seasons, and we were able to observe them in all their particulars very easily during the oppositions of 1882, 1884, and 1886, when the planet presented its northern pole to terrestrial spectators. The most natural and the most simple interpretation is that to which we have referred, of a great inundation produced by the melting of the snows; it is entirely logical and is sustained by evident analogy with terrestrial phenomena. We conclude, therefore, that the canals are such in fact and not only in name. The network formed by these was probably determined in its origin in the geological state of the planet, and has come to be slowly elaborated in the course of centuries. It is not necessary to suppose them the work of intelligent beings, and, notwithstanding the almost geometrical appearance of all of their system, we are now inclined to believe them to be produced by the evolution of the planet, just as on the earth we have the English Channel and the channel of Mozambique. It would be a problem not less curious than complicated and difficult to study the system of this immense stream of water, upon which perhaps depends principally the organic life upon the planet, if

organic life is found there. The variations of their appearance demonstrated that this system is not constant. When they become displaced, or their outlines become doubtful and ill defined, it is fair to suppose that the water is getting 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 in 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 miles), up to more than 100 kilometres (60 miles). The colour of the two lines varies from black to a light red, which can hardly be distinguished from the general yellow background of the continental surface. The space between is for the most part yellow, but in many cases appears whitish. The gemination is not necessarily confined only to the canals, but tends to be produced also in the lakes. Often one of these is seen transformed into two short, broad dark lines parallel to one another and traversed by a yellow line. In these cases the gemination is naturally short and does not exceed the limits of the original lake. The gemination is not shown by all at the same time, but when the season is at hand it begins to be produced here and there, in an isolated, irregular manner, or at least without any easily recognisable order. In many canals (such as the Nilosyrtris, for example) the gemination is lacking entirely, or is scarcely visible. After having lasted for some months, the markings fade out gradually and disappear until another season equally favourable for their formation. Thus it happens that in certain other seasons (especially near the southern solstice of the planet) few are seen, or even none at all. In different oppositions the gemination of the same canal may present different appearances as to width, intensity, and arrangement of the two stripes; also in some cases the direction of the lines may vary, although by the smallest quantity, but still deviating by a small amount from the canal with which they are directly associated. From this important fact it is immediately understood that the gemination can not be a fixed formation upon the surface of Mars and of a geographical character like the canals. The second of our maps will give an approximate idea of the appearance which these singular formations present. It contains all the geminations observed since 1882 up to the present time. In examining it it is necessary to bear in mind that not all of these appearances were simultaneous, and consequently that the map does not represent the condition of Mars at any given period; it is only a sort of topographical register of the observations made of this phenomenon at different times. 3. The observation of the geminations is one of the greatest difficulty, and can only be made by an eye well practised in such work, added to a telescope of accurate construction and of great power. This explains 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 compasses 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 with the present argument. Having regard, then, for the principle that in the explanation of natural phenomena it is universally agreed to begin with the simplest suppositions, the first hypotheses of the nature and cause of the geminations have for the most part put in operation only the laws of inorganic Nature. Thus, the gemination is supposed to be

due either to the effects of light in the atmosphere of Mars, or to optical illusions produced by vapours in various manners, or to glacial phenomena of a perpetual winter, to which it is known all the planets will be condemned, or to double cracks in its surface, or to single cracks of which the images are doubled by the effect of smoke issuing in long lines and blown laterally by the wind. The examination of these ingenious suppositions leads us to conclude that none of them seem to correspond entirely with the observed facts, either in whole or in part. Some of these hypotheses would not have been proposed had their authors been able to examine the geminations with their own eyes. Since some of these may ask me directly: "Can you suggest anything better?" I must reply candidly, "No." It would be far more easy if we were willing to introduce the forces pertaining to organic Nature. Here the field of plausible supposition is immense, being capable of making an infinite number of combinations capable of satisfying the appearances even with the smallest and simplest means. Changes of vegetation over a vast area, and the production of animals, also very small, but in enormous multitudes, may well be rendered visible at such a distance. An observer placed in the moon would be able to see such an appearance at the times in which agricultural operations are carried out upon one vast plain—the seed-time and the gathering of the harvest. In such a manner also would the flowers of the plants of the great steppes of Europe and Asia be rendered visible at the distance of Mars—by a variety of colouring. A similar system of operations produced in that planet may thus certainly be rendered visible to us. But how difficult for the Lunarians and the Areans to be able to imagine the true causes of such changes of appearance without having first at least some superficial knowledge of terrestrial nature! So also for us, who know so little of the physical state of Mars, and nothing of its organic world, the great liberty of possible supposition renders 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, the region referred to being that in which the central branch of the fork of the Y appeared. Since no such branch was conspicuously visible this year, it would therefore seem from the above that it was the opposition of 1892 that was peculiar, and not the present one.-TRANSLATOR.

3. This map may be found in "La Planete Mars," by Flammarion, page 440.-TRANSLATOR.