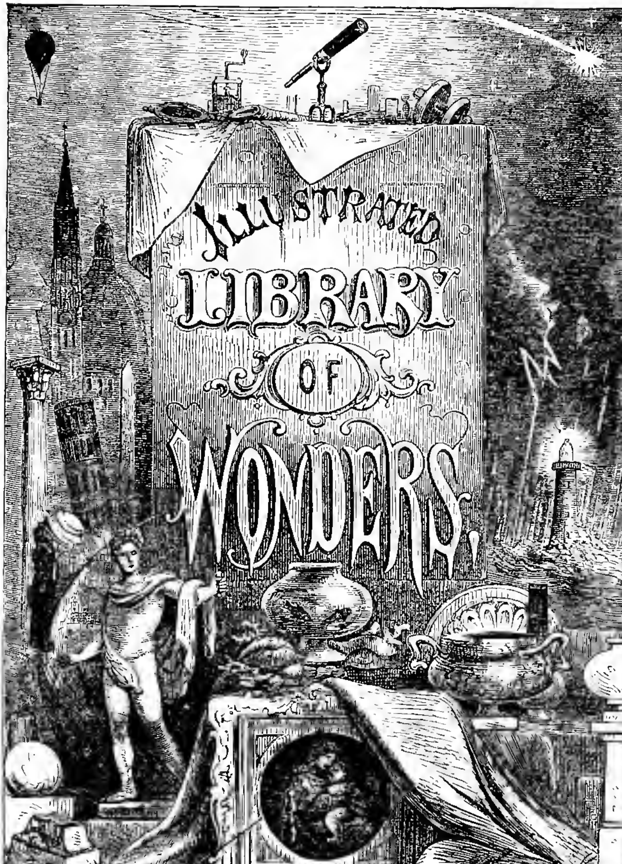
MARVELS OF NATURE
Science & Art



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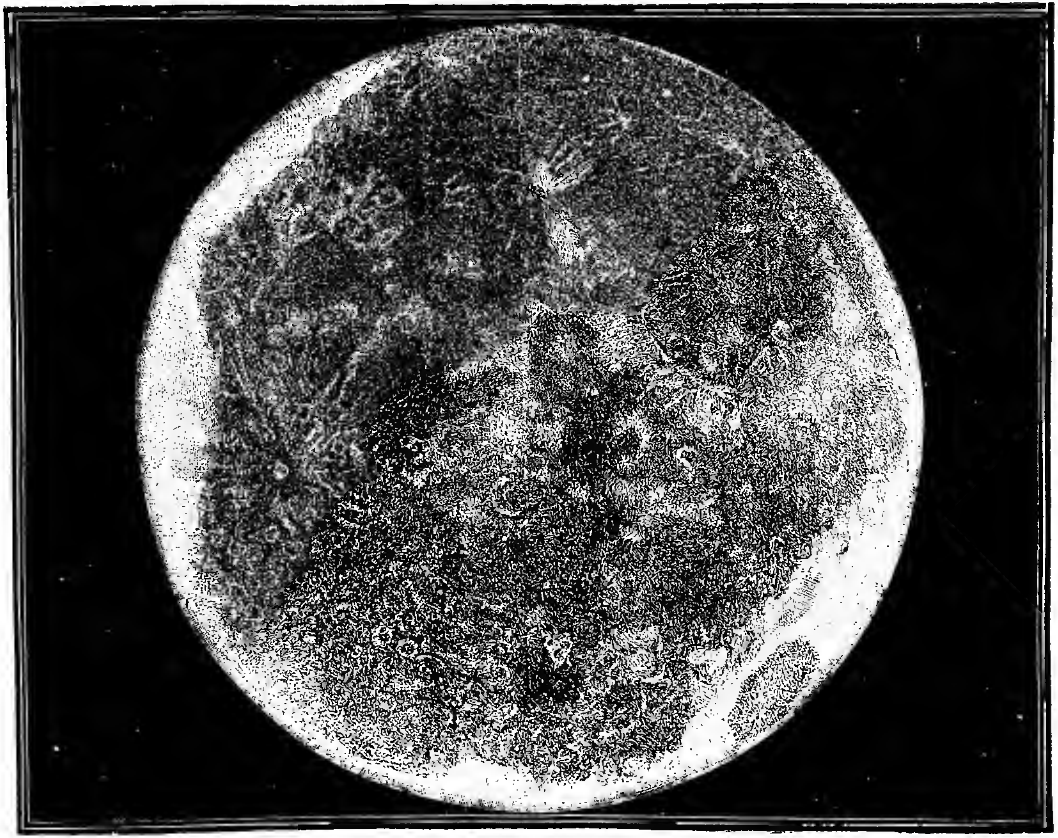

THE MOON AT ITS FULL.

WONDERS

OF

THE MOON.

TRANSLATED FROM THE FRENCH OF

AMEDEE GUILLEMIN,

BY

MISS M. G. MEAD.

EDITED, WITH ADDITIONS,

BY

MARIA MITCHELL,

OF VASSAR COLLEGE, N. Y.

Illustrated with Forty-three Engravings.

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EDITOR'S PREFACE.

M. GUILLEMIN's little book on the Moon is intended for popular reading ; it is neither for the school-room nor the observatory. It is adapted to that large class of persons, who, in an age which tends very decidedly to physical research, wish to know something of *scientific facts* ; those whose occupations do not afford them time for study, or who, from defects in their early training, believe themselves incapable of mathematics. From the first page to the last there is not a problem ; not a triangle is drawn.

Although astronomy and the laws of motion cannot be studied without the highest mathematics, the facts which observation and theory combine to make known, can be gathered together and made attractive to the general reader, so that the narrow boundaries of ordinary daily life may be extended by a conception of the expansions of space, and the cycles of time.

"The Moon" is a guide book to explorers of the lunar surface, to astronomical sight-see-ers. To those who are accustomed to the use of a glass, to whom the Moon is already somewhat known, it gives the same pleasure which the returned traveller receives when he takes up the book of the ready writer and finds details of scenery, sketches of views, and descriptions of ravines, narrow passes and steep ascents which he had supposed only known to himself. For such sight-seeing and such explanation, costly instruments and delicate apparatus are not necessary. The eye, or at best the eye aided by a small glass, is enough. Many of the phenomena of which "The Moon" treats can be seen by the naked eye; all of them with a glass of low power.

It is much to be desired that young women would give their spare time and unoccupied thought to some department of science. Scattered all over our country are thousands of young girls, leading aimless lives, to whom science might open new worlds. They have the very requisites necessary for observations of phenomena; in general their perceptive faculties have been cultivated beyond all others; they have been trained in minute details and in routine work. They could gather in valuable facts which might lead to new views of nature and new interpretations of its lessons. They could scarcely be observers of phenomena, without taking the next step, and becoming seekers after law.

The mission of the popular scientific works is mostly that of suggestion. My hope is, that, through them, a love of nature may be aroused; that after looking at "The Moon" the reader may be led to look beyond its surface to the beauty of order in the universe, and may become an earnest student of the wonderful revelations of God, through Nature.

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INTRODUCTION.

THIRTY years ago a humorist, relying on the credulity of the public, published a pamphlet which caused a great sensation. It treated of nothing less than the discovery of the inhabitants of the Moon, whom Herschel, by the aid of an immense telescope, had seen coming and going, not suspecting, certainly, that their actions and movements were witnessed 140,000 miles distant by an inhabitant of their planetary neighbor, more ingenious and more curious than the thousand millions of his compatriots.

The author of this hyperbolical narrative, compiled, as is well known, without the knowledge of the illustrious astronomer, gave all the evidence calculated to satisfy his readers concerning the accuracy of the facts of which he had constituted himself the historian; the dimensions of instruments, making of preparations, a minute description of the animals, the vegetation, and finally, of the inhabitants of the Moon. Nothing was wanting. The discoveries were declared to have been made at the Cape of Good Hope, where it was well known that Herschel was observing.

Great was the excitement of the public, so disposed to welcome the strangest and most impossible news, so indifferent or so disdainful toward the most positive and most fruitful discoveries. The infatuation was so universal, so complete, that Arago thought himself obliged to come before the Academy to give the lie explicitly to the author of this hoax, and to those who had been innocently its propagators. It was cold water thrown upon an enthusiasm not unlike that which three centuries and a half ago welcomed the recitals of Columbus and his companions concerning the discovery of a new world.

But is not the Moon a world to be conquered—a celestial body so near us, and which seems like an appendage—a miniature of the Earth? There it is, separated from our globe by 140,000 miles, accompanying it unceasingly in its annual revolution, as if drawn toward it by an invincible bond of sympathy, turning always toward the Earth the same face, alternately dark and bright, but which no cloud ever sullies, as if to invite us to solve the enigma of this celestial sphinx. The Earth and the Moon receive in common the same light, and during their nights, exchange in turn its rays.

A hundred and forty thousand miles, did we say? What is such a distance compared with the abysses of the visible universe—compared even with the dimensions of the solar system, of this family of stars which press around their common centre, which dispenses to them light and heat? It is less than the eighteen hundredth part of the interval comprised between the Earth and Jupiter;* it is less than the millionth part of the distance between us and the nearest fixed star of our universe. How can we be willing to be ignorant of what the Moon is, when we think that the crossing of ten times the length of the Earth's circumference would suffice to accomplish the journey thither?

This journey, however, which imagination undertakes so willingly, is forever forbidden to man. It is this which explains the attempts, continually renewed, of ingenious minds, ready to substitute for the inaccessible reality their fancies and their dreams. For lack of knowledge they are forced to conjecture.

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* The Moon's mean distance from the Earth is about 238,000 miles; that of Neptune is about 2,700,000,000 miles; that of Jupiter about 500,000,000 miles.

But human curiosity cannot be satisfied with pure chimeras; and if it sometimes feeds upon hypotheses, it is on the condition that these hypotheses shall contain, in positive, real facts, a sufficient portion of reality. Science alone is in a state to furnish these facts; it is astronomy, then, which we must question in order to learn what the Moon is—in order to penetrate as far as possible into the mysteries of its structure and of its physical constitution.

The means of exploration which the progress of optics has placed at the disposal of astronomers are limited; but, as we shall soon see, the skillfulness of observers — their long patience—their laborious studies, have made up, in many respects, for the insufficiency of the instruments; the genius of the spirit of induction and of analogy has done the rest.

Telescopes, notwithstanding their power, the effect of which is generally exaggerated by the public, seldom permit the eye of man to approach the lunar globe nearer than from 150 to 200 miles. It is possible, undoubtedly, to magnify more considerably, but then the want of clearness and of light destroys the benefit of a greater nearness. It can be seen by this how deluded are those who believe in the possibility of seeing living beings, trees, and edifices on the surface of the Earth's satellite. Telescopes capable of receiving eye-pieces magnifying 6,000 times are the most powerful which have been constructed—applied, if it were possible, to the observation of the Moon, they would still, under the most favorable circumstances, place its surface 37 miles distant from our eyes. The largest terrestrial animals would be totally invisible; still more so men, if they existed upon the Moon, having the same stature as ourselves. In this hypothesis, not yet realized, I repeat, we could at most only distinguish large masses, like forests or monumental structures.

Well, notwithstanding these obstacles, which the progress of optics will some day, perhaps, overcome, the Moon is already wonderfully well known, not only in its movements, in its form, and in its dimensions—elements purely astronomical and determined long ago with great precision—but also in the structure of its surface, whose geographical details have been pointed out with an exactness which is still wanting in vast regions of our planet. Lunar geology and meteorology have been largely sketched; and if they leave much to be desired, if the field of conjecture is still broad in this respect, we can even now form an idea of the physical phenomena of which our satellite has been, and still is, the theatre.

Considered in this point of view, the Moon is a strange world.

Days and nights succeed each other there as on the Earth; but their duration is so different that there must result contrasts of light and of temperature, which the absence of water and of an atmosphere renders still more startling. On the other hand, the changes of the seasons are, so to speak, unknown.

What would an inhabitant of our Earth say, if he were suddenly transported to the surface of the Moon? What would not be his astonishment at beholding the singular spectacle which would be presented to his eyes? The configuration of the surface, entirely covered with enormous ridges, little inferior in height to the loftiest terrestrial mountains, perforated here and there by deep circular cavities, bristling with abrupt peaks; the aspect of the sky, where stars shine at mid-day in a vault entirely black; the intensity of lights and shadows; the eternal silence which reigns in these desolate regions; the severity of the temperature, sometimes freezing, sometimes torrid; the strange conditions which result from such a physical constitution for the existence of organized beings, if, indeed, life is still possible in the midst of such a state of things; all, in short, would unite to overturn the ideas, which his residence on our globe had made familiar. Yet such, in its general appearance, is the world we are about to describe. Need we speak of the interest of such a subject? If the object were only to satisfy that curiosity of which we are all possessed, which impels bold travellers, through all obstacles and all perils, to seek the unknown regions of our globe, it would be sufficient reason for the publication of this monograph.

But science has, to us, a higher aim. In attacking the great problems which Nature is continually placing before our minds, in penetrating by means of study the secret of the eternal laws, science permits us to draw upon the living springs from which both imagination and poetry derive their nourishment. She initiates us into the harmony of the great whole, whose indescribable splendor it is our highest glory to comprehend. In place of that foolish vanity which compelled man to consider himself as the pivot and centre of the universe, she substitutes the noble pride of knowing how to assign himself to his true place, of comprehending his true mission, and of using for its accomplishment the knowledge of the very laws which he is powerless to violate, and which he cannot resist with impunity. Of all the natural sciences, is not astronomy the one which furnishes us, in this respect, with the most instruction?

But we are not all imagination, all sentiment. We need knowledge in order to develop our intelligence, in order to discipline it under the imperious yoke of positive methods, in order to resist the errors of sophistry and of passion. No one will deny that the natural sciences have, in this respect, a remarkable power.

Of all the heavenly bodies which pierce with their fires the transparent layers of our atmosphere, the Moon is the one which, by its very proximity, has demanded the greatest efforts towards a complete intelligence of its movements. The slightest perturbations in the element of its orbit have been rendered sensible by the frequency of its revolutions, in connection with its short distance. The motions of the Moon furnished Newton with the elements of the great problem which he solved; it was our satellite which revealed to him the secret of the gravitation of worlds toward each other and of the identity of this general force with the force of gravity. One after another all the lunar inequalities found their explanation in this universal principle, and what seemed at first a departure from law, has been found to be the most absolute confirmation of the same law.

Such efforts of genius, to which are attached the names of the greatest astronomers of modern times, ought not to be unrewarded. We have said that curiosity alone was a sufficiently legitimate motive for astronomical investigation. We shall see that to those who seek truth above all other things, the rest is given in addition.

The knowledge, more and more vigorous, of the theory of the Moon is a striking example of this. Thanks to the tables which have been calculated to show the successive positions of the lunar disc in the starry vault, sailors and travellers can to-day find their place at sea and determine their route. The immense distance of the stars makes their apparent distance from the Moon vary according to the position of the observer on the surface of the terrestrial globe. Our satellite (this comparison was made long ago) appears, on the immense dial-plate of the sky, to be like a movable needle marking the hour, without our fearing in the wheelwork of the clock any variation, any unexpected derangement. Is not this a noble use of the scientific knowledge acquired at the price of gigantic labor?

But the Moon concerns us still more nearly. Its mass, combined with the mass of the Sun, raises periodically the fluid strata of the seas, and moves the wave on the surface of the globe in proportion to its own movement and the rotation of our globe, producing thus the phenomenon of the tides. So long as we were ignorant of the cause of these movements, we could not foresee their variations, which interest so directly maritime navigation, the coasts of the ocean, and the ports situated upon it. Since the theory of tides is only a corollary to that of gravitation, we calculate in advance the intensity of the phenomenon, and so anticipate, by precise indications, the favorable movements for the entrance and exit of vessels.

Undoubtedly science has not yet had her last word upon all these questions. There remains much for her to do. But what has been done shows that astronomy, so interesting in an intellectual point of view, so grand when we see it revealing to us the harmony of worlds, is also important for its social utility.

In this little work, it is not, be it understood, the theory and its magnificent developments which we pretend to show; but we shall confine ourselves to the results, to the curious deductions which we can draw from it. The precise study of astronomical laws is possible only by means of the rigorous methods used in mathematical sciences, and those who wish to apply themselves to it should remember the saying of Archimedes: "There is no royal road to geometry."

Yet the field which remains to us is still large. In studying the Moon with respect almost exclusively to its physical constitution, we shall reap an abundant harvest of curious observations. Without inventing anything, without presenting any hypothesis except as conjectural, without treading upon the always dangerous ground of fancy, it is our hope that we shall make, and shall cause our readers to make, one of the strangest and most singular journeys which man has ever yet accomplished.

THE MOON.

CHAPTER I.

THE MOON AS SEEN WITH THE NAKED EYE.

I.

THE PHASES OF THE MOON.

Every one knows what astronomers mean by the *phases* * of the moon; they are the various phenomena presented by the disc in an interval of twenty-nine days and a half, and which are reproduced periodically in the same order. The period itself is called a *lunation* or *lunar month*; it begins and ends at the moment of *new moon*, at the epoch when our satellite is in conjunction with the sun, and has disappeared in its rays.

Among the ancients, the course of the moon furnished the first natural division of time, the duration of the year not being known with sufficient ex-

* The word *phase* is derived from the Greek φασις, which has the same etymology as the verb φαινω, I appear, I shine.

actness. We also find in the history of all nations the custom of celebrating New Moon or Neomenia with sacrifices and prayers. Since the Neomenia * served as the starting-point for regulating the assemblies, solemnities, and public exercises, and as the lunation was counted from the day when the Moon became visible, "in order to discover it easily, the people assembled in the evening on an eminence; when the crescent had appeared, they celebrated the Neomenia, or the sacrifice to the new month, and this was followed by fêtes or entertainments. The new moons which were concurrent with the renewal of the four seasons were the most solemn." (De Lalande.)

In our day, all trace of these ceremonies has disappeared,† at least among civilized nations; but, as we see, many of the prejudices which are connected with the pretended influence of the phases of the Moon are yet to be dissipated. Let us follow the Moon through the course of one of her periods, and note the various phenomena which attends each of her phases.

We say that there is a *new moon* when our satel-

* The Latins gave the New Moon the name *Luna silens* or *sitiens*.

† Among the Mahometans, the end of the fast of Ramadan is fixed at the new moon, which begins the Bairam, or rather at the instant of the first appearance of the crescent moon.

lite is not visible during the day nor the night. The reason of this invisibility is the situation of the Moon, its apparent position in the heavens being the same as that of the Sun. The dark side of the Moon is then turned toward the Earth, and becomes invisible in the dazzling rays of the Sun. This disappearance of the Moon continues two or three days; but the precise instant of new moon, indication of which is given in astronomical almanacs, takes place when the Moon and Sun have exactly the same longitude. The Moon is then said to be in *conjunction.*

On the second and third days after the instant of conjunction,* and in the evening, a little after sunset, the Moon appears in the form of a very narrow crescent, the convex side of which is turned toward the sun, then below the horizon. The obscure part of the lunar disc is then very distinctly seen,

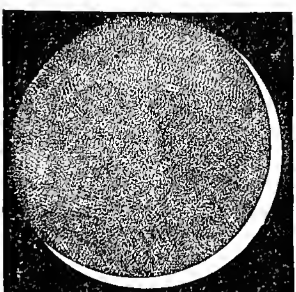


Fig. 1. First phase of the Moon. Ashy light.

* Hevelius asserts that he never saw the Moon sooner than forty hours after conjunction and twenty-seven before, so that the minimum duration of its disappearance is sixty-seven hours, a little less than three days. This period varies according to the climate and the latitude of the Moon.

being of a very faint color, as if transparent; this light, much less intense than that of the illuminated portion, is due to the reflection of the Sun's rays from the surface of the Earth.

On account of the diurnal motion the Moon soon sets in the western horizon. The next day the same phenomena are reproduced, but the crescent is already less sharp, the illuminated portion is larger, and the Moon, farther removed from the sun, sets, also, a little later than on the day before.

The fourth day after the *new moon* the form and appearance of our satellite, which sets only three hours after the sun, are represented in Fig. 2. The ashy light is still visible, although it diminishes more and more, until it disappears entirely in the following phase, called the *first quarter*. The Moon is then said to be *dichotomus* (divided into two equal parts. Fig. 3.) It is between the seventh and eighth days of the Moon that it appears to us in the form of a half circle, visible during a part of the day, and the diurnal motion does not cause it to pass the meridian until six hours after the Sun. Even in

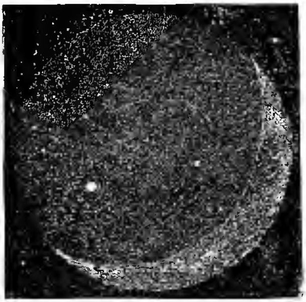


Fig. 2. Fourth day of the Moon.

Fig. 3. The Moon at its first quarter.

the preceding phase the spots with which the Moon's disc is covered were visible; now these spots are seen with great distinctness on the luminous semi-circle.

Between the first quarter and *full moon* seven more days elapse, during which the form of the illuminated portion approaches more and more that of a complete circle (Fig. 4); the Moon rises and sets later and later during this interval, but always turns the circular part of its disc toward the west. At last the whole side of the Moon is illuminated, about fifteen days after new moon (Fig. 5); the hour of its rising is then nearly that of the setting of the Sun, which in its turn rises when the Moon sets.

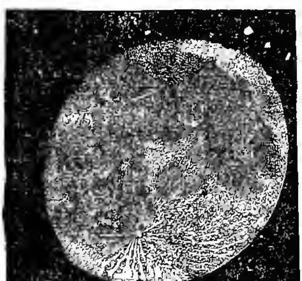


Fig. 4. Between the first quarter and full Moon.

It is midnight when it reaches its highest point, which is, in the language of astronomy, at the instant it passes the meridian; at the same time the Sun, below the horizon, passes the inferior meri-

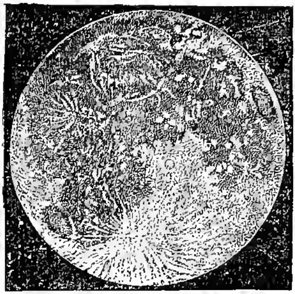


Fig. 5. The full Moon.

dian, so that, relatively to the Earth, the Moon is directly opposite to the Sun.

After the epoch of full moon until the following new moon (this second half of the lunation is called the *wane*) the circular form of the illuminated part of the disc gradually decreases, and finally assumes, as at the beginning of its course, the form of a very sharp crescent. But the convexity is now always turned toward the east, and that portion of the semi-circle whose light is disappearing is toward the Sun. (Fig. 7.) In the middle of the interval which separates the full moon from the period following, the *last quarter* presents a phase similar to the *first quarter*, but inversely situated.

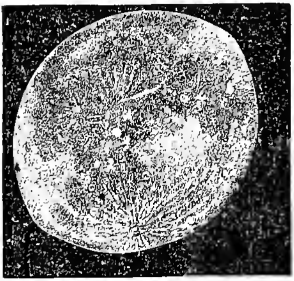


Fig. 6. Wane of the Moon. Between full moon and the last quarter.

In this second half of the lunar period, or of the *lunation*—that is the proper word—the apparent position of the Moon in the heavens reapproaches

Fig. 7. Wane of the Moon. Last quarter.

nearer and nearer that of the Sun. Toward the last days the Moon rises a very short time before the Sun, until at last it is obscured again in the Sun's rays, disappears, becomes a new moon, and begins a new lunation. The ashy light reappears after the last as before the first quarter, in proportion to the diminution of the illuminated part of the disc. (Fig. 8).

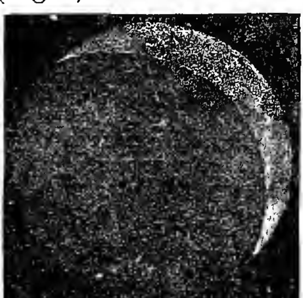


Fig. 8. Wane of the Moon. Between the last quarter and the new Moon. Ashy light.

This succession of the phases of the Moon, which is reproduced indefinitely, and always in the same manner, is evidently caused by the motion of the Moon around the Earth. This is easily understood by examining Fig. 10, and it is then plain why the phases of the successive lunations are precisely the same when the Sun, the Earth, and the Moon occupy the same relative positions: if the position of the Moon is referred to the

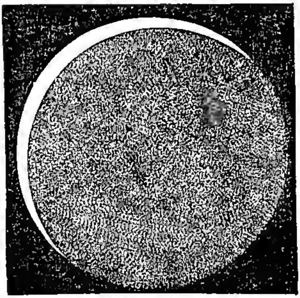


Fig. 9. Last phase of the Moon. Ashy light.

stars, in two or more consecutive lunations, it is seen that during the same phases (Fig. 9) it does not occupy the same point of the heavens; that it does not pass through the same constellations; this is due to the time, and to the motion of the Earth in its orbit, and to the variations of the motion of the Moon in its orbit. (Fig. 10.) We have already said that the duration of a lunar month was about twenty-nine days and a half; in reality it exceeds this by forty-four minutes and three seconds. It is therefore necessary to have a month of mean duration which evidently corresponds with the period of a lunation, just as the week corresponds with the duration of each of the four principal phases.*

* The days of the week, as you know, take their names from the seven planets known to the ancients: the Sun, the Moon, Mars, Mercury, Jupiter, Venus, and Saturn. The order of the days has been determined, it appears, by the custom which the ancients had of consecrating to the seven planets the twenty-four hours of the day. Each day, then, took the name of the planet to which the first hour was consecrated. This explains also how it happened that the order of the successive days of the week is not the natural order of the planets, of such, at least, as were

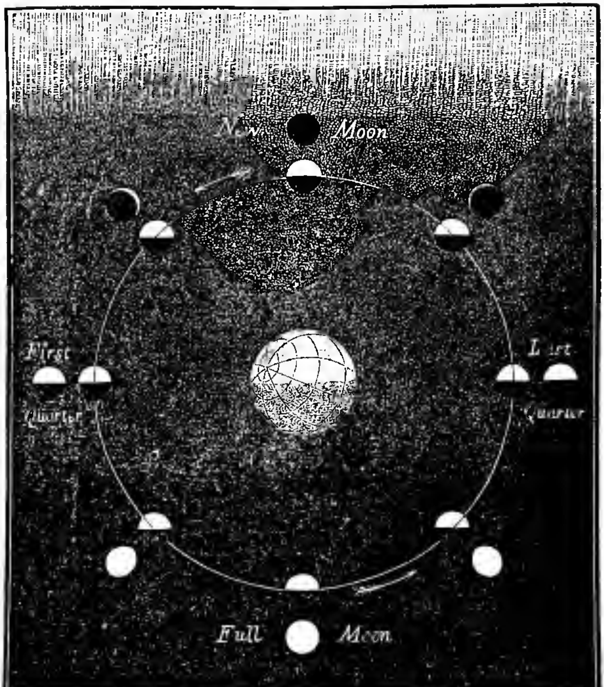
known to the ancient astronomers. That order was: the Sun, Venus, Mercury, the Moon, Saturn, Jupiter, and Mars. The first hour of the first day was consecrated to the Sun, the second to Venus, etc.; it happened that the first hour of the second day was consecrated to the Moon, the first of the third day to Mars, and so on.

II.

FORM OF THE LUNAR DISC.

At the epoch of full moon the entire disc is illuminated by the sun's rays and has the appearance of a perfect circle. Any one may suppose this to be the fact by simple observation, but astronomers are more particular in the matter, and endeavor to verify the apparent circular form of the moon by accurate measurements of all its diameters. The result of these measurements is that the impression made by simple observation is exact: the disc at the epoch of full moon is rigorously a circle.

This fact was all the more interesting to establish, because the greater part of the celestial bodies of our solar system appear in the telescope as oblate discs, of a form slightly elliptical or oval. This is true of the planets Mars, Jupiter, Saturn; and the Earth, also, as has been proved by direct measures of several arcs of meridian, is flattened at its poles of



ORBIT OF THE MOON. EXPLANATION OF THE PHASES.

rotation, or, which amounts to the same, is enlarged at the equator. As for the other planets, such as Uranus, Neptune, Venus and Mercury, the micrometrical measurements have not established any sensible oblateness; it is the same in the case of the Sun. But we regard these exceptions as merely apparent, and proving but one thing, which is that the actual oblateness is too slight to be appreciable in the instruments.

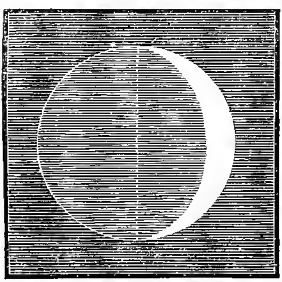


Fig. 11. Geometrical form of the lunar crescent.

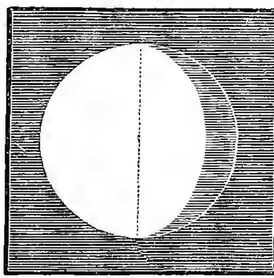


Fig 12. Geometrical form of the Moon after conjunction.

The circular form of the disc of a star indicates ordinarily a form *really* spherical. As it is thus with the Moon, shall we consider our satellite as having the form, if not rigorously, at least very nearly of a sphere? The observation of its phases permits us to reply in the affirmative. As we have seen, some days before or after new moon, the luminous crescent, more or less well-defined, is always bounded on the outside by a half circle very nicely terminated. (Figs. 11 and 12.) As to the concave edge, the curve which forms it is not exactly a half-circle, but more nearly a part of an ellipse, the extremities of which form with the exterior curve the horns of the crescent, which terminate in the two extremities of a common diameter. Little by little the line of separation between the light and shade extends, and at the first quarter it has become a straight line. Then the elliptical curve, which was concave, becomes convex, resumes the same forms in an inverse direction, increases little by little, and is finally transformed, at the epoch of full moon, into a half-circle, to resume again during the wane and until the last quarter the same forms and the same apparent dimensions. In fine, everything takes place as if the Moon had the form of a perfect sphere, whose opposite parts were successively illuminated and thrown into darkness: the study of the movements of the Moon, and of its positions in relation to the Sun and the Earth, leaves no doubt as to the reality of this appearance.

Thus the Moon, like the Earth, is a spheroidal globe whose oblateness, if it exist, is almost inappreciable, at least on the entire circumference which limits its visible half. Hereafter we will give more of the details of its true form, and we shall see that it is supposed to be slightly elongated in the direction of the earth.

Now that we are somewhat enlightened as to the form of the Moon, let us speak of its size. In order to be precise, let us begin by distinguishing the apparent size of an object from its true size. It is of the first that we shall speak at present. There are such confused ideas in this respect in the mind of many people, and errors are so widely spread that some explanation is necessary.

I have heard a hundred times—and I do not doubt that the reader of this passage, whoever he may be, will bear like witness—I have heard, I say, many an observer of a phenomenon, in order to give an idea of the apparent dimensions of the object he has seen, as the disc of the Moon or the Sun, the size of a meteor, the tail of a comet, etc., express himself thus: *Its length was about a decimetre, or a foot; it appeared as large as a plate* . . . . . . I have also read such expressions in journals, even in scientific collections. Now it is easily seen that this way of showing the apparent dimensions of an object and not the real, in which distance is wholly left out, is perfectly unintelligible. In fact, the same object—a decimetre if it has to do with length, a plate if it has to do with a circular disc—has not in itself a decided apparent dimension. That dimension is essentially variable according to the distance of the eye from the object which forms the term of comparison. In order that the expressions of which we are speaking should have a meaning, it is necessary, then, to add to the dimension indicated the precise distance from the eye at which the object is observed. A plate placed very near the eye covers an immense portion of the field of view, or, if one desires, the entire heavens. Placed at a little distance the surface which it covers is considerably diminished. Removing it still farther it may become imperceptible. In order to cover exactly the surface of the Moon, so that one circle will not be in any way projected beyond the other, it is necessary to place it at a certain fixed distance, determined either by observation or by calculation. It is only at this distance that the apparent size of the star and the object can be compared

Otherwise what would be the result of the circumstances I have just mentioned? If the phenomena had had several simultaneous observers, one would give the object the size of a decimetre, another of a foot, a third of a metre, each one having, moreover, at the instant he saw the object, a very vague idea of the supposed distance of the metre, the decimetre and the foot, which served as terms of comparison. Astronomers, and in general all those who have accurate ideas of geometry, overcome this difficulty. They do not compare the apparent dimensions of an object with a determined dimension. They indicate simply the portion of the field of view which is covered by the diameter of the object. They say, for example, that the apparent diameter of the Moon is about half a degree, meaning by a degree the three hundred and sixtieth part of the whole circumference of the horizon. It is precisely the angle formed by the two visual rays from the eye which meet the extremities of the Moon's diameter.

Thus, generally, it would require 360 moons, touching edge to edge, to complete the half circumference of a circle which, beginning at one point of the horizon, meets the horizon at a point diametrically opposite, following in the heavens any course whatever.

Let us speak in more accurate terms. The degree is divided into 360 equal parts called minutes : each sixtieth of a minute is called a second. Well, it is found by very accurate measurements that the mean diameter of the lunar disc is 31 minutes and 24 seconds, or, as we see; a little more than half a degree. This is very nearly the apparent diameter of the Sun. But it must not be concluded that the true size of the Moon is nearly equal to that of the Sun : it is necessary to take into account the distances, and later we shall see that our satellite is about four hundred times less distant from us than the common centre whence the planets receive heat and light.

Let us pass to another question. Are the apparent dimensions of the Moon always the same? If they are, it is because the distance of the Moon from the Earth is always the same. Or, do these dimensions vary?—in which case the distance will vary from one epoch to another. It is the second hypothesis which is the true one. In the course of a lunation—that is to say between two consecutive new moons, the diameter of the Moon varies constantly between two limits. This variation is quite sensible, since it reaches the eighth part of the whole diameter; nevertheless, it is difficult to ascertain it with the naked eye, and accurate instruments alone are able to show it. I should add, also, that in the course of successive lunations, the variations of the apparent diameter are not reproduced with exactly the same values. Therefore the Moon does not always remain at an unvarying distance from the Earth: it moves away from and approaches, following certain very complicated laws which astronomy has succeeded in explaining, but which we will not attempt to point out here.

In regard to the variations in distance, and consequently in diameter, I shall be very much astonished if among my readers there is not one who has at the end of his tongue the following question: Do you say nothing about the change which is observable in the apparent diameter of the Moon from the time it rises above the horizon until it reaches its greatest height in the heavens? In this case the testimony of the senses suffices, and it

Fig. 13. Variations of the size.

is not necessary to be an astronomer in order to judge. Let us look at the case.

When the Moon rises, at the period when it is full for instance, and the sky is very clear in the eastern horizon, its tinted disc appears enormous. But, gradually as it rises, or, to leave the language of appearances, as our horizon, by degrees, depresses itself below the Moon, in consequence of the diurnal motion of the earth, its dimensions are diminished, the brightness of its light increases, and it seems to resume its normal size. At the highest point of its course, when the Moon passes the meridian, its disc appears smallest. The contrast between the size of the Moon at the horizon and at its highest point of the heavens is moreover all the more marked when, owing to the circumstances of its movements, or else to the position of the place of observation, it also approaches the zenith.

Every one, however, is struck with the phenomenon. But what is the cause of it? It is here that opinions differ—I mean the opinions of those who ask the question; for many see it, are astonished, and there rest satisfied, sure at least that they are not deceived. Some consider the fact as an optical illusion, and imagine that the mists of the atmosphere in this circumstance assume the character of a magnifying glass; others think that perhaps the Moon moves to a greater distance from us in proportion as it ascends. Both are evidently wrong, for they make a common supposition that the apparent diameter is larger at the horizon than at the zenith, an erroneous supposition which micrometrical measures contradict. Imagine at the optical focus of a telescope two parallel threads placed in such a manner that the Moon when it appears in the horizon can be exactly contained between them, and be made to touch them without projecting beyond them.

Leave them in their present position and wait until the orb has reached its highest position in the heavens. Now point the instrument again upon its disc. If the apparent dimensions of the last have really diminished what will happen? The Moon will appear to be entirely contained between the threads without touching them. Well, just the contrary happens; the disc projects beyond the threads. Therefore we must say, contrary to all appearances and to all the illusions of our senses: *the moon appears smaller at the horizon than at the zenith.* (Figs.

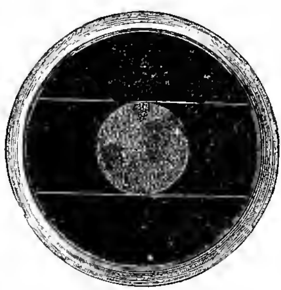


Fig. 14. Micronometrical measure of the Moon. Diameter of the Moon at the horizon,

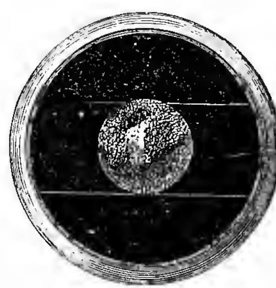


Fig. 15. Diameter of the Moon at the highest point of its course.

14 and 15.) It is then very clear that the opinions above mentioned have no foundation. Astronomers, who know this very well, have none the less tried to

account for the illusion, which is certainly indisputable. Some think it is an error of estimation, owing to the proximity of the lunar disc to the terrestrial objects situated in the horizon. In the zenith the absence of these objects causes us to believe that the star is nearer to us; we regard as smaller that which in preserving the same apparent dimensions seems less distant.

Euler assigns as a cause for the same illusion the elliptical form of the celestial vault, which causes us to estimate that part of the heavens situated in the horizon as more remote than the part directly over our heads. According to that mathematician, the comparison of the terrestrial objects situated in the vicinity of the Moon has nothing to do with the illusion. Whichever one of these explanations is true, it does not matter. That which it is necessary to remember is the fact that the discs of the Moon seen in the horizon and in the zenith do not differ in apparent size, as is supposed, or, if there is any difference, it is exactly opposite to what is supposed.

I have considered the Moon when it is full and is rising, but the phenomena are true for all the epochs, either when the Moon has the form of a crescent or of an incomplete circle, and they are the same, also, at its setting.

III.

THE LIGHT OF THE MOON.

THE LIGHT OF THE MOON IS DUE TO THE REFLECTION OF THE SUN'S LIGHT—ITS INTENSITY—QUANTITY OF LIGHT GIVEN BY THE DIFFERENT PHASES—COLOR OF THE MOON DURING THE DAY AND DURING THE NIGHT — CALORIC AND CHEMICAL INFLUENCES OF THE LUNAR RAYS.

THE soft and silvery light which the lunar disc diffuses over the Earth during our terrestrial nights has inspired many a poet and many an artist. But there is no necessity of making either art or literature a profession in order to enjoy the charm of a beautiful evening which the Moon illuminates by its rays, or, in order to admire the changes of light which are produced when the wind chases the clouds before its disc, and the vaporous masses, now dark, now brilliant, successively eclipse and unveil it. The character of the landscape aids, moreover, in the impressions, grave or gay, mild or severe, which the peculiar disposition of the individual makes still more varied. In considering natural phenomena, science has other interests than those of art or poetry; far from studying harmonies and contrasts with personal emotions, she tries to free herself from those influences, whose power she cannot forget. That which science desires above everything, is to study these phenomena in themselves, in noting their minute details, and in discovering their laws. And while poets and painters have long ago exhausted in their pictures all the varieties of beauty which the country illuminated by the light of the Moon can offer, science has not as yet determined all the questions which can be raised concerning that luminary; we shall see that some have been scarcely touched on.

It is known that the lunar light is no other than the light of the Sun reflected in space towards the Earth by the surface of our satellite. The proofs of this fact are entirely conclusive. In fact, the relative situations of the Sun, the Moon, and the Earth are always exactly in accordance with the form of the luminous part of the disc, or with the dimensions of the phases; it always happens that the parts are either illuminated or non-illuminated, according to the geometrical relation which their situations require. This fact is so simple that every one can observe it with the naked eye with the greatest facility. How then is the strange idea of the Chaldean astronomer, Béroze, to be explained, who considered the Moon as a globe half dark and half luminous, turning each hemisphere successively towards the Earth? There is every reason to suppose that he did not take the trouble to examine the positions which the principal spots occupy in the course of a lunation; he would have seen that these spots are always obviously on the same points of the disc, and that his hypothesis had no foundation.

In the telescope it is still more easy to be convinced that the source of the Moon's light is in the Sun; the innumerable irregularities with which the surface of the orb is covered are all illuminated on the side of the solar rays, and the shadows which they cast upon the surface are shortened or lengthened in the proportions which the obliquity of these rays requires.

Thus, that portion of the Moon which shines towards us, is that which enjoys the light of day; the obscure, invisible part, or the part which we are scarcely able to distinguish, is that which is plunged into night. Such would be the appearance of the Earth to us, if we were transported through space to the distance of the Moon, for example; casting our eyes toward our own globe, we should see that it had become a celestial, luminous body. Here, then, is the first question, as to the solution of which there is no doubt. Let us pass to some others.

What is the intensity of the light of the lunar disc, considered either intrinsically, or measured by the degree of illumination produced by the different phases? Of a given quantity of solar light which the surface of the Moon receives, how much is reflected to us? What proportion has been absorbed by the surface of our satellite? Is the light of the Moon white or colored? does it produce any appreciable chemical action on terrestrial substances?

We shall speak of what is known, and of what is thought to be known on all these points of the physical constitution of the Moon.

Compared with the light of the Sun, the light of the full Moon is only the $\frac{1}{801072}$th part; that, at least, is the number which is the result of the experiments of the philosopher Wollaston.* It would require, then, 800,000 full Moons to produce the light of day when the sky is perfectly serene.

* Bouguer, in the last century, obtained a very different number from that of the English philosopher; the light of the full Moon being, according to him, the $\frac{1}{300000}$th part of that of the Sun, more than double that which we have just cited from Wollaston. But the phonometer has not yet given the final decision; these two numbers, so different, are yet to be verified.

Indeed, the Moon is not always at the same distance from the Earth, but the question here is of the intensity of its light at its mean distance. The maximum intensity exceeds the minimum intensity by nearly a quarter, when the excess of the surface of the lunar disc at the epoch of perigee over the same apparent surface at apogee * is calculated.

The luminous intensity of the full Moon being estimated, it is easy to deduce that of the disc at its different phases. At the first and last quarters the intensity is, of course, diminished one half; at the two octants, the one of which precedes, and the other follows new moon, the light of our satellite is reduced to a seventh of its maximum intensity; at the two octants, on the contrary, the one of which precedes and the other follows full moon, it lacks only one seventh of the whole illumination of the disc.

These estimations are all geometrical, and infer that all the regions of the Moon, at the east, at the west, and at the centre, are equally luminous.

Now this is not the case. Arago has found that the light at the edge of the Moon is nearly three times as powerful as the light emitted by the large spots. As these dark spots are not distributed uni-

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* Perigee, the least distance, Apogee, the greatest distance of a star from the Earth; from the Greek words περι, near to, ἀπὸ from and γῆ, Earth.

formly over the different visible regions, it is necessary to measure the brightness of the disc in the whole course of a lunation.

Is the light of the Moon colored? According to Humboldt, it is slightly yellow, or at least appears so, when it is observed in full night. During the day, it is white, and appears to be of the same color as the clouds slightly illuminated by the Sun. Humboldt explains this difference in remarking that the natural yellow color of the Moon is modified during the day by the interposition of the blue color of the atmosphere. We know that blue and yellow are complementary colors—that is to say, that their mingling produces white light. During the night the sky has a much darker tone, a little greyish, so that the color of the lunar light is less changed.

At the horizon, the lunar disc is often a decided red, which is explained by the strong refraction which the luminous rays undergo while traversing the thickest part of the densest strata of the terrestrial atmosphere. Finally, when the Moon is seen from the streets of a city lit by the reddish-yellow light of the gas-burners, it appears a bluish-white; but this is evidently nothing but the effects of contrast.

We will speak further of the diverse tints which the different regions of the Moon present, as well as of the particular light of certain of its spots. Many things are said and repeated every day concerning the influence which the Moon exerts upon our Earth, and that which is said is so vague that it is necessary to study in a more exact and more scientific manner what foundation there can be for these free assertions. Let us see, then, whether the lunar light exerts any of this influence. First, the luminous rays which the Moon reflects towards our Earth, coming indirectly from the Sun, are without doubt accompanied by rays of heat with which our Sun floods all space.

It is probable that a portion of the heat received by the lunar hemisphere turned towards the Sun is absorbed by the surface. This is likewise true of our earth, and of all the celestial bodies of our universe. But another portion is, by reflection, sent back into space, and it is this which it is necessary to discover and estimate. Modern works on solar radiation establish, as a demonstrated fact, that the presence of an atmosphere, and, above all, of the vapor of water with which it is more or less pervaded, serves to diminish in a large proportion the radiation in space, and, consequently, the loss of the heat which the Sun sends us.* The gaseous

* See, on this interesting question, the volume of this collection which treats of the Sun.

stratum is a screen which allows the rays on entering to pass, and, on their return stops them.

The Moon, having no vaporous or gaseous atmosphere—as we shall see further on—the caloric radiation must be very intense, and, as the same point of the surface remains exposed more than 350 hours to the heat of the solar rays, it seems as if the quantity of heat reflected towards our Earth could easily be appreciated.

Is it so? The experiments of the ancients have given a negative result. The concentration, with mirrors or burning glasses, of the light of the Moon at the focus of these instruments has produced on the most sensitive thermometers no appreciable effect. Since then, Melloni has stated that there is heat, very slight, it is true, but very positive. M. Piazzi Smyth, in the Scientific Expedition of 1856 to the peak of Teneriffe, confirmed the experiments of Melloni. This is what M. Babinet stated in the fifth volume of his "*Studies and Lectures on the Sciences of Observation*:"

"'M. Smyth,' he said, 'could easily perceive the effect of the heat of the Moon, which Melloni had taken so much trouble to render perceptible in the experiments made in the vicinity of Naples. Although the Moon was then very low, the effect of its rays was still the third part of the effect of the caloric rays of a wax taper placed fifteen English feet distant.' "

Now, in order properly to appreciate this result, it is necessary to recall what we have said about the difficulty which the atmospheric strata caused in the passage of the caloric rays, which do not emanate directly from the source, or, if you will, which have already been once reflected. It is probable that it is the higher beds of our atmosphere which absorb the heat of the lunar rays, and that explains, also, the saying, *the Moon eats the clouds.* In fact, the elevation of temperature which it supposes, having the effect of rarifying the condensed particles of aqueous vapor of which the clouds are composed, these will be in part dissipated by the caloric action due to the presence of our satellite in the heavens.

There might be a method of verifying the exactness of this explanation, on the condition, however, of having previously established the meteorological phenomena themselves, by placing at different altitudes very sensitive thermometers, and there repeating the experiments of Melloni, not only at the epoch of full Moon, but for each of the lunar phases. It must be understood in advance that the variations, if they are established, must vary in proportion to the illuminated surface of the disc. The observations of M. P. Smyth, cited above, and which were effected at the altitudes of 2,700 and of 3,320 metres,* (about 9,000 and 10,900 feet,) allow us to hope that the means of verification which we propose will be efficient.

The light of the Moon exerts another influence which is not more doubtful :

We would speak of its chemical action on certain terrestrial substances. It is this action which renders possible the lunar photographs which are now obtained with a clearness and perfection so remarkable ; but this property which the Moon possesses, it shares, except in degree, with the solar light, a result which could be foreseen, since they have the same origin.†

Of late, the light of the Moon has been subjected to the operation of spectrum analysis. MM. Huggins and Miller have compared the spectrum obtained by examining limited parts of the Moon's surface with the solar spectrum. They have discovered no modification which allows the conclusion that the solar light has changed in nature by its reflection from the surface of our satellite.

Let us conclude then : if the Moon exerts upon

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* A metre = 3.28089 English feet.

† Photographs of the Sun are very easily obtained, the time necessary for the exposure to the light being a very few seconds.

the meteorological phenomona of our Earth a certain influence, that influence appears to be confined to very narrow limits. The heat which it radiates is almost entirely absorbed by the strata outside of our atmosphere ; the chemical action of its light, however slight it may be, is unquestionable. It remains to be determined whether it has anything to do with the advance of vegetation.

Finally, the calorific influence and the luminous influence must be at their maximum intensity at full moon, and at their minimum at new moon, a result which is in opposition to the popular belief.

IV.

THE ASHY LIGHT.

ORIGIN OF THE ASHY LIGHT—ITS INTENSITY—ITS COLOR—VARIATIONS IN ACCORDANCE WITH THE PORTION OF THE EARTH WHICH IS IN VIEW OF THE MOON.

THE bright portion of the moon, that which the sun directly illumines, varies in form during a complete lunation, from the slight luminous crescent of the new moon and of the last phase, to the complete circle which it presents at its full. But, besides this sufficiently brillant light, and what the intensity of this light is, compared with that of the Sun, we have just seen, the luminous disc presents in its dark part, during certain of its phases, a faint light much more feeble, known by the name of *ashy light*. The ashy light is very easily perceived with the naked eye. Every one can see it a few days before or after new moon, when our satellite appears in the form of a very slight crescent. The entire portion of the hemisphere turned toward us, which does not come in contact with the solar rays, is yet distinctly perceptible, so that the whole circle of the disc is complete. The faint light is feeble and phosphorescent. Arago has given a method by which its intensity may be estimated by comparing it with the constant intensity of the light of the rest of the disc, but we do not know whether any application has ever been made of the method.*

The ashy light of the new moon appears from the time the crescent is visible, and disappears scarcely before the first quarter; also, during the wane of the moon, it becomes visible a little after the last quarter, and disappears only with our satellite itself. (Fig. 16.) According to Shrœter and Lalande, it is near the third day which follows or precedes the new moon that it is the most vivid.

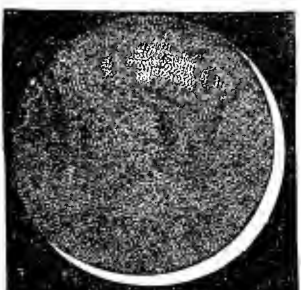


Fig. 16. Ashy Light.

* Except that Arago himself, who found that the intensity of the ashy light was $\frac{1}{4000}$ part of that of the luminous part of the Moon six days before the new moon and $\frac{1}{7000}$ part on the seventh day of the moon.

It is evident to every one that the exterior outline of the illuminated portion of the disc projects sensibly beyond the outline of that portion which the ashy light renders visible. This is an illusion produced by the optical phenomenon of *irradiation*, which gives objects an apparent dimension much greater when they are illuminated by a more brilliant light.

The intensity of the ashy light is strong enough to allow us easily to distinguish the largest spots even with the naked eye. But if a telescope of a certain power is used, a much larger number of details becomes perceptible. By means of telescopes the ashy light can be seen also for a much longer time than with the naked eye. Shrœter has observed it three hours after the first quarter, but according to the report of Arago, it was by using a magnifying power of 160, applied to a telescope of seven and a half feet in focal length.

Where does the ashy light come from? Is it a glimmer belonging to the Moon?

The ancients, who had no very positive ideas on physical astronomy, regarded it as produced by a kind of phosphorescence from the surface or the soil of the Moon. But it will be seen that the true explanation is too simple to admit of the least doubt on the subject. According to most astronomers it was Mœstlin who in 1596 discovered that the ashy light is only the light from the Earth reflected upon the Moon by the phases visible from our globe. But the same explanation—let us not forget to give due glory to a great painter—had been given a hundred years before Mœstlin, by Leonard de Vinci.

In fact the Earth sees upon the Moon precisely the same appearances that our satellite sees upon the Earth. But the terrestrial phases are inverse to the lunar phases, as figure 10 plainly shows. By turning to the illustration it is easy to see that the new moon corresponds to the *full earth*, so that the dark hemisphere of our satellite receives by reflection all the light of the illuminated hemishere of the Earth. At full moon, on the contrary, it is the dark hemisphere of the Earth which is in view of the illuminated lunar hemisphere, so that the Earth is then invisible. In fine, between these two epochs the Moon sees portions of the luminous hemisphere of the Earth, larger, in proportion as the Moon approaches new moon to us. (Fig 17.)

As, moreover, the apparent surface of our globe as seen from the Moon is about thirteen times greater than the lunar disc, it is easy to understand that the *Earth-light* must give to the nights of the Moon a light much greater than our Moon-light. The intensity will also be thirteen times stronger if the exterior surface of the two bodies are endowed with the same power of reflection.

Therefore the ashy light is merely the light of the Sun reflected first from the Earth to the Moon, and second from the Moon to the Earth. It seems cer-

Fig. 17. The Earth as seen from the Moon at the end of its course.

tain that the intensity of the lunar reflection is stronger during the period of waning than during the first days of the new moon. (Fig. 18.) Galileo has noticed it; since that great man, many other observers have confirmed the accuracy of the fact. To what is the difference due? Here is the explanation generally adopted:

When the Moon, at the end of its course, appears in the east, the luminous hemisphere of the Earth which, turned toward our satellite, illumines its obscure part and produces the ashy light, contains a large extent of land—eastern Europe, Africa, and above all Asia ; the seas occupy relatively a smaller

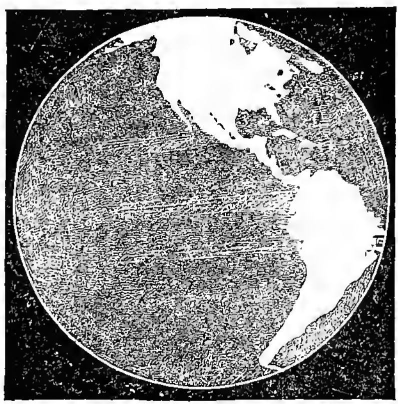


Fig. 18. The Earth as seen from the Moon at the beginning of the lunation.

extent. On the contrary, when it is in the west that we see the Moon appear, then the hemisphere which sends light to it is largely composed of the Atlantic and Pacific oceans. Now we know that the oceans absorb a much larger quantity of light than the land, so that the first of the two hemispheres seen from the Moon is evidently more luminous than the other; it illuminates then with greater power the dark regions of our satellite.

If this explanation is correct, it is clear that the contrary phenomena could be observed in Australia, where the ashy light will be less vivid during the waning of the Moon than during the crescent period of the Moon. But we do not know whether this fact has been established.

It has been said that this difference could proceed from the Moon in like manner, the eastern hemisphere of which presents a much larger extent of dark spots than the western hemisphere, and is consequently endowed with a greater power of reflection. This opinion seems quite plausible, and as it is not in contradiction with the first, it is very possible that the difference of intensity which has been observed proceeds from the two causes at the same time.

The term *ashy* light indicates, generally, a greyish color. However, various observers have considered it of a greenish-olive tint, which was perhaps only accidental. Arago, one of the latter, was inclined to believe that this tint is due to the effect of contrast produced by the vicinity of the luminous crescent, the color of which is a yellow-orange. But he inquires whether this phenomenon of color could not be attributed to the bluish-green tint reflected upon the lunar disc by the terrestrial atmosphere. If so, the explanation of Lambert, also reported by Arago, deserves more consideration. We give the words of the illustrious astronomer, which Humboldt cites also in his *Cosmos* :

"On the 14th of February, 1774, I saw that this light, very far from being ashy, was of an olive color. . . . . The Moon was vertically over the Atlantic Ocean, so that the Sun cast its rays perpendicularly upon the inhabitants of the southern part of Peru. The Sun then shed its strongest light upon South America, and if the clouds intercepted no portion, that great continent reflected upon the Moon a sufficient quantity of greenish rays to give this tint to that part of the Moon which the Sun did not directly illumine. This, I think, can be stated as the reason why I saw the light of the Moon an olive color, while it usually is called ashy. So the Earth seen from the planets could appear of a greenish light."

V.

THE MOON CONSIDERED AS THE LUMINARY OF NIGHT.

INEQUALITY OF THE ILLUMINATING POWER OF THE MOON — IRREGULAR DISTRIBUTION OF ITS LIGHT DURING THE NIGHTS OF THE DIFFERENT SEASONS— THE DURATION OF ITS NIGHTLY VISIBILITY IN A WINTER LUNATION.

In speaking of the Moon, poets never fail to call it the torch of night; this is periodically very true, that is, at the epoch of full moon, but it is very far from being correct for the rest of the lunation.

If it is true that the function of the Moon is to illuminate the terrestrial nights, and thus to supply the absence of the solar light, it must be admitted that it performs the task in a very inadequate manner; I do not speak of the intensity of its light, so remarkably inferior to that of the Sun, but of its regularity and constancy.

Let us first observe that the phases of the Moon are so arranged that in a lunar month it passes through all degrees of size—from new moon, when the Earth receives no light from its satellite, to full moon, when it receives nearly all. The terrestrial nights are thus seen to be very unequally supplied. In reality, the quantity of light reflected by the disc of the Moon is exactly equal to that which it would send us if it were constantly at its first or at its last quarter, since, in considering any phase whatever, during the increase of the Moon, that phase has its exact complement during the wane; the illuminated portions of the disc united at these two epochs, would exactly form a full moon.

This is not all. During the whole time that the Moon is visible, between two successive new moons, the nights alone can profit by its light. Now all the time that it is above the horizon at the same time as the Sun, the light is entirely wasted, just as is that of a candle when lighted in full day. In view of this the nights of our planet are very differently illuminated, according as they belong to one or the other of the four seasons. It is during the long nights of winter that the light of the Moon could show its greatest utility. Well, it is just at this very epoch that it discharges in the worst manner its pretended functions. I will give an example. The seventh of November, 1866, at about half past ten in the morning, the Moon had reached the epoch of conjunction; it was new moon. The lunar month terminated the seventh of December following, at half past five in the morning. In this interval, the total duration of the nights, counting from the setting to the rising of the Sun, amounted to about 466 hours and a half; now at the latitude of Paris, the Moon is not visible, or, at least, is not above the horizon at night more than 218 hours, less than half of the total duration.

That is not all. By the simple fact of its own motion, combined with that of the Earth, our satellite is a very poor illuminator of our nights; but there is more than this, if, with the irregularity and the insufficiency of its light, we join the obstacles which arise from the inclemency of the atmosphere. The clouds and the fogs aid, also, too often in our climate in intercepting its feeble rays. We can by this instance see how puerile and vain are the claims of those who wish to interpret phenomena especially to aid their own systems, and to substitute for the views of nature their feeble explanations. The Moon certainly has a reason for existing, but it is by studying that which is, not by imagination, à priori, that man can hope to lift a corner of the veil which hides the truth from us.

VI.

THE LARGE SPOTS ON THE MOON.

POPULAR OPINIONS ON THE FORM OF THE MOON—PERMANENCE OF ITS SPOTS—THE DARK SPOTS: SEAS, LAKES, AND SWAMPS—THE BRIGHT SPOTS ON THE CONTINENTS.

THE principal spots on the Moon are very distinctly perceptible with the naked eye. Some portions, of a more sombre tint than the general light of the disc, are cut with clearness on a background, the luminous intensity of which seems to be itself unequally distributed.

There is no one who may not, even without making a regular study of the spots visible to the naked eye, familiarize himself with the appearance which these differences of color give to the lunar disc. Every one can observe, also, that this appearance does not vary, or, at least, does not vary much, either in the same lunation, or in the course of successive lunations. The Moon, in fact, always presents the same side to the Earth; it is the same hemisphere which we see always. We shall see later that this permanency of the spots testifies to the motion of rotation of the Moon, the duration of which is exactly equal to that of its revolution around the Earth.

A popular opinion, very widely spread and very ancient, perceives in the figure of the full moon a human face or body, for, according to the imagination of the observer, it is either the one or the other of these two appearances which it most readily represents. "The dark and luminous parts," said Arago, "delineate vaguely a sort of human figure, the two eyes, the nose, and the mouth." Others see in the same spots a head, arms, and legs; in our country, it is Judas interred in the Moon, in punishment for his crime of treason and felony.

We will not dwell upon these passing remarks, the sole merit of which is to prove that this fact, to which we would call the attention of the reader, has long been established.

In the course of a lunation, the disc not being entirely visible except on the day of full moon, it is to this epoch that we must give the preference for studying the general distribution of the spots.

At the first quarter we see the western part of the visible hemisphere; only the last quarter shows the eastern part.* When the crescent is very slight, it is difficult to distinguish any spots with the naked eye.

Let us then take the instant of full moon for our description.

Let us first remark that the large greyish and dark spots occupy especially the northern half of the disc, while the southern regions are white and very luminous; this luminous color is seen again on the northwest edge, as well as toward the centre; and, on the other hand, the spots invade the southern regions on the eastern side, while at the same time they continue around to the west, though less dark. Except a slight portion of the northwestern

* In order to observe the Moon in its passage over the meridian, we must evidently turn toward the southern part of the horizon. Then the two extreme points of the diameter of the disc perpendicular to the horizon give the northern and southern points. At the left we find the east, and at the right the west. If it is observed with an astronomical glass, the image is inverted, the south is at the top, the north at the bottom of the disc; the west is at the left, and the east at the right. In order to distinguish the different regions of the Moon, we consider either the southern and northern regions, or the western and the eastern parts, each of these parts comprehending the half circle, at the vertex of which we find the point which gives it its name. The northern and southern poles are situated, the first in the northern region, the second in the southern, but without coinciding exactly with the north and south points of the disc.

edge, the entire curve of the Moon is white and luminous, and partakes of the tone of the southern regions. Let us now enter upon certain details.

You will see toward the west, and very near the edge, a large greyish spot, of an oval and regular form, isolated in the midst of the more luminous color of the edge; this is the *Mare Crisium*. Do not attach to the name of this sea any special meaning; it is the common name by which the first observers designated all the large greyish spots of the Moon; farther on, we shall give the reasons which impelled them to consider these spaces as large extents of water, while they considered the brilliant parts with which they were surrounded as the lunar continents. The situation of the Mare Crisium, on the western boundary of the Moon, enables us to recognize it from the time of the first phases of the lunation, until the full Moon; for the same reason it is the first to disappear at the beginning of the wane.

Between the Mare Crisium and the centre of the disc, a large dark space cut at its lower part by a kind of pointed promontory, has received the name of *Mare Tranquillitatis*. It throws towards the west two appendages, of which the most westerly and the largest forms the *Mare Fœcunditatis*, so that the other, smaller and nearer the centre, is the *Mare Nectaris.*

If now from the Mare Tranquillitatis we look towards the north, we find the *Mare Serenitatis*, smaller than the first, but also a little more regular in form than the Mare Crisium. This spot is crossed in its entire length by a brilliant ray, almost rectilinear, which gives it a certain resemblance to the Greek letter phi (Φ). The *Mare Vaporum* is like a prolongation towards the centre of the Mare Serenitatis.

Finally, the *Mare Imbrium*, round in form, is the largest of all those which we have mentioned, and terminates at the north, the series of greyish spots, called seas, which improper name we have agreed to preserve. We must now cross towards the east in order to find the *Oceanus Procellarum*, the boundaries of which are more indistinct, and are lost towards the south in the *Mare Humorum* and the *Mare Nubium*, at a very short distance from a luminous point, at which whitish streaks of great length separate in all directions.

We perceive, also, above the Mare Serenitatis, and in the vicinity of the north pole, a narrow spot elongated from east to west, and known by the name of *Mare Frigoris ;* at the limit of the northwest edge, a spot of an oval form, very much elongated, is the *Mare Australe;* and, finally, on the extreme edge of the southwest portion, the *Mare Humboldtianum*, of which we, without doubt, perceive only a part.

All these pretended seas form on their shores, or in prolongations, smaller dark spots which have received the name of *Sinus*, *Lacus*, or of *Palus*. Wo will mention a few. Between the seas Serenitatis and Frigoris, the *Lacus Somniorum* and the *Lacus Mortis* extend. The *Palus Putridinis* and the *Palus Nebularum* occupy the western portion of the Mare Imbrium, the northern bank of which forms a round gulf known by the name of the *Sinus Iridium*, or *Bay of Rainbows.* The *Sinus Roris* is the prolongation towards the centre of the extreme northwest corner of the *Oceanus Procellarum.*

Finally, to end this nomenclature, which by-and-by will be very useful to us in the geographical description of our satellite, let us mention the *Palus Somnii*, to the west of Mare Tranquillitatis. The *Sinus Medii*, which is the southern prolongation of the Mare Vaporum; and, also, the *Sinus Æstuum*, which is on the southern border of the Mare Imbrium.

As to the large, luminous, and brilliant spaces which encompass the grey spots, they have, for

Fig. 19. CRATERS AND LUNAR CIRQUES ACCORDING TO NASMYTH.

some unknown reason, received no general name; they are quite unlike them, as we shall see by the details, invisible to the naked eye, which the telescope shows.

CHAPTER II.

THE MOON SEEN THROUGH A TELESCOPE.

VII.

THE MOUNTAINS OF THE MOON.

GENERAL DESCRIPTION.

THE lunar spots which we are about to describe, when examined by the naked eye only, teach us nothing of the real structure of our satellite. It is through the telescope that we must now study these, as well as the brilliant regions which surround them, of which we have as yet said nothing, except that they differ in brightness from the first.

Place the eye, then, at an instrument of medium power, that is to say, one magnifying from 30 to 60 diameters. Choose the period when the Moon is in one of its quarters; that is, when the disc presents to us its eastern or its western illuminated half.

An astonishing spectacle immediately offers itself to our view. All the white or brilliant parts of the disc appear to us studded with an immense multitude of cavities of a circular or oval form, and of very different dimensions.

It is in the central regions, or rather on the limits of the illuminated parts of the Moon that these irregularities of the surface seem the better to indicate the structure of which we speak, and which it is impossible not to recognize. They are like so many hollows, the verges or edges of which, in the form of ramparts, raise themselves both above the general level, and also above the bottom of the cavity. Each one of them is vividly lighted on the same side of the luminary, that is, on the exterior of the half circle which presents its convexity to the solar rays, and on the interior of the other part of the circumference, which presents its concavity to them.

On the obscure side of the disc, on the contrary, we perceive very marked shadows, which serve to show wonderfully the general form of the irregularities of the surface; yet the bottom of the cavity is sometimes very luminous, sometimes of a more sombre hue, and in some of the cavities we perceive very clearly eminences which cast shadows upon the interior ground.

Their dimensions, we have said, are very varied.

Some seem like little hollows, from which the soil is sifted; others are like vast circles or circular enclosures, which contain, sometimes on the inside, and sometimes on the edge, cavities of much smaller dimensions.

This first glance cast by the aid of a telescope on the disc of the Moon shows clearly to us that the lunar ground is covered with depressions and elevations. These elevations are nothing else than the mountains of the Moon.

Let us continue our investigation.

We have seen that the form of the irregularities of the surface is sometimes circular, sometimes oval. Is there a real difference between the two aspects? No, as we can readily convince ourselves.

Notice this circumstance. The accurately circular form belongs to all the cavities, to all the spots situated in the central regions of the disc. When we examine those which recede from the centre, approaching little by little the edge, we perceive that this form becomes insensibly oval or elliptical, and the oval is all the more elongated as the cavity which we examine is nearer to the edge, whatever may be the direction we have chosen in making this examination. Moreover, the greatest diameter of each ellipse is always parallel to that portion of the arc of the circle of the lunar edge, which we obtain by joining the centre of the disc with the centre of the cavity examined.

The least reflection upon these singular circumstances forces us to recognize that the real form of each cavity is circular. The elliptical appearance is only due to an effect of perspective, arising from the fact that every circle is drawn on different parts of a half sphere. The portions of the surface which are opposite to our visual ray, perpendicular to its direction, do not appear to us distorted; the others, on the contrary, are seen obliquely, and their distortion is greater in proportion as they are seen at a greater obliquity. Therefore, when we speak here of circle and ellipse, it is understood that we speak exclusively of the particular irregularities which the outlines of this cavity present.

Suppose, now, that we have observed the Moon at the precise period of its first quarter. The next day and the days following, if the sky permits, let us continue our examination.

We shall see the light invade by degrees the eastern regions of the disc, and little by little, new elevations appear, the tops of which alone were first lighted by the Sun. Nothing is more curious than to see at the bottom of the shadow the interior side of a new cavity first appear in the form of a crescent, then the light increase, penetrate to the bottom of the cavity, and finally light up the whole outline.

At other times it is an isolated, luminous point, the summit of which shines, although the base of the eminence is still entirely plunged in darkness.

In proportion as the Moon follows its course, and its illuminated phase enlarges, we see, as we then expect, the shadows of mountains diminish in extent, the bottom of the plains become lighted with greater brilliancy, and the structure of our satellite display itself to our eyes in all its details.

Let us say at once, to simplify the language, that we have given to the lunar cavities of small and medium dimensions the names of craters or volcanoes; to those of larger dimensions, the names of "*cirques*,"* and that the isolated mountains of pyramidal or conical form are peaks. We shall soon see what legitimacy there is in these different denominations.

Let us now see how the mountains are distributed on the surface of the Moon.

At first we are struck with the inequality of this distribution. Notwithstanding that in general the luminous regions are scattered over with cavities,

* We have kept this word, "cirques," although it might perhaps have been translated "circus," or "amphitheatre." Webb uses the term "walled plains."

and bristling with elevations, the great greyish spots which we have called seas are almost totally destitute. Where they are the most numerous is principally in the southern part of the Moon, in the large space which is surrounded on the north by the Mare Nectaris, the Mare Tranquillitatis, and the Mare Vaporum, and on the east of the Mare Nubium, and the Mare Humorum. There the craters and the cirques are so numerous that they barely leave narrow valleys between their ramparts or boundaries.

At the north pole, beyond the Mare Frigoris on the southeast, on the borders of the Ocean of Tempest, and lastly, in the northwest region, near the Mare Crisium, we find the same character of surface, covered with the same crater-like elevations, although the borders of the west and east are evidently the prolongation of regions occupied by seas.

At the period of full Moon the lunar mountains appear entirely illuminated; some, those of the central regions, because they receive the solar rays vertically; the others, those of the regions near the border, because their shadows are thrown, relatively to us, behind the eminences which form them. Nevertheless, all are easily distinguished, thanks to the more vivid light with which their edges shine.

Among them are some notably more luminous than the generality of the others; we shall describe them, because they will serve us as signs or land-marks for a more detailed description of the orography of the Moon.

In the southern part of the disc, south of the Mare Nubium, at an apparent distance from the lower edge of the Moon, nearly equal to a sixth part of the diameter of the orb, a crater, whose dimensions exceed the medium, is distinguished at once by its brightness, by the presence of a peak in the centre of its circumference, and by the multitude of white and brilliant beams which radiate all around it to a great distance. This is Tycho, which appears to be the centre of a vast system of crater-like mountains.

Copernicus, Aristarchus, and Kepler are three other remarkable craters, all situated in the midst of the region of seas, towards the northwest, and all surrounded by luminous, radiant beams. Their position causes them to be easily distinguished; the first appearing to be the centre of a small system which separates the Mare Nubium from the Mare Imbrium; and the other two, very brilliant, standing out in relief from the greyish bottom of the Ocean of Tempests.

Nearly in the middle of the disc, to the south of the Sinus Medii, (Fig. 19,) three large cirques, the circumferences of which are almost contiguous, and whose dimensions are almost equal, have received

Fig. 20. Copernicus.

the names of Ptolemæus, Albategnius, and Arzachel. Their ramparts render them distinctly visible, especially at the period of the first quarter of the Moon. (Fig. 20.)

Other craters or cirques, instead of being distinguished by their brightness, are remarkable on account of the sombre shade of their bases. Such are especially the crater Plato, on the northern shore of the Mare Imbrium, which appears like a black oval spot ; Endymion, a large crater, near the northwest, between the Mare Humboldtianum and the Lacus Mortis, and which appears very dark even in full moon ; finally, the large crater Grimaldi, on the shore of the Ocean of Tempests, whose dark oval rises from the luminous bottom of the eastern border of the Moon.

Before studying more intimately the lunar topography, and stating what we know of the principal formation of our satellite, let us give some details of the dimensions and areas of the large spots, called seas, and of the heights of the lunar mountains.

VIII.

THE MOUNTAINS OF THE MOON.

DIVISIONS OF THE ANNULAR MOUNTAINS, OF CRATERS AND OF CIRQUES—ALTITUDES OF RAMPARTS AND OF PEAKS.

In considering the Moon rigorously a sphere, we find that its total area is about 14,684,000 square miles. This calculation gives 7,300,000 square miles for the surface of the visible hemisphere (about 7,342,000). Three tenths of this last extent are occupied by dark spots, seas, lakes and marshes, or rather by the lunar plains, and the other seven tenths belong to the mountainous regions, that is to the brilliant parts of the disc, which are covered by the numerous craters, cirques and walled plains visible through the telescope. But, as we have already said, and as we shall see farther on, if the seas and plains compared with the mountainous regions seem unitedly and relatively destitute of these asperities, otherwise so numerous, here and there crater-like mountains are seen in the midst of their precincts like so many elevated summits which a general inundation has not been able to reach.

While, the eye at the glass, we contemplate the multitude of cavities with which the surface of the Moon is marked, it is impossible not to be struck by the resemblance which these circular openings bear to the terrestrial volcanoes. Hence the name of volcano has always been given to most of the mountains of the Moon. But the analogy of form may lead us into error when we endeavor to seek the causes of the lunar phenomena if we do not first give an exact idea of the dimensions of these mountains, the surfaces which their bulwarks enclose, and the height of their elevation above the surrounding surface.

Let us begin with the large excavations which have received the names of "*cirques.*"

The most considerable of all appears to be Schickard, an immense cirque situated near the south-west border of the Moon, a little below the Mare Humorum. Its diameter is estimated at 160 miles, which would give to the embankment surrounding it an extent of 507 miles and to the enclosure itself a surface of more than 19,500 square miles: it is the 760th part of the whole area of the Moon, and the 11th part of the area of

France. Clavius, a large irregular cirque which we perceive a little south of Tycho, and Grimaldi, come next, the first having a diameter of 143 miles, the second measuring 140 miles in width.

Let us also give among the annular mountains which we have already had occasion to mention, Ptolemæus, Hipparchus, Plato, Copernicus and Tycho; the diameter of the large cirques are respectively 115, 88, 60 and 55 miles. More than thirty other cirques present diameters of more than 50 miles.

If we proceed from cirques to craters, we shall still find a considerable number of the latter whose extent in diameter and surface will be much greater than that of the volcanoes on the Earth. This is the case in the mountainous region situated nearly southwest of Ptolemæus; the cirque of Abulfeda, whose diameter is about 23 miles, is surrounded at different distances by a number of craters, whose transverse diameter is from one to three miles. The largest volcanic areas of the Earth are about ten miles: Such is the volcanic circumvallation of Teneriffe, but the real craters are only from 500 to 650 feet in diameter. As Humboldt says, craters of this size would be barely visible in the Moon.

We give here (Fig. 21) a small part of the beautiful chart of the Moon, the details of which have been collected and drawn by Beer and Mædler.

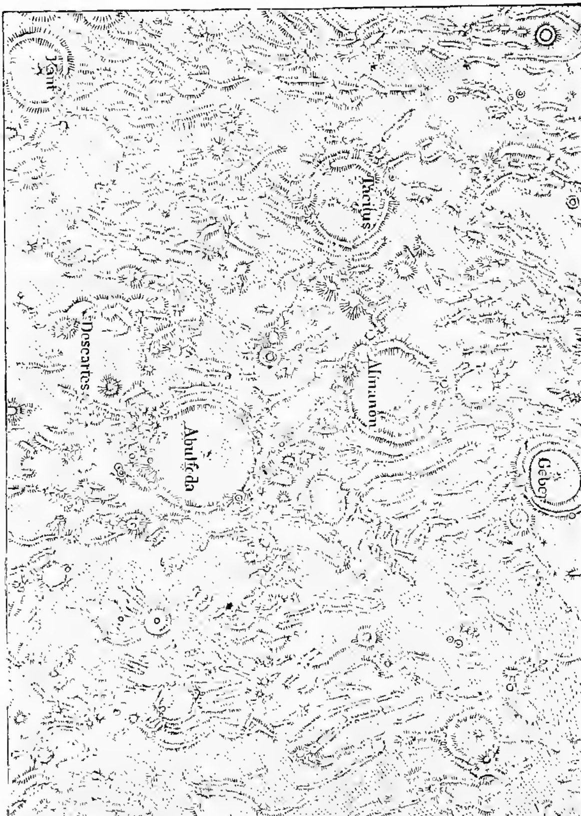


Fig. 21. Circular and elliptical forms of the lunar mountains.

This fragment represents a section of the mountainous region which covers a large portion of the southern part of the disc between Tycho and the Mare Nectaris. Five large cirques, Geber, Tacitus, Almanon, and Abulfeda, and Descartes are accompanied by numerous smaller craters. The valleys which separate these annular mountains are themselves very irregular; a number of small hills grouped in parallel ranges extend in every direction.

As for the intrenchments of the cirques, we can see that they are not contiguous throughout; some peaks tower over summits of different altitudes. Finally we may remark that the boundaries are sometimes formed of two lines or layers, parallel or circular, forming tiers.

But what are these heights? How much are they elevated above the surrounding surface, above the bottom of the circular spots, and above the exterior valley?

These are questions which are not only interesting, but are of great importance in the topographical and geological study of our satellite.

We have a good deal of data on these points. Without speaking of the measure of the altitudes of a certain number of mountains, inaccurately estimated by the astronomers of the last century, let us say that Beer and Mædler have determined the altitude of eleven hundred points on the surface of the Moon. We will not enter upon an exposition of the methods adopted for this kind of measurement, although they are very simple and based upon elementary geometry. We will content ourselves by giving the results.

It is in the neighborhood of the southern pole that the most elevated summits of the lunar mountains stand. Two peaks belonging to Mounts Dörfel and Leibnitz attain a height of 25,000 feet, much higher, as we see, than those of our Mt. Blanc (15,800 feet.)

From the summit of one of these mountains the eye embraces an horizon of more than 50 miles, a great distance upon a globe whose curvature is so marked.

Four other mountains exceed 19,000 feet in height. One of the peaks which rises on the west from the enclosure, called Clavius, measures 23,000 feet above the base of a crater situated in an immense cirque. The annular mountain of Newton, near the southern pole, is bordered by embankments which tower over 24,000 feet above the base of the crater: this is the altitude of the highest summit of the Andes. "The excavation of the crater of Newton is such," says Humboldt, "that the base is never lighted either by the Sun or by the Earth," a circumstance which arises, also, from its extreme position on the disc of the Moon. Mounts Casatus and Curtius rise to the heights of 22,800 and 22,200 feet.

In the northern regions, we find, also, extensive elevations. Calippus, one of the peaks of the Caucasian chain, and Huggins in the Apennines, attain respectively 20,400 and 18,200 feet in height. The ridge of this last chain is bordered on one of its sides by precipices of a frightful depth, and the peaks of which it is formed cast their shadows a distance of more than eighty miles.

The mountains, in the form of isolated domes and pyramids in the centre of cirques and craters, are generally less elevated than the summits of the boundaries. But, if we measure their heights from the level of the lower surface we still find summits which exceed the highest mountains of Europe : the peak of the crater of Tycho is 16,400 feet high, and that of Eratosthenes, at the extremity of the Apennine chain, rises 16,000 feet above the base of the cirque. According to Humboldt, Beer and Mædler have measured 39 summits whose heights are greater than that of Mont Blanc, and, as we shall see, four exceed 19,000 feet, that is to say, they compete with the highest peaks of the Cordilleras and Andes.

Strictly speaking, the measure of the lunar mountains cannot be compared with that of terrestrial mountains. These are all computed from a common level, the ocean. Such a common surface does not exist in the Moon;* the heights are there counted from the surface of the surrounding plains. When craters are in question, the height is generally greater above the base of the spots than above the exterior level; both of these altitudes have often been measured.

However this may be, it is certain that, all proportions regarded, the elevations of the surface of the Moon are greater than those of our planet.

Mounts Dörfel and Leibnitz are, it is true, lower by nearly 4,000 feet than the famous Gaurisankar of the Himalayas. But while this giant of terrestrial mountains does not exceed the 720th part of the radius of our planet, Mounts Leibnitz and Dörfel have a height equal to the 229th part of the lunar radius. That is relatively more than triple.

* The large plains called seas appear in general to be of a lower level than the valleys which extend between the cirques and the craters of the mountainous regions. The surface is otherwise more even, so that they can serve as a common level for the measurements of height, but we do not know that the difference in the level of the two regions has been accurately determined.

IX.

TOPOGRAPHY OF THE MOON.

CRATERS, CIRQUES, AND CHAINS OF MOUNTAINS.

There are, then, two characteristics which distinguish the elevations of our satellite from our terrestrial mountains. First, their very general circular form; second, the prodigious height of a great number of them.

Let us enter into details which are more particular and more characteristic, and which, as we shall see, show more plainly these differences.

Most of the mountains of the Moon, as we have said, assume an annular form, their tops either collecting together and forming immense circles, surrounding a level and smooth plain, or, more likely, one bristling with isolated peaks, or else resembling a volcanic cone, whose interior cavity or crater is rounded in the form of a bowl. A very small number are of a decidedly oval form; the numerous ellipses which we see on the borders being nothing but circles foreshortened to our sight. There do exist, however, a certain number of elliptical forms, such as those of Figs. 21 and 25 (pp. 84 and 100). One, very regular, appears between the cirques Abulfeda and Almanon. Two others, the cirque Godin, south of Agrippa, and an inclosure surrounded by hills, slightly elevated between Triesnecker and Agrippa, present also plainly an elliptical form. It is similar in the other regions of the Moon; but after all these are few in number.

The large plains are limited by circular arcs, and bordered by very high and steep mountains, whose great expanse has caused them to be regarded as chains. The Sea of Crises bears in form a strong resemblance to a cirque. The Sea of Serenity and that of Rains have elevations in a large part of their craters, thus showing the character of all the irregularities of the lunar surface.

We shall now speak of mountain chains. There exist, in truth, on the Moon, certain series of elevations, which we can liken to our terrestrial mountain chains. We shall name the most important. The greater part are found in the northern regions of the disc.

At the southwest of the Mare Imbrium, over a length of 460 miles, rises a succession of peaks and bluffs, which separate this great plain from the Sea of Vapors, the immense height of which we have already cited ; they are the Apennines. Their general direction is from northwest to southeast.

At this last limit another chain begins, which runs from west to east, and which, under the name of Carpathians, is only an extension of the Apennines. It is at the south, and about 100 miles from the Carpathians, that the radiant cirque of Copernicus is found.

The Caucasian Mountains and the Alps limit, on the west and northwest, the Sea of Rains. (Fig. 22.)

Fig. 22. Lunar Mountain Chains. The Apennines.

The first of these chains is formed of a series of isolated peaks or needles, some of which rise to a height of 19,000 feet. The Alps, also, are analogous in structure.

For the most part, the remaining chains of lunar mountains, such as we are about to describe, seem to be portions of immense circuits, reminding us, in their general form, of cirques of the smallest dimensions. Such are Mounts Taurus and Hémus, on the shores of the Sea of Serenity, whose highest summits attain an elevation of 9,000 and 6,300 feet. West of Taurus is seen a crater 25 miles in diameter, the terraces of which reach a height of 11,600 feet. It is known by the name of Rœmer. Such, also, are the Altaï Mountains and Pyrénées, which surround the Sea of Nectar; the Altaïs offer an extent of about 100 leagues from north to south and southwest; next to the Apennines, it is the largest chain.

The Urals and Riphées seem to be fragments of a chain, at one time more extended, which doubtless separated the Mare Nubium from the Oceanus Procellarum, and that from the Mare Humorum.

On the extreme eastern border of the visible hemisphere, two ranges of mountains have received the names of Cordilleras and Alemberts, and are prolonged toward the south by the Rook Mountains. Their summits stand out in relief on the border of the disc, at elevations of 19,000 feet.

We have already noticed the prodigious height of the two chains which surround the south pole of the Moon, Leibnitz and Dörfel.

In recapitulation, the configuration of the lunar mountains differs materially from the mountains of our globe. While the terrestrial chains extend oftener in a straight line, or parallel to a great circle of the sphere, forming a series of systems which intersect each other at different angles, each one of which corresponds to a particular period of upheaval, the mountains of the Moon are all or nearly all developed in arcs of circles, from the small craters and cirques to the immense circumvallations which surround the plains.

[NOTE TO CHAPTER IX.—The accompanying engravings of lunar craters, or walled plains, are from wings by Miss E. R. Coffin, of Brooklyn, March 9th and May 16th, 1872. The instrument used for this was the equatorial telescope of the observatory of Vassar College. In both cases the time is shortly after the first quarter of the Moon.

The sunlight appears to be falling upon the Moon's surface from the left, illuminating t' raised portions of the disc so that they form stror contrasts with the unilluminated portions.

The peculiarities of the first figure are the two interior small peaks, one of which throws its pointed shadow on the floor of the enclosure; and the narrow spurs or ranges of elevations which seem to run out from the walls.

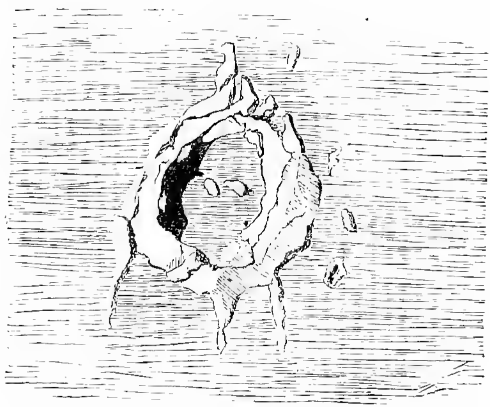


Fig. 23. Lunar Crater. Moon about ten days old. April 17th, 1872

The second figure (which I think remarkably faithful in detail) is of a crater just at the terminator; the blackness of the unilluminated Moon is seen on the right.

On the left, the sunlight is falling upon an irregular wall, which throws its black shadow upon the enclosed plain. Within the enclosure are four similar formations; raised walls, surrounding elliptical depressions, into whose depths the sunlight has not yet shone—craters within craters. Near these small craters are several small, bright points—peaks which, like the walls of the craters, throw dark shadows on the right.—Ed.]

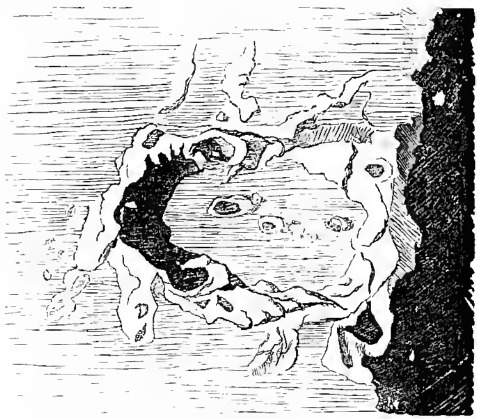


Fig. 24. Lunar Crater, with group of interior craters. Moon about nine days old. May 16th, 1872.

X.

TOPOGRAPHY OF THE MOON.

GROOVES AND HILLS.

At the period of full moon we perceive in some regions of the disc long, whitish furrows ordinarily rectilinear, or, at least, presenting only slight curves, and, for the most part, so narrow that it requires great attention, eye-pieces of high powers, and very favorable atmospheric conditions to distinguish them from all other irregularities of the lunar surface. During the phases, these furrows appear like black lines.

These are "*rainures*" or grooves. Their dimensions vary in length from 10 to 180 miles, and in breadth from 1,500 to 10,000 feet. In the entire extent of their course this breadth varies very little, and when it increases, it is never at either of the extremities, but at an intermediate point. The narrowness of these grooves suffices to distinguish them from the bright, radiating bands which we have already mentioned, and which we shall soon describe more minutely. But we must notice between them a difference altogether characteristic.

While the luminous bands have no projections or bluffs, and are altogether superficial irregularities of the surface, the grooves, on the contrary, are formed by excavations, the parallel edges of which are very steep, but without exterior embankments.

This structure is very apparent when we observe them in the phases which follow or precede full moon. Then each one of them appears like a black line, indicating the shadow cast by the edges on the bottom of the crevice.

Most of the grooves are isolated, sometimes running through the plains, sometimes passing by the sides of the craters, sometimes even traversing their enclosures. Some are bounded by mountains, but there are also some which terminate without any obstacle opposed to their prolongation.

They are to be met with in all the regions of the surface of the Moon, in the mountainous regions, as well as in the plains, and if they are more numerous towards the centre of the disc, it arises, without doubt, from the fact that we perceive such delicate objects with much greater facility when they are seen in the front, without being distorted by the obliquity of the visual rays.

In several points the grooves appear in groups of parallel lines; such are, for example, the grooves which extend to the northwest of Gutenberg. More rarely they cross each other and unite like veins; such are the grooves in the neighborhood of Triesnecker, on the border of the Sinus Medii. Finally, among the isolated grooves there are some which are entirely situated in the interior of cirques, like those which traverse the great circular valley of Petavius, without bordering otherwise on its ramparts. The cirques of Almanon and Abulfeda (see Fig. 21) are united by a groove tangent to the two boundaries, which stretches from one to the other, traversing a succession of small and medium-sized craters, which are on the borders of the two cirques.

The rectilinear form is the most general. We find, however, some grooves of sinuous form, such as that which extends on the northwest of Aristarchus. This remarkable groove commences near a mountain in the neighborhood of Herodotus, at first narrow and of slight depth, then describes two sharp angles and becomes steeper and larger.

Near Aristarchus it rises abruptly to more than 3,300 feet above the neighboring plain; then, changing direction, it winds itself, and, finally, at a breadth of two and a half miles, it contracts considerably, and terminates in the crater of Herodotus, which it enters as by the mouth of a river.

The depth of the grooves is considerable, often reaching from 1,000 to 1,500 feet.

Such are the most interesting peculiarities offered by these hollow furrows, or clefts, as it were, of the lunar surface, whose form contrasts so completely with most of the mountains which cover our satellite.

It was not till toward the end of the last century that the grooves were observed for the first time, and it is to Schrœter, one of the most successful modern observers, that their discovery is due. On the 5th of December, 1788, the astronomer of Lilienthal recognized the groove of Hyginus (Fig. 25), one of the most curious of all, because it traverses ten craters from one and a quarter to two miles in breadth, and breaks the embankments of the largest of these, called also Hyginus.

Beer and Mædler have more recently noticed this. In our illustration nearly the whole of this remarkable cleft can be seen.

Other observers, Pastorf, Gruithuysen and Lohrman, have discovered several more, but the industrious authors of the selenographical map have observed the greatest number of these singular formations. Thanks to them, we know to-day nearly one hundred grooves spread over all the regions of the visible hemisphere.

Fig. 25. Clefts of Hyginus and Triesnecker.

But what is the origin of these long and narrow valleys?

Schrœter, who believed the Moon to be inhabited, who supposed a city to be situated north of the crater of Marius, who, in his works, dwelt continually on the arts, the industry, and the culture of the inhabitants of the Moon, Schrœter, I say, could not doubt the artificial origin of the grooves. According to him, they are canals dug by the inhabitants of the Moon for their commercial needs.

In accordance with this idea, Doctor Gruithuysen, another partisan convinced of the existence of inhabitants of the Moon, finds no difficulty in admitting the explanation of Schrœter.

But the wise professor has more than once taken the fancies of his imagination for realities.

It has also been said that the grooves are nothing but the beds of the rivers and streams of the Moon.

These two hypotheses are both improbable.

How can we imagine, for example, that the inhabitants of the Moon have been able to produce such gigantic works of art? The canals of our civilized country, many of which seem to us so considerable, demanding so much time and labor in digging, would be only small pits compared with the canals of the Moon. Grooves, several miles in breadth, and several hundred yards in depth, are extended over lengths of 150 miles and more. We see the impossibility of digging such trenches.

Moreover what could become of the materials from these immense excavations?

Evidently Schrœter and Gruithuysen had not reflected upon these difficulties, or perhaps they did not consider the real dimensions presented by most of the grooves.

The other explanation does not appear more probable. We shall see that it is almost certain that there does not exist on the Moon water, or anything resembling water.

The grooves then can only be the beds of dried-up rivers, whose existence goes back to primitive times.

But their rectilinear form, with one or two exceptions only, appears at least singular on a surface as irregular as that of the Moon. Moreover it is difficult to conceive that a running stream could wear beds of such depth, so vastly superior in this respect to the beds of terrestrial rivers; above all, if we reflect that on the surface of the Moon the weight is six times less than on the Earth.

Evidently, we can only reason by analogy of the phenomena presented by celestial bodies compared with the phenomena which we observe on our globe. But the laws of matter are the same on the Moon as on the Earth, and it is impossible for us to conceive of rivers whose greatest width is in the middle of their course, which ascend the sides of mountains, leap over their tops, and terminate abruptly at beginning and end.

On many grooves the length does not exceed ten or twelve times the breadth, although in terrestrial rivers this ratio is hundreds of times greater.

It appears then altogether probable that the grooves owe their origin neither to artificial work nor to the movement of water. It remains to be seen, if the natural forces which have produced all the other irregularities of the lunar surface can account for these, so entirely different in their formation.

XI.

TOPOGRAPHY OF THE MOON.

RADIATING CRATERS—LUMINOUS BANDS—DIFFERENT HYPOTHESES ON THE NATURE OF THESE BANDS.

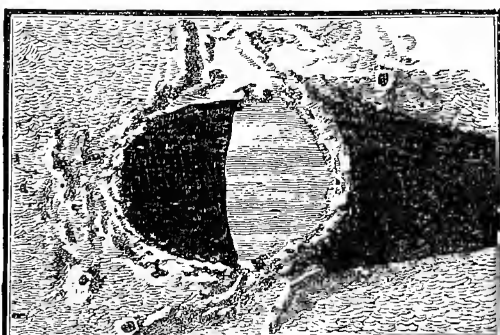
THE physiognomy of the different regions of the lunar surface changes from one day to another, according as the rays of the Sun, falling more or less obliquely on the surface, produce a more or less marked contrast of light and shade. All the irregularities, cirques, craters or hills cast opposite to the Sun, that is, on the eastern side of the disc,* shadows which diminish in length from the period of the rising of the Sun, to that of the lunar midday. The shadows are then thrown toward the west, in-

* In our description of the Moon the east always has reference to the terrestrial observer; for an inhabitant of the Moon, the words west and east should be reversed.

creasing in length as they have before decreased, until the Sun sets to those regions under consideration.

From the new to the full moon, it is the rising of the Sun which we observe on our satellite; during the waning, on the contrary, we have the view of the settings of the Sun for all the meridians of the visible hemisphere.

But it is easy to conceive that the shadows cast by the mountains (Fig. 26) of the western border



Eig. 26. Lunar Crater after sunrise.

towards the setting of the Sun, and by those of the eastern border towards its rising, are almost invisible, concealed as they are from us by the lighted slopes. At opposite periods, the shadows of the regions on the borders are visible, but we only see them very obliquely, on account of the perspective.

It is, above all, the central regions, situated on both sides of the first meridian, that the solar illumination permits us to distinguish clearly, especially when it is near the line of separation of light and shade. All the craters and cirques are then sharply defined ; one part of the black shadow invades the interior hollow of the cavity ; the other part, the exterior slope of the embankments ; the peaks themselves cast their elongated shadows to a great distance. On the opposite side a bright light vivifies the same objects, and renders their form and all their contours clearly visible. We have seen elsewhere that it is in measuring the shadows cast by the mountains that we are enabled to measure with precision their height above the surface which surrounds them.

At the epoch of full moon, it is no longer by the contrast of the lights and shades that the irregularities of the surface are visible. At this period it is only by the intensity of their brightness that these irregularities appear to stand out in relief. This intensity depends upon two causes ; one, purely optical, arises from the angle at which the objects reflect to us the luminous rays (Fig. 27), and this angle is also in conformity with the inclinations of

Fig. 27. Lunar crater before sunset.

the different sides of the mountains; the other cause is due to the nature itself of the substances which compose this or that region of the Moon, and to the difference of their reflecting powers. It is to this last cause that we must certainly attribute the sombre hues which characterize the large greyish spots of the seas, or rather of the plains, the appearance of which presents such a forcible contrast to the surface of the mountainous regions. It is equally probable that several cirques, such as Plato and Grimaldi, owe to the same cause the dark color of their cavities; while other mountains are so brilliant that they have given the idea of active volcanoes. Such is Aristarchus, which we perceive distinctly during the eclipses, or in the midst of the ashy light, a little before the first quarter.

Let us now speak of the singular appearances known by the names of luminous bands. It is principally during the full moon that these irregularities of the lunar disc are visible.

The luminous bands are distinguished from the spots in this respect: the oblique light of the solar rays causes them to disappear, or at least renders them difficult to see, although they shine with all their brightness when this light falls perpendicularly on the surface.

Most of them form radiating systems which have for centres some of the principal lunar craters or cirques.

Of all these singular systems, the greatest is that which belongs to Tycho. Imagine more than a hundred luminous bands, of various sizes, diverging in all directions from north to south, and from east to west, like so many meridians drawn around Tycho as a pole, running with the same intensity over mountains and plains, crossing the embankment of cirques, and losing themselves at various distances, the greatest of which reaches 1,865 miles, more than a quarter of the circumference of the Moon.

These luminous bands are not, as were known early, chains of mountains; neither are they long valleys. In both cases their boundaries would cast shadows, now on this side, now on that, as the Sun's rays fell. But they are at all times equally brilliant throughout their length, which reaches even twelve to eighteen miles.

Some astronomers have said that the radiating system of Tycho is not visible excepting at about the period of full moon. It is an error.

I have before me the charming photographs of Mr. Warren de la Rue, obtained by him at different periods of a lunation. It is easy to distinguish the luminous bands, at least the most brilliant among them, from the first to the last quarter of the Moon. But it is true that it s at the period of full moon that they are shown with the greatest clearness and brilliance.

Tycho is the only radiating mountain of the southern hemisphere, but it is also the most remarkable of these systems.

In the northern hemisphere the radiating mountains are numerous. Copernicus, Aristarchus, and Kepler, all situated within or upon the Oceanus Procellarum, are among the most brilliant. (Fig. 28.) The luminous bands which radiate from each of these craters are not only shorter than those of Tycho, but they are also less regularly distributed; those of Aristarchus, for example, radiate only from the southwest to the southeast; they are wanting upon all the northern periphery of the crater. On the other hand, the three radiating systems appear to be in connection with each other, and many of their bands unite, which arises, perhaps, from their proximity.

Like the bands of Tycho, those of Kepler, Copernicus, and Aristarchus are visible even after full moon.

Euler, Mayer, Timocharis, and Eratosthenes are also mountains, situated, like the preceding ones, in the eastern part of the northern hemisphere; but their bands attain less length.

The western part of the same hemisphere contains, also, Proclus, east of the Mare Crisium, Cassini, and Aristillus, and Autolycus, three craters, situated at a little distance from each other in the Palus Putridinis and the Palus Nebularum. The radiating bands of these last mountains unite like those of Kepler and Copernicus.

We must not confound these luminous bands with the slopes which separate the embankments of Aristillus and Autolycus, and which have been compared to volcanic eruptions and currents of lava.

Besides these radiating systems, each having an annular mountain for its centre, we perceive, also, upon the disc of the Moon, luminous bands which appear isolated, and are not attached to any visible system.

Fig. 28. LUMINOUS BANDS OF COPERNICUS, ARISTARCHUS, AND OF KEPLER.

Such are seen in the neighborhood of Copernicus, whose direction is not that of rays from a central crater. Another traverses the Mare Serenitatis, though from north to south. Beginning at the steep crater of Menelaus, it runs in a straight line over the even surfaces of the surrounding plains, traverses the crater Bessel, and loses itself near the Lacus Somniorum.

Although Menelaus is the centre of some radiating bands, this of which we speak does not appear to belong to its system. Mr. Webb considered it, with much reason, as the prolongation of one of the bands of Tycho, which, as we have seen, extends to a distance of 1,865 miles from its centre.

What is the nature of these singular appearances, what is the origin of their systems? This is a very interesting problem, but a difficult one to solve. We have said that it was impossible to confound them with the white furrows of the lunar hills, because those forming projections on the surface cast, when the incidence of the solar rays permits, shadows on each side. It has been supposed that the bands were produced by the currents of lava, whose brilliant traces are imprinted on the surface which they have traversed. But how shall we explain their immense length? How account for their course above the highest craters?

Some have supposed the luminous bands to be composed of white crystalline matter, of strongly reflecting power, which has been thrown upon the surface of the Moon through fissures caused by volcanic action. This hypothesis is liable to strong objections, and does not appear more probable than the former.

According to M. Babinet, it is entirely to the structure of the surface that we must attribute these mysterious appearances, which arise from the reflection of the solar light thrown upon peculiar formations, a phenomenon analogous to that which is presented by certain crystalline geodes.

Finally, an eminent observer, Chacornac, has presented a theory which is connected with a system of lunar geology ; we shall soon explain it in developing the ideas of that scholar on the periods of the formation of the surface of the Moon.

XII.

THE INVISIBLE HEMISPHERE OF THE MOON.

IS THERE A DIFFERENCE IN PHYSICAL CONSTITUTION BETWEEN THE VISIBLE AND INVISIBLE HEMISPHERES?

THE Moon always turns the same face towards the Earth. Has this always been the case, and will it continue to be so? Arago, who propounds the same question in his Popular Astronomy, cites in support of the affirmative some verses of an ancient poem collected by Plutarch, the vague import of which, it seems to us, is far from proving anything. That Agesianax and his contemporaries saw in the disc, covered with dark and brilliant spots, a human figure, which the people of our day still think they see, is very slight evidence in favor of the invariableness of the fact in question.

Modern observations, and above all the modern theory, are more convincing. Laplace has shown that "the cause which has established a perfect equality between the mean motions of rotation and revolution of the Moon, deprives the inhabitants of the Earth forever of all hope of discovering the parts of the surface opposite to the hemipshere which is presented to us. The terrestrial attraction in continually drawing towards us the large axis of the Moon, makes its motion of rotation participate in the secular inequalities of its motion of revolution, and constantly directs the same hemisphere towards the Earth."

Thus our curiosity is bounded, and the imagination of framers of hypotheses apparently put to rest. That the ancients supposed the invisible side of the Moon to be of a concave form, or again, half transparent, is not to be wondered at; their knowledge of physical astronomy amounted to almost nothing. But what appears more strange is that the moderns have imagined that the hemisphere opposite to the Earth is possessed of water, air and inhabitants of which the hemisphere turned towards us is entirely destitute, and that the latter only has the advantage, or disadvantage as may be, of being covered with abrupt and rugged elevations.

It would be difficult to refute assertions so improbable, which moreover, are purely imaginative, if positive observations did not prove them false. When, indeed, we say that the Moon always turns the same face to the Earth, this assertion is not rigorously accurate, and here is the reason :

The revolution of the Moon around the Earth is performed with a variable rapidity, while its motion of rotation is uniform. The result of this inequality of the two motions is that the Earth is sometimes east and sometimes west of that point in space opposite to the same point of the surface of the Moon, considered as the centre of the visible hemisphere. We thus discover, either on the east or west regions, near the edge, which, were it not for this circumstance, would remain concealed from us.

Besides, the inclination of the plane of the lunar orbit, added to that of its equator on the plane of the terrestrial orbit, causes the moon sometimes to present its north and sometimes its south pole, and thus discovers to us certain portions of the polar regions.

The result of these two librations, the name given to these motions, is that of 1,000 parts of the surface of the Moon, 569, that is more than half, would be visible to an observer at the centre of the Earth, while only 431 would remain concealed from him.

But it is not from the centre of the globe only that we observe the Moon, it is, on the contrary, from points of its surface often remote from each other, and, as the dimensions of the Earth are appreciable compared to its distance from the Moon, the result is that two observers placed at different points of the terrestrial spheroid would not see the centre of the lunar disc at the same point of its surface, or, which amounts to the same thing, would perceive different parts of its edges. This increases still more the dimensions of that part of the Moon which is accessible to us, so that by an accurate calculation, of 1,000 parts only 424 remain absolutely and positively concealed from us, while 576 are visible. Of the 14,670,000 square miles, which, as we have seen, compose the total surface of our satellite, we are enabled to observe nearly 8,500,000.

The part of the Moon totally concealed from the Earth embraces from east to west about 2,800 miles; from north to south 2,820 miles; from 40 degrees of north latitude to the same number of degrees of south latitude 2,700 miles. While the same dimensions reckoned on the visible surface are respectively 3,200, 3,100 and 3,300 miles. (Beer and Mædler.)

A large zone, then, of that part of the Moon which is opposite to the Earth is visible to the eye of man.

"But observations have not enabled us to perceive—it is two of the most industrious observers of the Moon who speak—any essential difference between the regions which form the seventh part of the lunar surface which is concealed from us, and that with which we are acquainted; we find the the same mountainous countries and the same Mares (the plains called seas). Beyond the north pole we perceive some large circular valleys separated by chains of mountains of a medium height and by level plains of a less extent, resembling those which we perceive in the arctic regions on this side of the north pole. On the northwest the Mare Humboldtianum, the high surrounding mountains of which we can readily perceive, extends into the hemisphere which is invisible to us; the same is true of some parts of the Oceanus Procellarum on the east, of the Mare Australe on the southwest, and of the great plain called Kästner, which approaches the smallest seas in extent on the west. . . Almost directly to the east rise the high summits of the Alembert Mountains, similar to the less elevated ones of the Cordilleras on the hemisphere which we see.

So, at the south pole we perceive on the two sides an equal accumulation of colossal heights and of enormous depths; the great inequalities of the lunar edge which appear in this part belong mostly to the invisible hemisphere." (Beer and Maedler).

Thus nothing warrants us in considering the hemisphere of the Moon which is turned from us unlike that which we see; this may well lessen our regret that we can never see the whole surface of our satellite.

Besides, the visible regions are sufficiently remarkable, on account of the variety of their configuration, to present a vast field for the study of lunar geology and topography. But to those whose interest is not limited to mere facts, who wish to inquire into causes, to discover the origin of these peculiarities of the lunar surface, to whom knowledge means knowledge of laws, to the true scholar, the visible hemisphere of the Moon offers abundant opportunity for research.

CHAPTER III.

GEOLOGY OF THE MOON.

XIII.

VOLCANIC CONSTITUTION OF THE LUNAR SURFACE.

IGNEOUS ORIGIN OF THE LUNAR MOUNTAINS—PERIODS OF FORMATION.

The lunar mountains are of volcanic origin. This is a leading fact, which is shown directly by the rounded, annular form of the large valleys, of the plains, and of all the smaller cavities to which, as we have seen, the name of Craters has been given.

Astronomers have long agreed in considering the formations of the lunar surface as due to a reaction of internal forces against the exterior crust of the globe. Robert Hooke "attributed these phenomena to the effect of subterrauean fires, to the eruption of elastic vapors, or, which is the same, to an ebullition setting free bubbles which burst at the surface. Experiments made by boiling calcareous earths appear to him to confirm his views; and since then the circumvallations and their central mountains have been compared to the forms of Ætna, the Peak of Teneriffe, of Hecla, and the volcanoes of Mexico." (Humboldt.)

Sir John Herschel is not less positive in this respect. "The lunar mountains," he says, "present in the highest degree the true volcanic character, such as is presented by the crater of Vesuvius and the volcanic districts of the Champs Phlégréens, or of the Puy-de-Dome." (Outlines of Astronomy.)

But if the igneous origin seems to be the only very probable one by which all the mountainous irregularities and crater-forms can be accounted for, this does not imply that they are wholly the result of volcanic eruptions in the limited sense of the word. The Moon was primitively, like the Earth, a fluid globe on whose surface the cooling, due to a calorific radiation, has caused the formation of a solid crust. It is the crust which has been the seat of subsequent phenomena whose traces remain to-day under the form of prominences of all sizes; and the causes of this series of productions are, without doubt, the expansive forces of gases and vapors which the high temperature of the centre incessantly developed. Originally, the solid crust of the Moon (Fig. 29) being thinner was, for this reason, less resisting; and, as it had not yet been agitated by previous convulsions, it would present at all points nearly the same homogeneity and the same thickness. The expansive force of the gases acting then perpendicularly to the superficial layers, and following the lines of least resistance, would break the envelope and produce upheavals of a circular form. It is to this period, doubtless, that the formation of the immense circumvallations whose interior is to-day occupied by the plains called seas, should be referred. We have spoken of the circular form of the Mare Crisium, and of Serenitatis, Imbrium and Humorum. Their walls, half ruined by subsequent convulsions, still form the longest series of asperities on the lunar surface, the Carpathian, the Apennines, the Caucasian and the Alps among the chains, and Mounts Hæmus and Taurus.

Then came new upheavals, but these, occurring at an epoch when the crust of the lunar globe had acquired a greater thickness, or perhaps in consequence of a decrease in the elastic force, formed the largest cirques, yet much smaller than the primitive formations. The cirques of Shickardt, of Grimaldi and of Clavius seem to belong to this class.

Subsequently a multitude of cirques of smaller dimensions appeared, whose walls covered the entire surface of the Moon, and appeared even in the very heart of the primitive circumvallations. We understand readily the reason of the successive diminution in dimensions of the annular mountains, craters and cirques. Each crater is due, as we have seen, to the uprising of a bubble or blister, whose depression has produced in the interior a cavity of elliptical form, and upon the borders one or several walls in the form of ramparts. But the dimensions of these inflations should be in proportion both to the intensity of the internal force which produced them, and to the resistance of the solid, or rather plastic crust of the lunar globe. It is probable that these two causes have united to produce the most marked results, therefore the largest circumvallations, and the greatest cirques or craters were formed first. (Fig. 30.)

But it is time to make a distinction between the two kinds of soil which characterize the surface of our satellite. The first comprises that which has been called from the beginning the continental soil; it is that of the mountainous regions which cover almost all the southern portion of the visible hemisphere. "Its porous structure," says an observer very familiar with selenographical studies, M. Chacornac,* "its great reflecting power, and, above all, its elevation above the plains, make it easily distinguishable from the levelled ground, whose dark color and smooth surface, according to Sir John Herschel, give it all the appearance of plains of alluvium.

Are, then, the lunar mountains plains of alluvium? No, not exactly in the terrestrial meaning of the word. Even the astronomer whom we have just quoted, rejects this expression as improper. But he relies upon numerous and very interesting phenomena in order to prove that the early period when the largest circumvallations appeared was succeeded by a kind of general diluvium or muddy overflowing. "This overflowing would have buried under a brown mass more than two-thirds of the visible surface of the Moon, and, in spreading itself from one extremity to the other, filled the bottom of all the large craters, obviously, to the same level."

Indeed, among the innumerable craters whose cavities indent the surface of the lunar body, some present in the interior an excavation of regularly conical or rather elliptical form, perfectly sloped, whose borders or walls are unimpaired. (Fig. 31.)

Others, on the contrary, have their walls broken,

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* Note upon the appearances of the lunar surface.

and the bottom of the cavity is flat and on a level with the ground of the surrounding valleys.

It is especially upon the borders of the seas that these half-ruined craters are found, and it appears evident that the cavity has been filled by the overflow which M. Chacornac describes. "The configuration of these shores presents vast semi-circular

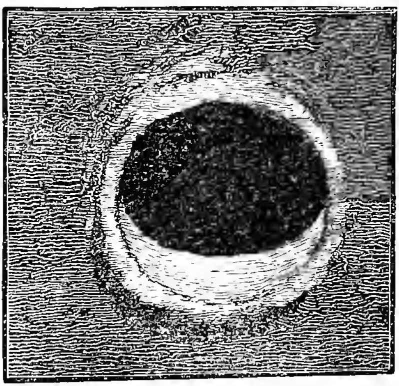

Fig. 29. Cirque, elliptical at the bottom, in the form of a bowl.

bays, whose entrance is partly obstructed by the debris of the ruined wall in the exact direction of the width, as has happened in the bottom of the crater of the island of St. Paul (Indian Ocean), covered in our day by the waters of the ocean." The Sinus Iridium, on the borders of the Mare Imbrium, is one of the most remarkable examples of this encroachment. But many examples of others can be cited, among which we shall mention at random Hippalus and Doppelmayer in the Mare Humorum, Davy and Bonpland in the Mare Nubium, and Fracastorius upon the southern border of the Mare Nectaris.

Several of the craters which are elevated in the

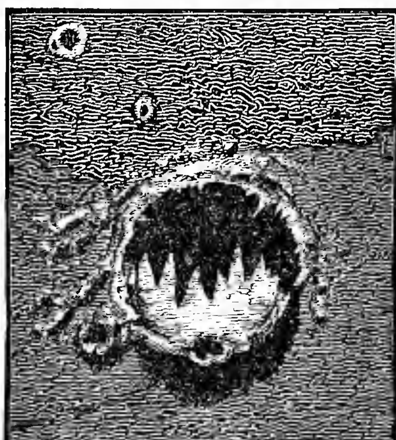

Fig. 30. Lunar cirque, flat at the bottom.

very interior of the plains seem partially covered by the same eruption of liquid matters ; M. Chacornac cites the cirques Kies and Lubiniezky as curious types of this formation. "Each presents bounding ridges or walls about forty-five leagues in extent, rising perpendicularly in the bosom of an immense desert, even to two or three hundred miles in height." (Fig. 30.)* Other cirques appear almost entirely buried, and we see only faint vestiges of their circular walls.

We will mention an immense cirque, neighbor to the crater Flamsteed, which has risen upon the borders of the original enclosure. (Fig. 31.)

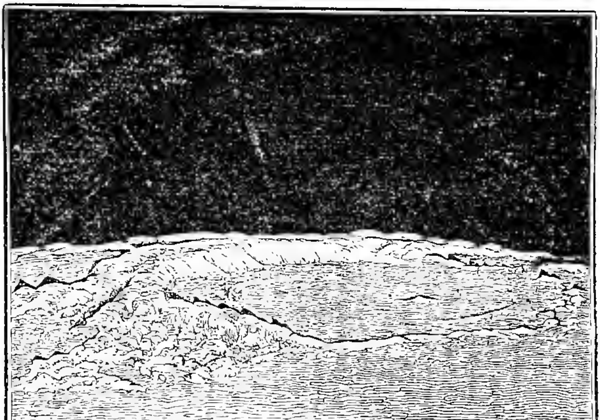

Fig. 31. Crater buried on the banks of the Ocean of Tempests, according to the design of M. Chacornac.

According to these views, to which the facts noticed give a great degree of probability, we see that the difference in appearance of the soil of the moun-

* The reader will see that the sunlight comes from above, and the jagged black shadow is thrown by the irregular outline of the upper wall.—Ed.

tains and the soil of the plains is due to a difference in origin. We can then explain " the uneven rugged appearance, diversified with prominences and dross-like masses, which gives to the continental soil the aspect of slag." We perceive then the contrast presented by the " smooth appearance of the surfaces called maritime, like wet plaster, or better still, an immense plain of dried mud." *

Now, to what crisis shall we ascribe the appearance of this diluvium? It is difficult to answer this question, whose solution would require that we should know exactly the previous conditions through which our satellite has passed. The learned observer from whom we have borrowed the very curious comparisons which precede, attributes the origin of the muddy overflow to the precipitation of non-permanent gases which constituted formerly the lunar atmosphere. " We see, finally," he says, " that our satellite having reached a certain degree of coolness, the atmospheric pressure favored the precipitation of gases and vapors which spread themselves in the form of rain over all points of the surface, and thus filled up the large craters formed on all

* Another comparison which is often made by persons who are looking at the Moon through a telescope is that of " trodden snow."—Ed.

sides, so that those of the epoch posterior to the consolidation of these fluids are completely sheltered from all sedimentary deposit."

XIV.

VOLCANIC CONSTITUTION OF THE LUNAR SURFACE.

LUNAR VOLCANOES COMPARED TO TERRESTRIAL VOLCANOES.

ALTHOUGH certain analogies exist between the lunar and the terrestrial volcanoes, yet there are some very perceptible differences.

The common side, or side of resemblance, consists principally, as geologists say, in the igneous or plutonic origin. But it is probable that the phenomena which, upon the lunar globe, have been the result of interior action, have not occurred, in general, in the same manner as the terrestrial phenomena. A variety of reasons may be assigned for this difference. First, the substances composing the mass of our satellite are, without doubt, different from those which form the nucleus of the earth. At least we know that their mean densities differ greatly. Gravity at the surface of the Moon being six times less than on the surface of our globe, we perceive easily how much this element alone is capable of modifying effects due to subterranean action. Besides the absence, or, at least, the extreme rarity of the lunar atmosphere compared

Fig. 32. The Peak of Teneriffe and its environs; topographical details according to M. Piazzi Smith.

to the considerable envelope which has surrounded the earth, adds still another to the causes which we have just enumerated to account for the essential differences which the eruptive phenomena of the two globes present.

The cones of eruption of the terrestrial volcanoes most frequently are elevated to a great height above the level of the surrounding plains, while the crater properly so-called has much less depth. This crater should be considered rather as the widened orifice of a straight chimney which communicates to a great depth with the internal strata of the globe. Upon the Moon it is entirely otherwise; there the interior cavity is deepest and the sides of the enclosure are less elevated in proportion to the level of the exterior plain, so that the mountain appears rather formed by the sinking away of a primitive bubble than by an actual volcanic eruption.

Perhaps among the craters of small dimensions, whose depth does not permit the internal level to be seen, there are those altogether analogous to the craters of terrestrial volcanoes. We have seen that they are in general those of apparently the most recent origin.

Finally, it is possible, also, that the difference of structure which we see between the lunar surface and the continental material of our globe may show that no true sedimentary formation has destroyed or effaced the traces of plutonic formations. This is the opinion of Humboldt: "We can imagine our satellites," he says, "about the same as the Earth in her early state, before being covered with sedimentary layers rich in shells, gravel and transported rocks, due to the continued action of the tides and currents. We can scarcely concede that there exist in the moon any light layers of conglomerate and of detritus formed by friction. In our chains of mountains, elevated above the fissures with which the terrestrial surface is furrowed, we see here and there partial groups of eminences which represent a species of oval basins. How very different the Earth would appear to us if we saw her robbed of her tertiary and sedimentary formations, and of the materials of the drift.

The mountainous enclosure of Bohemia, although of a less regular form than the large cirques of the Moon, nevertheless recalls them both by its form and dimensions. (Fig. 35.)

We have seen that a great many of the cirques and of the cavities of lunar craters, contain in their interior isolated mountains in the form of peaks or pyramids. There are even instances where we observe several summits of this kind : thus, the enclosure of Copernicus presents six central mountains. A singular circumstance is that no one of these prominences attains the height of the walls of the enclosure, the majority being of an inferior height to that of the lunar surface from which the crater has risen. According to Mædler and Jules Schmidt a large number of central mountains have an altitude inferior, by more than 6,500 feet, to the

Fig. 33. Topographical relief of the Isle of Bourbon, (the Reunion), according to M. Maillard.

mean height of the circular ramparts, and still about 650 feet below the mean level of the surface in this part of the moon. Humboldt, in citing these facts recalls the opinion of Léopold du Buch, who does not regard these masses as produced by volcanic eruption, and compares them "to the large trachytic domes, closed at the summit, which are spread in such number over the surface of the Earth, such as those of the Puy-de-Dôme and Chimborazo."

A frequent arrangement of lunar mountains consists in the existence of parasitic craters, formed subsequent to the principal cirques and craters, and usually situated upon the walls of their enclosure. A great number of these can be seen in the drawing we give of the surroundings of Tycho according to the photograph of Mr. Warren de la Rue. The large cirque of elliptical form, Maginus, situated to the southeast of Tycho, is remarkable in this respect. The walls of these secondary craters often encroach upon each other, and the result is a series of deformations which easily permit of classification according to the order of seniority. But in making this classification by successive ages we find again the law which we have mentioned above, according to which the smaller craters are almost always most recent.

It remains for us, in order to terminate this study of the successive formations of the lunar globe, to state what is known, or rather what is conjectured of the origin of the irregularities described above, under the name of *luminous bands, radiating craters,* and *grooves.*

XV.

VOLCANIC CONSTITUTION OF THE LUNAR SURFACE.

RADIATING CRATERS AND LUMINOUS BANDS — THE GROOVES—EXPLANATION OF THE LUMINOUS BANDS BY THE PROJECTION OF GASES INTO SPACE—HYPOTHESIS OF M. CHACORNAC.

If the formation of the annular mountains of the Moon is due to elastic forces acting perpendicularly to the partly solidified crust of its globe, if the regularity of their circular outlines show the homogeneity of the resisting masses, can we assign the same origin to the numerous hills which furrow in all directions the interspaces of the crater and cirques? It seems to us that these secondary elevations can be explained in two different ways, equally probable, and perhaps both are true.

When, primitively, the mass of the Moon had still a semi-fluid or plastic consistency, the process of cooling would produce contractions of the exterior crust, consequently folding of the surface, which would remain after the positive consolidation, and would give place to numerous hills, the majority of which would follow parallel lines. To these it is useless to assign the action of central forces.

There are also those which appear to date from the epoch when the craters upon which they border were formed, and it is probable, indeed, that they are no other than the result of modifications wrought upon the surrounding country by the central eruption and by the receding of the volcanic bubbles.

We can also, independently as regards these two kinds of formations, distinguish those which proceed from internal forces acting upon the envelope, but which, meeting with masses of unequal resistance, and not homogeneous, would act in lateral directions and produce either elongated crater-hills, or, perhaps, seams like the grooves. Indeed it is to this kind of action that Beer and Mædler attribute the fissures known under this last name. They say, "We should consider these grooves as the effect resulting from elastic forces which, instead of making their way through to the surface, in following the direction opposed to gravitation, as would be the law, are obliged, by particular local circumstances, to extend themselves in a parallel direction under the surface, and to plough the ground lengthwise." In certain cases, which, however, present themselves quite frequently, the forces in question have not had the necessary energy to pierce the envelope. Hence arise simple rectilinear veins; such is the very steep vein which we perceive at the east of the crater Thebit, which, "under certain angles of light, offers a striking resemblance to the grooves."

It is worthy of notice that upon the direction of these protuberances or of these rectilinear cleavages the volcanic action shows itself often under the form of small craters terraced in the direction of the vein or fissure. The groove which bounds the craters Abulfeda and Almanon presents a curious example of this. (Fig. 21.)

We have stated, in describing the luminous bands which surround the radiating craters, different hypotheses upon the nature of these singular phenomena. We shall now show the ingenious theory which refers them to other movements of the lunar surface, a theory due to M. Chacornac, and which we quote almost verbatim from a very interesting letter which the learned astronomer recently wrote upon this subject.

"Examine, on one of the charming lunar photographs of Warren de la Rue, the luminous rays which emerge from Tycho. You will see that the bands which reach as far as the Mare Nectaris are not from a single source: for example, that which passes over the crater situated on the southern border of this sea, is formed by successive rays, running in the same direction, and starting from the summits of the different ridged craters upon its passage. To have a clearer idea of the matter, suppose that all the summits of the craters surrounding Tycho, even to great distances, had been covered with fine dust or snow in the state of *nevé*.* Then imagine that a violent wind, radiating from Tycho in all directions, had blown away this dust: those particles emanating from the summit of Tycho, even, would not have been able to spread as far as the Mare Nectaris; gravity having brought them to the ground before they could have reached this distance. But the gaseous current passing over the summits of the elevated craters, situated far from Tycho, continued to carry away in the same direction the fine particles which covered these summits. What ought then to be the result? That, where a white ray emanating from Tycho ended, another ray began, forming the prolongation of the first, but having for its point of departure another crater;

* This word is given as in the text.

such is, for example, the luminous band which passes by the group of the three craters Rabbi, Lindenau, and Zagut. It is certain that this ray is not continued, and that on leaving Zagut, it takes another direction and receives an increase of light, as if from the top of the ramparts there had been detached, anew, masses of powdery matter, carried away by the eruptive power of Tycho, as far as the sides of the crater Fracastorius, and even to the northern banks of the Mare Nectaris.

"In the region northwest of Tycho these phenomena present no ambiguity: the whitest trains start from the summits of the mountains and spread themselves like comets' trains in the direction of meridians having Tycho for a pole.

"Is a more complete explanation of the radiating mountains of the Moon desired? Notice that all the radiating craters are of comparatively recent origin, that is, are not filled up. Their bottom is concave, of a porous structure, like all the volcanic region of the lunar continents, so clearly differing from the smooth surface of the seas or the vast cirques heaped up by this deposit of sediment. Now, after the consolidation of the atmosphere of of the Moon, or, if you please, after the precipitation of its non-permanent gases, the interior forces, having not yet lost their activity, formed the craters Tycho, Proclus, Aristarchus, Euler, Kepler, etc.

" But at each disengagement of the gases ejected by the eruption, these gases flowing about in space would spread over the whole surface of the globe with great rapidity, carrying away everything in their course. In this way the ashes from the cones of craters, formed, without doubt, like those of terrestrial volcanic cones, of powdery materials and of stones, scattered themselves in all directions around the central crater. . . . . . .

"Think of the effect of an eruption of Tycho, of the power of the gases thrown forth by this crater in precipitating themselves into space with a rapidity superior to that of a cannon ball, sweeping away all the dust and stones of the surrounding mountains with a radius equal to a quarter of the circumference of the Moon, and you will find a class of destructive phenomena unlike any known on the Earth.

XVI.

ARE THERE STILL ACTIVE VOLCANOES UPON THE MOON.

LUMINOUS POINTS OBSERVED UPON THE OBSCURE PART OF THE DISC BY D'ULLOA AND W. HERSCHEL—DEFORMATION OF SOME CRATERS ACCORDING TO MR. WEBB.

"M. D'ULLOA is confident of having seen a luminous point upon the Moon during the total eclipse of the Sun, June 24th, 1778, and believes that this came from a hole in the Moon; but it must have been more than one hundred leagues in length. Herschel is certain of having seen a volcano, and that will explain the luminous point seen by M. D'Ulloa." Thus says Lalande, in the article *Selenography*, of the Encyclopédie Méthodique, and on this subject the French astronomer does not enlarge.

At present, no one believes in holes in the Moon, nor in the existence of burning volcanoes visible from the Earth.

Arago regards the observation of Don Antonio D'Ulloa "as resulting from an optical illusion, and not from a phenomenon of incandescence which could have then existed on the surface of the Moon."

The observation of Herschel, to which Lalande alludes, dates from the 4th of May, 1783. But the illustrious astronomer returned later to the same subject, affirming that on April 19, 1787, he had seen on the obscure portion of the disc three volcanoes in action. Finally, in the total eclipse of October 22, 1780, he noted upon the Moon's surface more than a hundred and fifty luminous points, of a reddish color, of whose nature he says nothing. Previously, Rianchini and Short had observed luminous points.

But we know now that all these effects are due to the intrinsic brilliancy of certain mountains, among which we have signalized as most remarkable Aristarchus, Proclus, etc. This brilliancy, doubtless owing to the particular nature of the substances of which these mountains are formed, and to their reflecting power, is sufficiently intense to reflect towards us the terrestrial light, and to give to these mountains a particular visibility upon the background of the ash-colored light.

As to the red tinge with which these points are covered during eclipses, it is due to the refraction of the solar rays by the atmosphere of the Earth.

Nevertheless, if the question of the visibility of volcanoes in action appears to-day decided in the negative, it is not thus with the continuance of eruptive action at the surface of the Moon.

Beer and Mædler, those industrious explorers of our satellite, whose magnificent chart is authority on doubtful points, were little disposed, in 1840, to regard as probable, actual changes of the surface of the Moon. "We own," they say, "that such an hypothesis has very little probability. If the observations which have been made up to the present do not absolutely exclude it, they nevertheless unite in favor of the contrary hypothesis, which regards the lunar globe in its exterior form as a body actually finished in a manner too simple and too natural for any one to listen to the supposition that violent transformations still take place at the surface of the Moon."

Their own observations are negative, and they remark with justice that new observations in order to have a positive significance should apply to objects whose dimensions exceed the smallest and most delicate irregularities of the disc. Otherwise, it is likely that objects recently discovered have escaped former observations by reason of a less favorable illumination. On the other hand, the same points of the disc present in their details at different epochs aspects varying with the degree of libration, with a difference in the phase which shows the objects illumined in a different way, and, finally, with the optical instruments employed in the observations.

In truth, observers are divided in opinion upon this interesting point. So much so that while, according to Mr. Nasmyth, volcanic action has ceased upon the Moon for thousands of ages, Messrs. Webb and Birt notice several facts which testify to the continuance of this action.

For example, in examining the crater Marius and its environs, situated in the middle of the Oceanus Procellarum, these two observers have discovered two small craters which Beer and Mædler had not noticed. Also, in comparing the drawings of Cichus, made by Schrœter, and later by Beer and Mædler, it appeared evident to them that the difference presented by the dimensions of a smaller crater situated in the ramparts of Cichus, are due to real changes having occurred since 1792, the time when Schrœter observed. (Fig. 36.)

A third observation by Mr. Webb appeared more decisive. There exists in the Mare Fecunditatis, at a little distance from the equator, two craters which have received the common name of Messier. These craters, very near each other at the time when Beer and Mædler constructed their picture of the Moon, were notable for their regularity and equal size.

Mr. Webb, in observing them again, found that the eastern crater appeared larger than the other. Five months after, he noticed not only the difference

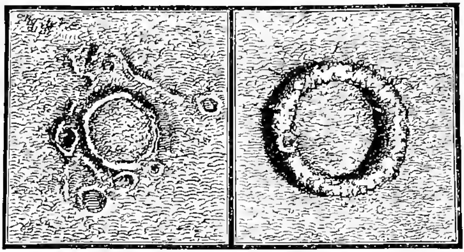

Fig. 34. The Cichus crater, according to Schrœter, in 1792; according to Beer and Mædler in 1833.

in size of the two craters, but deformation of the western crater, still the smaller. In reality, instead of having an oval form, elongated from north to south, it was from east to west that its diameter appeared the greatest. (Fig. 35.)

Mr. Webb insists especially upon a particularity entirely in favor of their hypothesis. Schrœter having discovered on the east of Messier two long luminous bands, which gave to these objects a certain resemblance to a comet and its tail. Beer and

Mædler examined them more than 300 times without ascertaining any change from 1829 to 1837. The multiplicity of these observations hardly permits us to raise a doubt as to the perfect accuracy

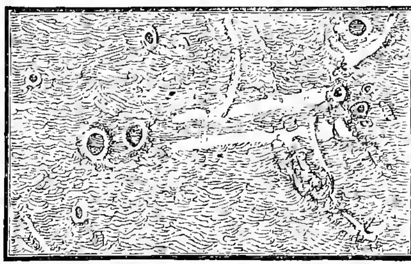

Fig. 35. The two craters of Messier according to Beer and Mædler in 1834.

of the *Mappa Selenographica.* Therefore, if the appearance of the two craters is to-day so different, it must be thought that the changes observed have really been made since 1837. (Fig. 36.)

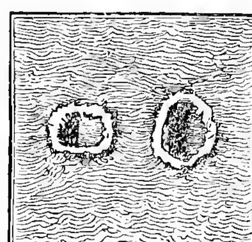

Fig. 36. The craters of Messier, according to M. Webb, February 28, 1857.

Certainly such facts are very interesting; it is impossible not to take them into consideration in the examination of the subject under discussion. But it is important that they should be multiplied before we can draw from them a positive conclusion.

It must not be forgotten that our globe, as regards the exterior structure, is considered as finished; and yet we see under our eyes volcanic action going on, and producing very noticeable changes of configuration; slow but continued movements change the coasts of Norway. But ages are necessary to ascertain these effects of internal forces. Volcanic action may still continue on the surface of the Moon, and even manifest itself upon a much larger scale than upon the surface of the Earth, without producing any appreciable results in a small number of years.*

Time alone can decide such a question, and the inquiry becomes easier and surer now that patient and conscientious researchers have examined the surface of the lunar disc in its minutest details, and that there are authentic documents to serve as terms of comparison with later researches.

Is it not already a wonderful result to have established lunar geography upon mathematical and positive bases? to know all the regions of the hemisphere which it turns towards us with a topographical precision superior to that of many of the

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* A small crater, known as Linné, in the new quadrant, has of late shown changes; it is said to resemble a whitish cloud—as if it were either filling up, or becoming capable of reflecting light.—Ed.

terrestrial countries? Thanks to the excellent works with which modern observers have enriched science, the time approaches when one can study the lunar formations in the geological point of view, and trace the history of our satellite as we have traced that of the Earth.

Without doubt, there will always be wanting an essential element, the chemical or mineralogical knowledge of the substances which compose the body, and particularly the succession of internal strata of the solid crust, nor can we see how it will ever be possible to supply this latter deficiency. But as to the former, science has not yet said its last word, and we may hope that at length we shall find a means of analyzing the substance of the Moon; this hope is the more legitimate since only a few years ago it would have appeared chimerical to endeavor to discover of what substances the solar globe is composed.

We have seen, however, how this curious problem has been solved by the aid of a method which is one of the most admirable conquests of contemporaneous science.

CHAPTER IV.

METEOROLOGY OF THE MOON.

XVII.

HAS THE MOON AN ATMOSPHERE?

PROOFS OF THE ABSENCE OR OF THE EXTREME RARITY OF AN ATMOSPHERIC ENVELOPE—THE PHENOMENA OF LIGHT ON THE SURFACE OF THE MOON; DARK AND SHARPLY DEFINED SHADOWS—ABSENCE OF SOUND—NO WATER OR LIQUID TO BE REDUCED TO VAPOR ON THE MOON'S SURFACE.

The atmosphere is certainly the most important of all the elements which compose what we call the physical constitution of a celestial body. Without an atmosphere, without this gaseous envelope from which organized beings draw that which supports their existence, it is impossible for us to conceive of anything but immobility and the silence of death.

Neither animals, nor vegetables, even of the lowest organization, seem to us capable of living and of being developed otherwise than in a fluid, elastic and variable, whose molecules are necessarily exchanged with their own organisms. Undoubtedly, we are very far from knowing all the forms under which life manifests itself; but unless we leave the domain of observed facts and enter that of pure imagination, we are obliged to admit that the atmosphere seems to us one of the conditions most essential to the existence of organized beings.

Well, such is, if we may believe the opinion generally held by astronomers, the physical constitution of our satellite; the Moon has no atmosphere.

This is a fact of such vital importance that we feel obliged to give an account of the reasons which have caused it to be admitted in science, and of the observations which have made its establishment possible.

The existence of a gaseous or vaporous envelope around a star may be revealed to us in many ways. Let us study them successively.

Among the spots scattered over the Moon's disc, are there any which are movable and temporary? This is the first observation which astronomers must make in seeking for proofs of the existence of an atmosphere.

In a word, if the Moon is surrounded by gaseous envelopes, it is probable that in the midst of these envelopes, the variations of temperature, which proceed from the movement of the different lunar regions in connection with the Sun, would give rise to condensations of a vapor analogous to our clouds. The precipitation of these vaporous masses by cooling, their evaporation by an increase of heat, in short, the aerial currents of the atmospheric mass, would not fail to produce continual changes such as happen on our Earth. The presence of a lunar cloud would hide that part of the disc on which it was thrown; its disappearance would make it again visible.

Do we observe such phenomena on the lunar disc?

No. Neither by the eye simply, nor by the aid of the most powerful telescope, have we been able to perceive, among the spots scattered over it, anything indicating the existence of the least cloud. Never has the distinctness of the smallest visible spots appeared changed by the least accident, and we know that a cloud a hundred metres in diameter could easily be distinguished. No traces of variable bands, dark or shining, as in Jupiter; of changing spots as in Mars. The Moon's sky has evidently an absolute serenity.

This is not, however, sufficient to prove the absence of a gaseous envelope. But we can say that the Moon's atmosphere, if it exists, does not contain vapors capable of vesicular condensation. Would the Moon's atmosphere then be always perfectly transparent ?

Another method of establishing the presence of a gaseous envelope is the following :

Gases, vapors, and all transparent bodies in general, possess a property known in physics by the name of refrangibility. If a ray of light traverses them, its path is changed ; it is broken, and when it reaches the eye, it makes the object from which it emanates seem otherwise than in its real direction ; it is the phenomenon known by the name of refraction.

If the Moon possesses an atmosphere, this atmosphere ought to break the luminous rays which traverse it, in other words, to refract them. Let us see what will be the effect produced on a star which passes behind its disc, to an observer on the Earth who studies the phenomenon. As soon as the luminous point comes behind the gaseous envelope which surrounds the disc, the refraction will make it appear farther from the edge than it really is, at each moment of its progress. There will then be at first a gradual diminution in its very progress. Then at the moment when the star is really occulted by the disc, refraction, carrying it always farther from its true position, will still permit it to be seen. Summing up the whole, the interposition of an atmosphere will have the effect of retarding the moment of the star's disappearance.

By the same reasoning, when the luminous point is still concealed by the opposite edge of the Moon, refraction will still cause it to appear, thus anticipating the moment which the observer's eye would consider as the end of the occultation. In this way, the duration of the stellar eclipse would be abridged. The whole question, then, is to know if it is possible to assure ourselves whether this happens or not.

The progress of the Moon over the starry depths of the sky has been calculated in advance with great precision. Formulas and tables enable us to calculate the precise moment that a given star ought to pass behind the lunar limb, and the chord which marks the invisible portion of its route. In these tables, only the progress of the Moon and the dimensions of its solid part have been taken into account. Consequently, if an atmosphere exist, observation should show discrepancies between theory and observation; the duration of the observed occulation should be shorter than the duration of the calculated occulation. By how much? That depends evidently on the given case, on the greater or less density of the gaseous envelope.

Now, nothing of the kind has been ascertained; if a lunar atmosphere exist, its density is less than the 2000th part of the average density of the terrestrial atmosphere. It is rarer than the vacuum which exists, after an experiment as complete as possible, under the receiver of our best air-pumps.

This fact appears decisive, and in short would prove that the Moon had no atmosphere, or, at least, no atmosphere appreciable by us, if the apparent diameter of the Moon was measured and known with sufficient precision. Has this been done? This objection still exists. It would have been removed if the method proposed long ago by Francis Arago had been put in practice. We do not know that this has been done.*

For the rest, the profile of the Moon's disc, as seen from the Earth, appears uniform, only because the mountainous ridges cover each other, owing to perspective. The observations of which we have just spoken only prove, then, that there is no lunar

* Arago proposed to measure the distance from the occulted star to a neighboring star, and to observe a little before the occultation if this distance would diminish regularly. This should happen as soon as the light of the first star enters the gaseous envelope surrounding the disc.

atmosphere at the height of the mountainous summits of which we have spoken. Could this atmosphere be confined, as has been supposed, to the level of the plains, or to the bottom of the craters? In this case, occultations of stars ought to give evidence of the refractive power of the atmosphere every time that they take place in those parts of the limb, the level of which is not above the average level of the lunar plains. No positive observation of this kind has been described, since Mons. P. de Cuppis, fourteen years ago, drew the attention of astronomers to this point. The refraction due to a lunar atmosphere should also manifest itself in solar eclipses, annular or total. (Fig. 37.) And, in truth, the phenomena known by the name of Baily's Beads, and the rounded and truncated form of the horns of the solar crescent, observed in the total eclipse of July, 1860, by M. Laussedat, might be so many proofs in favor of the existence of an atmosphere. But it remains to be seen whether these optical phenomena are not capable of another kind of explanation.

Fig. 37. The slope of the solar crescent.

Still other means exist for assuring ourselves whether or not the Moon has an atmosphere. At the distance which we are from our satellite, a distance small enough for us to be able to observe the brightness which the Earth's light gives to its nights, the twilights ought to be easily distinguished. The line of separation of light and darkness, instead of being clearly defined, ought to blend itself into a luminous tint with a diminishing intensity on the side towards the obscure part of the disc. Here observation shows many inequalities and indentations, but they are very clearly detached, and certainly give evidence only of great differences in the levels of a mountainous and diversified surface. Schrœter only seems to have observed a lunar twilight, perceiving, on the extremity of the horns of the crescent, a faint light which gradually diminished on the side towards the obscure part of the disc. This glimmer could not be confounded with the greyish light, since it was seen at a moment when the terrestrial twilight was still sufficiently strong to render invisible the regions of the Moon farthest from the luminous crescent.

How happens it that such an interesting observation has not been repeated? It is a question which we are unable to answer, and which might present itself in many a problem, still obscure, of physical astronomy.

Schrœter has supposed from this fact the existence of an atmosphere of the Moon, extending 1,500 feet above the average level of the plains.

Finally, when we examine the shadows thrown by the peaks, the craters, and in general by all the elevations so numerous in certain regions of the Moon, we remark that these shadows are clearly and everywhere equally defined, at the summit as well as at the base of the mountains; nowhere do they present that softening in the tints which would be the natural consequence of the interposition of gaseous envelopes of varying densities.

Summing up everything, and considering the present state of astronomical knowledge, the reasons for the existence of a lunar atmosphere are much less decisive than those against it, and it appears certain that the Moon has no sensible atmosphere.

Now, if it really is so, let us consider the aspect which lunar landscapes must present with regard solely to light and shadows. All objects, which receive the solar rays directly, shine there with a brilliancy which distance does not lessen. The shadows there have everywhere the same intensity; they allow the objects which they envelop to be seen only by the reflections of luminous bodies near by—the diffusion of daylight by aerial molecules being impossible there. At the horizon, the contours of objects stand out with extreme boldness against the black depths of the sky,* where the stars and all other luminous bodies shine at mid-day. The Sun's disc is outlined in the midst of a starry sky whose sombre tint offers nowhere any softening. No aerial perspective there; none of those plays of light—of those vaporous tints which give to terrestrial landscapes such charm and sweetness. Neither twilight at night, nor aurora during the mornings; night succeeds day abruptly, and without transition, except at the points where high mountains, still illumined by the solar rays, reflect their vivid light into the midst of the darkness which reigns at their base.

The optical phenomena, due to the presence of a gaseous medium or to that of aqueous vapors, do not exist on the Moon's surface. Refraction there does not decompose the white light into seven colors and into a thousand varied shades. The rainbow

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* The color of the sky on high mountains may give an idea of the aspect which the celestial vault would present to an observer placed on the surface of the Moon. Saussure, in his ascent of Mont Blanc in 1787, compared the color of the sky to different shades of tinted paper, from pale blue to blue almost black. At mid-day the sky was nearly as dark as the darkest cloud. It is probable that, during the night, the color of the starry vault may even approach black.

and the beautiful tints which, on our Earth, purple the horizon at sunrise and sunset, are unknown there.

The absence of air on the surface of the Moon implies the absence of water. If lakes, seas, or simply rivers existed, the liquids which formed these reservoirs or these currents, would be at once reduced to vapor, owing to the single fact that they would not be held by atmospheric pressure. But solar heat, acting still more energetically, would cause a gaseous envelope, thick clouds of vapor. A cloud of 600 feet diameter could easily be seen. Now we have just said above that no moving spot has ever been observed on the Moon's disc.

No air and no water! no winds and no currents; there is immobility everywhere. At most, under the influence of alternations of heat and cold, the disintegration of matter and the destruction of the equilibrium of heavy bodies, causing the fall of rocky debris, break the monotony of immobility and of eternal silence. For sound, not being able to be propagated by any aerial medium, is transmitted at most at the moment of contact, by the vibrations of solid molecules. For an inhabitant of the Earth, the star of night is then, according to Humboldt's expression, only "a hushed and silent desert."

XVIII.

LUNAR DAYS AND NIGHTS.

COMPARISON OF LUNAR DAYS AND NIGHTS WITH TERRESTRIAL DAYS AND NIGHTS—ABSENCE OF TWILIGHTS AND AURORAS—THE EARTH SEEN FROM THE MOON—EARTH LIGHTS—THE NIGHT ON THE INVISIBLE HEMISPHERE.

WHAT is the climate of the Moon? What are the days, the nights, and the seasons on our satellite? What is, in a word, its meteorology, and how are the phenomena which we ordinarily comprehend under this latter denomination, distributed in the different regions of its globe?

The phases of the Moon, which are reproduced every lunation with regularity and constancy, prove already that the days and nights succeed each other there alternately, as on the Earth. Only the duration of this phenomena is there much longer;

in $29\frac{1}{2}$ days the lunar globe presents all its faces to the sunlight. Thus the Moon's solar day is about 709 hours, more exactly 708 hours 44 minutes 3 seconds. As the axis of the Moon is almost perpendicular to the plane of the ecliptic, it follows that the days and nights divide this period almost equally. Every point on the Moon's surface sees the Sun dawn upon its horizon, above which he rises slowly for 177 hours; it is then noon, the middle of the lunar day. During the other half, the sun describes in an inverse way an arc equal and symmetrical with the first, then disappears with the same slowness below the horizon. The day has lasted about $354\frac{1}{2}$ hours.

Then begins a night of the same length, almost thirty times as long as that of our Earth at the time of the equinoxes.

But is it only in respect to duration that lunar days and nights differ from terrestrial days and nights? No, indeed; that is very far from being the case. In order to judge, let us compare the lunar day with the terrestrial day in the same latitude, that for instance of our temperate zone.

Just before the Sun makes his appearance above our terrestrial horizon, the shades of night give place to the ever-brightening glimmer of the aurora; gradually the light penetrates the atmospheric layers which reflect it to the surface. Even at the period of short twilights, in March and September, this gradual approach of sunrise is very perceptible, and the thickest clouds, the densest fogs lessen without destroying it. I will not stop to paint the beauty of the celestial landscape, the variety of aspect which the whole sky presents a few moments before the rising of the radiant star, the brilliant light of the eastern horizon, and the vivid colors and charming shades which contrast with the cold and sombre grey of the west. No one, whom the beauties of nature have power to move, can fail to admire so beautiful and touching a spectacle, whose infinite variety prevents it from ever becoming monotonous. Even then, when the Sun has shown himself in its splendor, it is only insensibly that he acquires all his glory ; the thickness of the layers of air, greater at the horizon, diminishes the intensity of its light and accustoms us to endure his extreme brillancy.

In the same manner, the evening twilight renders the transition from daylight to the obscurity of night less sudden, and the purple tints of the western horizon are not inferior in beauty to those of the morning. At midday, too, with a pure and serene sky, the celestial vault offers a blending of tints and lights full of charm ; all around the solar disc, whose brilliancy the eye cannot endure, a luminous crown, a tint of resplendent gold, melts gradually in the deep azure, and north and south, east and west are distinguished by different shades of light and color. This spectacle would be greatly varied, if, instead of considering only one climate, we should try to paint the terrestrial days and nights from the burning sky of the tropics and of the equator to the icy solitudes of the poles.

On the Moon, do the days and nights form pictures so varied in coloring? Do they succeed each other by transitions so skillfully arranged? No, and the reason is easily seen.

The absence, or at least the extreme rarity of the atmosphere, produces a sudden transition from day to night and from night to day. I mistake: the only gradation of light which is observed there is due to the slowness with which the Sun rises above or sinks below the horizon. It is only gradually that his disc shows itself above or is concealed below the most distant plains of the landscape, and it is nearly ten hours from the moment when the first luminous point gleams forth and that in which the whole disc of the Sun has made its complete ascension. But the intensity of the solar light, collected, attains at once its full power; and the eye of man, which cannot endure its brilliancy through an atmospheric thickness varying from 30 to 500 miles, would be, on the Moon, dazzled and cruelly injured by receiving it directly.

When the Sun has once risen, whatever may be his altitude, he throws over all objects with equal power his sharp and vivid light; were it not for the reflections of the illumined ridges, mountains and hills, every object plunged in shade would be, even at midday, in complete darkness, which the glory of the celestial vault, studded everywhere with stars, would alone relieve. In truth the illumination of the surface varies there according to the hours of the day, because a surface is illumined in inverse proportion to the obliquity of the luminous rays.

During the night darkness is so great that our blackest nights can give no idea of it. On the Earth, the sky still preserves its transparency, the deep hue of the spaces which separate the stars is always colored and bluish; moreover it goes on diminishing in the east and in the west according to the hour of the night. It is not so with the lunar nights: the intense blackness of darkness which the firmament presents is still more augmented by the brilliancy of the stellar lights, and the presence of the terrestrial disc can only add to this contrast.

But, on the other hand, what magnificence in the prodigious multitude of visible stars, in the resplendent glory of the Milky Way, in the beauty of the Zodiacal Light, so difficult to be seen in our terrestrial nights! What astronomer is there who would not be transported with joy at the thought of being able to install his observatory on the surface of the Moon, and to observe there at his ease, even for ten or twelve lunar nights!

I have spoken of the visibility of the Earth. It is easily understood that this visibility is possible only for the hemisphere turned towards us. A curious circumstance, and one which contrasts with the constant motion of the Moon in our sky; the disc of our planet shines always in the same part of the starry vault, suspended above the horizon like a lamp, and oscillating around this almost invariable position only in an insensible manner.

Let us transport ourselves in thought to a place on the visible hemisphere, for instance just opposite our Earth, that is on the central meridian. At midnight—at the hour when the new moon begins for the inhabitants of our planet—the full earth shines in all its glory. More than thirteen times as large as the lunar disc seen from the Earth, the terrestrial disc presents to us varied spots which mark its continents and seas, here and there hidden by other shining and moving spots, the atmospheric clouds. Two whitish caps, like those of Mars, surround the poles; the seas are of a deep bluish shade, while the continents are spotted in parts by a pale green, and the whole contour of the disc, more luminous than the central parts, is slightly reddish, the natural effect of atmospheric refraction.

The Earth remains almost immovable at the same point of the sky, more or less near the zenith, according to the latitude; but the aspect of its disc varies with a rapidity relatively very great. We see spots passing from the eastern to the western edge (with regard to the south point of the lunar horizon). If the Asiatic continent were first seen, it would disappear first to make room for Europe and Africa, and finally for the New World and the Pacific Ocean. Every 24 hours this procession recommences, and the Earth seems thus like a clock with a movable dial-plate, whose hours correspond to the different spots.

As the night advances, the terrestrial disc flattens, and the circular shape becomes oval upon one of its halves, until at sunrise it is presented under the form of a half circle. The reverse takes place in the first half of the lunar night, so that in 354 hours the Earth has passed from the first to the last quarter. The other phases are completed in the entire day, and our planet appears in the midst of the stars like a great crescent whose curve is bounded by an obscure tint like the greyish light; such are the lights of the terrestrial Moon. These phenomena, we have said, are unknown in the days and nights of the opposite hemisphere: nothing is known there of the Earth. A zone only of a certain extent sees our globe appear on the horizon, remain there some time and then disappear, never rising more than a few degrees. Still this appearance of the Earth does not take place every night, so that in this zone there are bright nights and nights entirely dark. Everywhere else, the nights have an intense obscurity which no twilight relieves, but where the magnificence of the starry vault permits the observer to witness, for 350 hours, the most delicate celestial phenomena.

The duration of the day and of the night varies within very small limits on the surface of the Moon, a circumstance which arises from the small inclination of its axis to the ecliptic. The parallels described by the Sun are but a short distance from the equator. But it is necessary to except the regions quite near the poles, where the duration of the night and that of the day may be much shorter or longer. At the very poles, the mountains are perpetually illumined by sunlight. "The Sun descends below the true horizon of a lunar pole only by a quantity equal at most to the inclination of the

Moon's equator, that is by 1° 30′, but the smallness of the Moon's globe is such that, even at an elevation of 1,900 feet, the eye penetrates 1° 30′ below the true horizon. Now there are at the North Pole mountains 9,500 feet, and at the South Pole, 13,000 feet high; consequently the summits of these mountains can never be hidden from the Sunlight." (Beer and Mædler.)

We shall obtain in another way a more exact idea of the little difference which exists in the duration of the shortest days at different latitudes of the Moon, by the following table, whose elements are borrowed from the Popular Astronomy of Arago, and which may of course be applied to the longest and shortest nights.

At the equator the days and nights do not vary, and are constantly of 355 hours, 22 minutes and 1 second.

Latitude, N. or S.	Duration of longest day.	Duration of shortest day.
0°	354 h. 22 m. 1 s.	354 h. 22 m. 1 s.
15°	355 h. 9 m. 19 s.	353 h. 34 m. 43 s.
30°	356 h. 3 m. 54 s.	352 h. 40 m. 8 s.
45°	357 h. 18 m. 30 s.	351 h. 25 m. 38 s.
60°	359 h. 27 m. 47 s.	349 h. 16. m. 15 s.
75°	362 h. 21 m. 40 s.	343 h. 22. m. 22 s.

The difference between the longest and shortest days is, as we see, very little at first, and becomes very sensible only after the 60th degree. At 88° of latitude, 2° from the poles, this difference is more considerable ; it has already increased to 190 hours, and finally at the very poles the Sun is visible for 179 days, a little less than half a terrestrial year.

The invisible hemisphere has days a little shorter than the hemisphere turned towards the Earth. The greatest difference is at the points situated on the two halves of the central meridian, and reaches, for the average duration of the day, 1 hour, 7 minutes, 54 seconds.

XIX.

THE MOON'S CLIMATE.

THE SEASONS—HEAT AND COLD—TORRID TEMPERATURE OF THE LUNAR DAYS; INTENSITY OF COLD DURING THE NIGHTS—VARIATIONS IN THE COURSE OF A REVOLUTION AROUND THE SUN.

THE Moon has days and nights, like the Earth; has it, like our planet, a year and seasons?

When we consider a celestial body which moves directly around the Sun, describing an orbit of an elliptical or nearly circular form, the year of this celestial body is the interval of time which elapses between two consecutive returns of the body to the same point of its orbit. For the Moon, the movement being more complex, the definition of a year can be understood in two ways, and each of these is subject to different interpretations.

Do we consider the revolution of the Moon around the Earth? In this case, the lunar terrestrial year may be understood as the return of our satellite to the same point of its orbit, and its duration is 27 days, 7 hours, 43 minutes, a little less than a lunation; or again, as the return of the Moon to the same position in regard to the Sun and the Earth, and in this case the lunar year and the lunation are one and the same thing. That would amount to saying that the Moon's day is identical with its year, which is composed in all of a single day and a single night. Finally, if we consider the lunar year relatively to the movement of the Moon around the Sun, it will be very nearly of the same duration as the terrestrial year.

But it is not the purely geometrical side of the question which we have in view here; what it concerns us to know is the influence which the variations in the position of the Moon may have on the temperature and the climate of the different lunar regions.

These variations are very slight. This results from the axis of rotation, as it moves in space, remaining always parallel to itself, and nearly perpendicular to the plane of the ecliptic. The Sun, whether in the course of a lunation or in successive lunations, varies little in its altitude above the same horizon. Oscillating from one degree and a half below the equator to one degree and a half above, its total variation reaches only three degrees. Hence a uniformity in the climate of each region, so much the more sensible because there are no corresponding atmospheric phenomena.

But let us try to form an idea of the Moon's climate, with reference to the variations of its temperature.

For 354 hours, nearly 15 terrestrial days, the Sun darts its rays without intermission to the ground, at first obliquely in the hours which follow its rising; then more and more vertically as mid-day approaches. The temperature of the surface, under the prolonged influence of such an intense radiation, must attain an extraordinary elevation, "perhaps much greater," says Sir John Herschel, "than that of boiling water." After the lunar noon, the heating of the soil continues, and attains, undoubtedly, its maximum between this time and sunset, as on the Earth.

In truth, the absence of an atmosphere must permit the radiation of heat to be developed with an extreme intensity, depending also on the nature of the substances which compose the soil. It follows that the Moon's climate offers a certain analogy to our Alpine climates. We know that if we ascend high mountains, the Sun's heat directly received is insupportable; the soil itself is easily heated; but the layers of atmosphere have a lower temperature, and we experience distinctly a sensation of cold, specially noticed when we are in the shade. In the elevated regions, "the soil radiates rapidly, and if it is heated more than the air under the influence of the solar rays during the day, it cools off sooner when the Sun's rays no longer strike it directly—that is, in the shade, and during the night." (Martius.) It is the rarity of the atmosphere which favors the heating of the soil on the summit, and which, rendering also the radiation more intense, favors still more its cooling off in the shade or during the night.

On the Moon the air is wanting, or, if there are traces of it, its rarity is much greater than that of the air in Alpine regions. The contrast is still more striking there; we ought to find at the same time a torrid temperature in places exposed to the solar light, and an intense cold in places which are deprived of it; for instance, in the shade of cavities, of craters, and of circular enclosures.

During the 354 hours of the night, all this accumulated heat being no longer retained by a gaseous envelope, the temperature decreases with extreme rapidity. It sinks, undoubtedly, much below that of our polar winters.

From the equator to the two poles, the difference of climates is due only to the greater obliquity with which the rays of light and heat strike the soil. So that the decrease of temperature with the increase of latitude ought to have much analogy with the thermometric variations which characterize the different periods of a lunar day.

On our Earth, the extremes of winter, as well as of summer, are often mitigated by atmospheric phenomena, by aerial or oceanic currents, by the presence of clouds, by rain or storms. In the Moon there is nothing of the kind. A leaden Sun darts its piercing arrows without pity upon all points exposed to its action. If the lunar surface were covered here and there by sheets of water, by seas, by lakes or rivers, how could these liquid masses escape a rapid evaporation, especially as no atmospheric presence would hinder this change of state? So much for the day. During the night, every trace of water or of aqueous vapor would disappear by an inverse phenomenon, and the liquid sheets would be found transformed into frozen lakes, and the vapors, also, rapidly condensed, would fall suddenly under the form of snow. Sir John Herschel has expressed an opinion of this kind; but, if he does not consider such phenomena as impossible, at least he considers them as confined to very narrow limits. The alternation of two opposite temperatures, both excessive, he says "should cause a constant transfer of whatever moisture may exist on its surface, from the point beneath the Sun to that opposite, by distillation *in vacuo*, after the manner of the little instrument called a cryophorus. The consequence must be absolute aridity below the vertical Sun, and constant accretion of hoar frost in the opposite region. It is possible, then, that evaporation on the one hand, and condensation on the other, may, to a certain extent, preserve an equilibrium of temperature, and mitigate the extreme severity of both climates; but this process, which would imply the continual generation and destruction of an atmosphere of aqueous vapor, must, in conformity with what has been said above of a lunar atmosphere, be confined to very narrow limits."

If the hypotheses of the illustrious astronomer were a statement of facts, it would account, in a certain degree, for the feeble radiation of heat from the Moon to the Earth; since it is the vapor of water, according to physicists, which forms an obstacle to the radiation of heat emanated from a source not incandescent. But what destroys in our eyes much of the probability of this hypothesis, is that the evaporation of which Herschel speaks ought to give birth to clouds at least in the regions situated near the limits of light and shade—that is, during the lunar nights and mornings. We know that nothing of the kind has ever been observed.

To finish what we have to say of the lunar temperatures and their variations, considered thus far in the interval of one revolution only around the Earth, let us see what these same variations are in the course of a terrestrial year. As the Moon unceasingly accompanies our planet, its distance from the Sun varies as the distances of the Earth itself—that is, nearly in the ratio of the numbers, 1,019 and 0,980. The intensity of the solar heat will then vary in the inverse ratio of the squares of those numbers; so that if we represent this intensity by the number 1,000 at the mean distance, it will be 1,038 at the maximum distance or aphelion, and 960 only at the minimum distance, or perihelion. That is a difference, more or less, of nearly $\frac{1}{25}$, a very appreciable and sensible quantity.

XX.

IS THE MOON INHABITED?

VEGETATION—HABITABLENESS—EXAMINATION OF THE CONDITIONS NECESSARY TO THE EXISTENCE OF ORGANIZED BEINGS ON THE MOON'S SURFACE.

Are there upon the Moon vegetables, animals and men? In a word, is the Moon inhabited? These are questions which human curiosity has been agitating for a long time, and such as we never fail to put to ourselves whenever our imagination and our thoughts transport us to any of the celestial bodies which illumine the starry vault.

The answer is generally very difficult, so long as we do not wish to leave the solid ground of observation and of facts. Undoubtedly, when we consider the problem in its generality, and from an entirely philosophical point of view, it appears very probable that the Earth is not the only planet of our universe where the proper conditions for the development of animal and vegetable life are to be found. Still more, we must believe that the suns, scattered through the infinite space, and which are the sources of heat for so many planetary worlds invisible at such great distances, do not spread light and heat over their satellites in vain; we refuse to imagine the silence of death, where the principal sources of life appear to us in full activity, and seem to spread themselves abroad in such marvellous profusion. Indeed it is impossible for us to conceive of this universe otherwise than as a harmonious whole, where are grouped in infinite number the sources of life and of power.

But we also know that if the laws of nature have an undeniable character of universality and of unity, their manifestations are indefinitely varied.

The history of the Earth itself shows us that it has not always been the abode of life, that before the periods when the first attempts at organization appeared upon its surface, other periods had elapsed in which the conditions necessary for the appearance of the simplest organisms did not exist; that then, in a word, the Earth was not inhabited. Perhaps, without quitting our solar system, we may find planets which have not yet passed out of their embryonic state, and where life has not yet been generated. It is also possible that revolutions, of which we have no idea, may have destroyed, on this or that globe, all animated beings, or even that a planet may have been from its origin so constituted that animal or vegetable life may be forever impossible upon its surface.

All these hypotheses seem to us equally probable; but they are only conjectures, and we might reason for a long time upon such suggestions without ever drawing from them anything but vague and arbitrary conclusions. We must resign ourselves to this for the unknown planets of other systems, perhaps even for several of the celestial bodies of our own system; but we may hope to solve the question in a positive manner as far as concerns our satellite, too near to escape decided investigations.

Let us see what is already known or supposed concerning the existence of animated beings upon the surface of the lunar globe.

Conjectures are not wanting: there have always been people who have given the Moon inhabitants; they have been appropriately called selenites (from σελήνη, which in Greek signifies the Moon.) But they have had no other reasons than the analogies which the Moon and the Earth present in an astronomical point of view, and they have hastened to extend these to all other physical phenomena. Not more than a century ago, one of the most learned astronomers of the period reproduced from the English Encyclopedia the following lines :

"The Moon is in every respect a body similar to the Earth, and which appears adapted to the same end ; in short, we have seen that it is dense, opaque, that it has mountains and valleys ; according to many writers it has seas with islands, peninsulas, rocks and promontories ; a varying atmosphere where vapors and exhalations rise and fall again ; finally, it has a day and a night, a Sun to lighten the one, and a Moon (the Earth) to lighten the other ; a Summer and a Winter, etc. Hence we can infer, from analogy, an infinite number of other properties in the Moon. The changes to which the atmosphere is subject ought to produce *winds* and *other meteorological phenomena ;* and, according to the different seasons of the year, rains, fogs, hail, snow, etc. The inequalities of the Moon's surface ought to produce on their part lakes, rivers, springs, etc.

Now as we know that nature produces nothing in vain, that the rains and the dews fall upon our Earth in order to make the plants vegetate, and that the plants take root, grow and produce seeds in order to nourish animals ; as we know besides that nature is uniform and constant in her processes, that the same things serve for the same ends ; why should we not conclude that there are plants and animals on the Moon? If not, for what end this display of provisions which seem so well adapted to their existence?" (Encyclopedia, Art. *Moon.*)

We have nothing to say of the value of the reasoning in itself, which draws all its power from the principle of final causes, generally abandoned to-day by learned men; but it is very evident that the data are far from being incontestable. We have stated the reasons why astronomers no longer believe either in the existence of liquid masses, or in that of a gaseous envelope, composed either of aqueous vapor or of atmospheric air, and that there results from this the impossibility of all the meteorological phenomena, the enumeration of which we have just read.

What are, at least upon the Earth, the primary conditions indispensable to life? Water, air, a certain temperature.

Now, if it is not rigorously proved that the Moon is totally deprived of an atmosphere, it is at least certain that its density is extremely slight, compared with the density of the earth's atmosphere. Yet, rare as it may be, it would suffice to furnish vegetables with the gaseous elements which their nutrition and their development require. But we have no knowledge of an animal organism capable of living in a medium analogous to the air which remains under the bell-glass of our air-pumps, when the pressure is only a few hundredths of an inch If the lower layers of the supposed atmosphere were sufficiently dense to permit animals to live there, the inhabitants of the Moon would be obliged to inhabit the bottoms of craters, in groups separated from each other by impassable ridges. Neither does water exist upon the Moon's snrface; we have seen two conclusive reasons for this: first, the absence or the feebleness of atmospheric pressure, owing to which every liquid would be spontaneously reduced to vapor; then the prolonged intensity of a torrid temperature, which would parch the soil at each lunation. Have we any idea of organized beings whose tissues could neither preserve nor renew their supply of moisture? On our earth undoubtedly we see vegetation developing itself with astounding rapidity in the warmest climates of the torrid zone; but such a development is due to a mingling of moisture and of heat: vegetation ceases almost entirely wherever dryness and heat are found combined. Finally, life disappears, even in regions where air and water are certainly far superior in quantity to what our satellite possesses, when the altitude is sufficient to produce a glacial temperature analogous to that of our polar climates or of the Alpine regions.

Now such a temperature certainly prevails on the Moon during its long night of fifteen terrestrial days. How can living beings resist these alternations of excessive heat and cold? Besides, we know that it is the vegetable kingdom which, directly or indirectly, furnishes to animals the assimilable elements necessary to their existence; so that the first question to solve would be to know whether the physical constitution of the Moon is adapted to vegetation. We have just seen how unfavorable this constitution seems in connection with the three most indispensable elements: air, water, and the degree of temperature.

Let us add that the soil itself does not appear favorable to the development of the vegetable kingdom. Its eminently volcanic nature, and the absence of lands analogous to the tertiary and sedimentary formations of the terrestrial globe, except perhaps in the vast open plains called seas, cause the Moon's actual state to agree with the primitive geological epochs; and we know that vegetation did not appear upon our Earth until in later periods, when the atmospheric agents, by disintegrating the rocks, had rendered the soil fit for the production and for the life of the lowest organisms.

Are there, then, many probabilities against the possibility of the existence of living beings in the

Moon? Is there an absolute impossiblity in it? No, undoubtedly; only we are left to imagine conditions of vitality different from those of which we have any knowledge, that is, to enter into pure hypothesis.

Attempts have been made to solve in other ways the interesting question of the Moon's habitability, I mean by direct observations. Have they succeeded any better? Does the telescope permit objects as small as animated beings to be seen with sufficient distinctness on the surface of the Moon? Let us see.

Much has been said of large telescopes or of powerful glasses, possessing fabulous magnifying powers—for example, of 6,000 diameters. For the observation of the Moon, a magnifying power so considerable is simply impossible, and that for several reasons. We must not forget that with an increase of power, we obtain a more than proportional diminution in the intensity of the light of the observed object, when that object, like the Moon, is not self-luminous. Hence a limit to the magnifying power of an instrument. Moreover, the terrestrial atmosphere is never still enough to permit the employment of such very powerful instruments, and the undulating images, badly defined, destroy all the nicety of vision.

Thus, in the actual state of applied optics, we cannot use for the observation of the Moon this magnifying power of 6,000 diameters, which would make us see the star as if it were at a distance of only forty miles. We must content ourselves with magnifying powers of 1,100 or 1,200 times, which put, in the case of the minimum distance, the central parts of the lunar disc at 200, or, at best, at 180 miles from our eyes.*

With an instrument sufficiently perfect to permit the employment of the strongest of these magnifying powers, we can perceive an object of 1,300 feet in diameter. The highest of the pyramids of Egypt would still be invisible. Supposing that we reach a magnifying power of 6,000 we could still perceive only objects presenting at least 250 feet in diameter.

We must not expect then to be able very soon, in observing the Moon, to recognize living beings, animals or vegetables. Vast forests would certainly be visible, but, like dark spots, poorly defined; we could judge of their existence by their color only.

Have we seen, on the lunar disc, colorings which

* Mons. Guillemin supposes a power of 1,100 or 1,200 to be used. In practice this is very rarely done. Very few nights, at least in our Northern States, are sufficiently still and clear to admit of the use of a power greater than 400.—Ed.

would lead us to believe in the existence of vegetation, covering vast spaces?

Several observers agree in saying that independently of the variations in brightness which the different lunar regions present, they have also found, in several places, differences of tint.

We will name the principal.

Mare Crisium is of a grey color, mixed with dark green, according to Beer and Mædler. According to Webb, it is during the full moon that this greenish tint shows itself. Mare Serenitatis is of a bright green color; Mare Humorum offers distinctly the same tint, surrounded by a narrow greyish border.

Are these colors, as Arago is inclined to think, simple effects of contrast arising from the opposition of the brilliant and slightly yellow light of the luminous parts of the disc with the feeble light of the dark spots? If it were so, why should not this green color be common to all the plains, or at least to the parts which border upon the mountainous regions? Mare Fœcunditatis, Mare Nectaris and Mare Nubium would be admirably situated for presenting the same effect of color by contrast, and yet observation says nothing with respect to them.

What seems, moreover, to establish the fact of a real color is, that other places seem reddish. The crater Lichtenberg, in the neighborhood of Montes Hercynii, and of the northwest border, offers this tint, and Palus Somnii is of a yellow shade approaching brown.

Vitruvius, a crater very dark in the inside, is surrounded by a region of a pale blue color. Then, too, "the circular plains, whose centres are not occupied by mountains, are for the most part of a dark grey approaching blue, which resembles the brilliancy of steel." Humboldt, in referring to these last facts, adds that "the causes of these different shades on a soil formed of rocks or covered with movable substances are entirely unknown." We are ignorant, in short, whether the rocks themselves are thus closed, which would be very natural, or whether these tints are due to this or that luminous incidence; finally, whether this has any connection, as was at first supposed, with spaces covered by vegetation, forests or prairies.

Undoubtedly, this last hypothesis would appear probable, if the reasons, which have made us believe in the total absence of air and water from the surface of the Moon, did not render the existence of organized beings upon its surface very hypothetical.

CHAPTER V.

THE MOTIONS OF THE MOON.

XXI.

THE REVOLUTION OF THE MOON AROUND THE EARTH.

DIFFERENCE BETWEEN THE LENGTH OF A LUNATION AND THAT OF THE REVOLUTION OF THE MOON—DISTANCES FROM THE EARTH—DIMENSIONS OF THE ORBIT, AND VELOCITY OF THE MOON—REAL FORM OF THE CURVE DESCRIBED IN SPACE BY OUR SATELLITE.

WHAT have we learned of the phases of the Moon and their succession in periods of about $29\frac{1}{2}$ days? It is that the Moon moves in space around the Earth from west to east, and, at the end of a lunation, is again in the same position with respect to the Earth and Sun, considered as fixed. If the Earth were really motionless, the length of the lunar revolution would be that of the lunation—that is, 29 days, 44 minutes, and 3 seconds. But while the Moon describes its orbit, the Earth itself describes its own around the Sun, or, at least, describes a portion, which is about 29 degrees of arc. And, as the direction of the two motions is the same, the evident result is that the Moon has effected an entire revolution before the lunation is accomplished. This is shown by the accompanying figure. (Fig. 41.)

The Moon, starting from the point, L, at the time of conjunction, reaches L′, where its revolution is

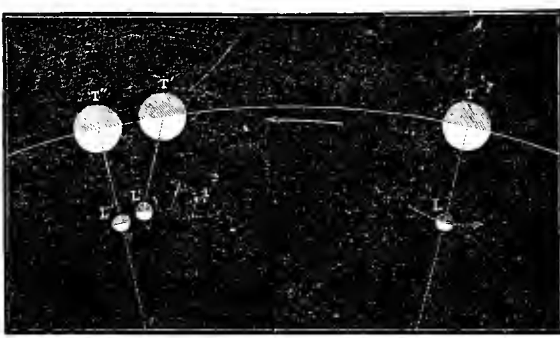

Fig. 38. Difference between the duration of a lunation and that of the revolution of the Moon around the Earth.

terminated,* before reaching L″, where it will again

* To understand clearly the difference that we mention, we must have a definite idea of the independence of the two simul-

be in conjunction. Now, from L′ to L″, there remains an arc of about 29 degrees—that is, an arc equal to that described by the Earth during the Moon's revolution. This revolution is then less than a lunation, and an easy calculation shows that it is 27 days, 7 hours, 43 minutes, and 5 seconds.

Now, what is the precise form of the curve described by the Moon? This is a question which astronomers have answered by measuring the apparent dimensions of the lunar disc, during its whole revolution.

If their dimensions, reduced to the centre of the Earth, remained constant, the distance of the Moon would not vary, whence we should conclude that it moved in a circular orbit.

But this is not the case; their dimensions vary, and, in calculating the corresponding variations of distance, we perceive that the curve has the form of an ellipse, and that the Earth is at one of the foci. We give an idea of the real form of the lunar

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taneous movements. If the Earth were motionless the Moon would finish its revolution at the moment it returned to the point L. But, during this time, the Earth has moved, and the Moon with it; consequently, the point L becomes L′ in a direction T′ L′ parallel to the line T L. But this point L′ is no longer in the direction of the Sun, and, in consequence, new moon happens afterwards, when the Moon has advanced to L″, in the direction in which, seen from the Earth, the Moon would go around the Sun.

ellipse—that is, of its eccentricity or the quantity by which it differs from a circle, by means of the following numbers, which are the extreme and mean distances of the Moon from the Earth, the mean distance being taken as unity.

Greatest distance, or at apogee	1.0549
Mean distance	1.0000
Least distance, or at perigee	0.9451

These numbers indicate relative distances only; but the true distances have been calculated, and may be expressed in values of the radius of the Earth, in ordinary measurements. The methods employed in solving this very interesting problem of the distances of the heavenly bodies cannot be explained in this place, but we have given elsewhere a sufficiently minute explanation to make one readily understand the principle.* The greatest distance of the Moon from the Earth is about 64 times the equatorial radius of our planet, (more exactly, 63.583,) while at the epoch of perigee, or at its least distance, it is no further removed from us than 57 radii of the Earth (56.964). The mean distance of our satellite is 60¼ radii (or 60.273)—that is, nearly equal to the 400th part of the distance from

* See the third part of the work on "The Heavens."

the Earth to the Sun, which is, as we know, about 24,000 terrestrial radii.*

Between the Earth and the Moon, or rather, between the centre of the Earth and the point of the Moon nearest to us, there must be placed a chain of thirty globes equal to the terrestrial globe, in a straight line, touching one another, to fill the interval which separates the Earth from its satellite, when the Moon is at its mean distance.

One hundred and ten lunar globes would be necessary to fill the same space. Let us now change these spaces into distances in miles. The centre of the Earth and Moon are 251,947 miles distant at apogee; at perigee, 225,719 miles; and finally, at the mean distance, it is 238,793 miles.

It is readily seen that we must subtract from all these numbers the two radii of the Earth and the Moon, if we would obtain the distances of the two nearest points of the surfaces of the globe; so the preceding numbers become the following:

Distance at apogee................	246,910 miles.
Distance at perigee................	219,682 miles.
Mean distance....................	233,756 miles.

233,756 miles! This is not nine and a half

* The distance of the Earth from the Sun was formerly considered to be 95,274,000 miles. It is now called 91,130,000.

times the entire circumference of the Earth!* There are sailors, doubtless, who, in the course of their voyages, have traversed distances as great, which our express railroad trains would pass over in less than 300 days.

Suppose the space which separates the Moon from the Earth to be filled with air, so as to allow the passage of sound from one globe to the other; then, at the time of full moon, if a volcanic eruption took place on its surface, the noise of the explosion would not reach us until 13 days and 8 hours after the event, so that we should not be aware of it until nearly the next succeeding new moon.

This calculation supposes the temperature of space to be at the freezing point of water, 32° Fahr. It would require a little less time, about eight or nine days, for a cannon ball to pass through the same distance, supposing that it kept a constant velocity of 1,640 feet a second. Light, which has the most rapid of all motions, comes from the Moon to the Earth in 1¼ seconds.

In these familiar comparisons, which are useful in fixing, in the memory and imagination, distances so difficult for the mind to conceive, we consider only the constant velocity of moving bodies. We can also calculate the time which it would take a body to fall from the centre of the Moon to the centre of the Earth, or, what amounts to the same thing, the time which it would take for the Moon to reach the Earth, if the tangential force, which, combined with the force of gravity, causes it to describe its orbit, were to be suddenly destroyed. At the end of 6 days, 5 hours, 40 minutes, and 13 seconds, the catastrophe, the terrible consequences of which we need not describe, would be consummated.

Suppose the Earth to be motionless in space, the Moon describes around her an ellipse, the circumference of which is 1,500,000 miles; the velocity with which it moves through this orbit is variable, but in general it is 3,350 feet a second. In reality, the lunar orbit is much more intricate, because our planet, in moving around the Sun, draws the Moon through space with it. It is thus that a person placed upon the deck of a ship in motion, in walking around the mast, appears to himself to move in a circle, while the line which he describes on the surface of the sea is a sinuous curve, the form of which is analogous to that of the real orbit of the Moon. In reality, the path which this person pursues is still more complicated, and to draw its true form we must combine his own motion, the motion of the ship on the sea,

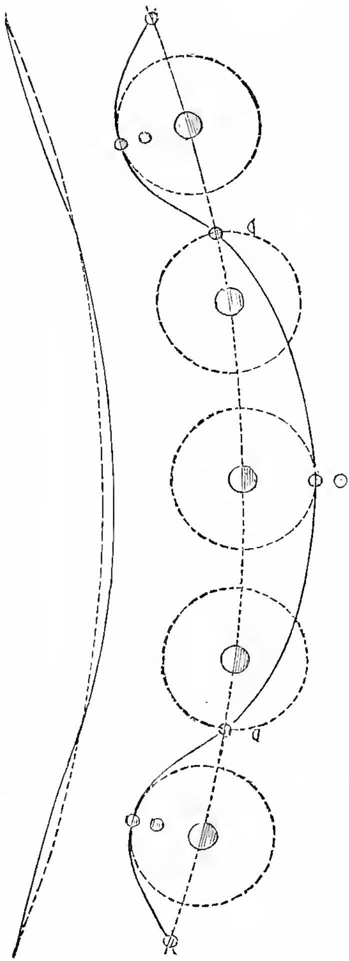

Fig. 39 Sinuous form of the lunar orbit; 1st, amplified; 2d, reduced to its true dimensions.

and the double motion of the rotation of the Earth on its axis, and of the revolution of the Earth around the Sun. We shall see, further on, that the Sun also moves in space, drawing with it the Earth, the other planets and their satellites; hence result the sinuous forms of the orbits of all these bodies, the degree of complexity varying with the number of motions by which they are impelled. Fig. 42 gives an idea of the sinuous curve which the Moon describes, upon the supposition that we remember the true proportions of the distances of the Moon from the Earth, and the Earth from the Sun. Yet the curve given above, appearing sometimes as convex and sometimes as concave, toward the Sun, is really always concave.

But the Moon is not always in the plane of the ecliptic, in the plane of the Earth's orbit. The plane of its orbit is inclined to the plane of the ecliptic, at an angle of about 5° 9′. In consequence, our satellite is sometimes above, sometimes below, the plane of the figure, through which it passes twice in a revolution. Each of these two particular positions is called a node ; it is the ascending node when the Moon passes from the south to the north, and the descending node when it passes from the north to the south of the ecliptic.

No two consecutive nodes occupy positions diametrically opposite on the lunar ellipse, and these positions vary from one revolution to another. It is only after an interval of eighteen years and eight months that the nodes are again in the same relative situations. This is one reason why the eclipses of the Sun and Moon do not repeat themselves at every lunation.

The motion of the Moon presents many other inequalities which we have not mentioned, and which render the theory very difficult. Their explanation would not have been possible if the theory of gravitation, permitting us to separate the causes of these inequalities, had not found observations to compare with calculations. But this is not the place in which we should even touch such difficult questions.

XXII.

THE MOTIONS OF THE MOON.—ROTATION.

THE EQUALITY OF THE TWO LUNAR PERIODS OF ROTATION AND REVOLUTION—LUNAR POLES AND EQUATOR.

The Earth revolves on its axis in the interval of a sidereal day; the diurnal motion of the stars and of the other heavenly bodies from east to west, testifies to the reality of this rotation. The spots on the Sun, those which are visible on the disc of the planet Mars, on that of Jupiter, the slopes of the crescents of Mercury and of Venus, long ago made known the fact that these bodies are subjected to the same motion, which affects them in the same manner, but whose periods are of very different durations.

The Moon does not escape from this law, which seems common to all celestial bodies. At the same time that it performs its monthly revolution around the Earth, it turns, also, upon an invariable axis. and, by a singular circumstance, the duration of its rotation is exactly equal to its motion of revolution. The Moon, like the Earth, has also its poles, an equator, and meridian, and parallel circles.

Hence the phenomena which we have already studied, and which make it necessary that each point of the lunar globe should possess a night and day, according as the light of the Sun leaves it immersed in darkness, or illuminates it by its rays. As upon the Earth, there is reason for distinguishing upon the Moon two different days, unequal in duration; the sidereal day, comprising the interval of time between two successive rotations, and whose duration is 27 days, 7 hours, 43 minutes, and 11 seconds; and the solar day, comprising the interval between two successive returns of the Sun to the same meridian, and whose duration equals that of a complete lunation—that is to say, 29 days, 12 hours, 44 minutes, 3 seconds.

The difference between the sidereal and solar days, as we see, is 53 hours, 51 minutes; while the terrestrial, sidereal and solar days do not differ by 4 minutes (3 minutes, 56 seconds). The cause is, however, the same, and it depends entirely upon this circumstance, that each of the two orbs, the Earth and the Moon, at the same time that they are turning on their axes, are carried through space, and describe an arc around the Sun.

But the real duration of the rotation of the Moon being more than 27 times greater than that of the terrestrial rotation, there results from the difference in the sidereal and solar days of the two bodies an inequality doubly proportional. How is this motion of lunar rotation manifested to our eyes? Do the spots upon its disc move from one edge to the other, as is the case with the spots on the Sun, and with those on the other planets?

Not at all; we know, on the contrary, that the Moon always presents the same face to the Earth, with the exception of the slight periodical oscillations which present, sometimes at the north and south, sometimes at the west and east, certain regions of the invisible hemisphere.

It would appear, then, at first sight, that the Moon does not turn on its axis, and, unlike all other celestial bodies, has no rotary movement. This is indeed what has been claimed; it is still claimed by certain savants * who have never accurately calcu-

* An English scientific review, *The Astronomical Register*, has published on this subject, in its numbers of 1864, a series of articles, in which the arguments for and against the lunar rotation have been largely developed in verse and prose. The discussion, *The Moon Controversy*, threatening to become interminable, the

lated the geometrical conditions of the question. Doubtless, if the Moon and the Earth formed an immovable system in space, and if the first had not the motion of revolution around the second, the rotation of the Moon would manifest itself by a uniform change in the position of its spots, which we should see had a parallel motion upon its disc. Without doubt, the permanency of the same face would be an evident indication of its immobility, of the absence of all movement of rotation. But, on the one hand, the Earth and Moon together move around the Sun, and, on the other hand, the Moon revolves continually around the Earth.

Under these circumstances, the rotation of the Moon follows from the very fact to which it seems opposed—the permanency of the visible spots—and this permanency proves only one thing, that the time of rotation and that of revolution are the same.

What is, indeed, a motion of rotation? How can one know that a body—a sphere, for example—has performed an entire revolution around one of its diameters?

Evidently, when the sphere has presented succes-

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editor saw the necessity of cutting short the British tenacity of the disputants.

sively one of its faces to all the points of space which surround it.

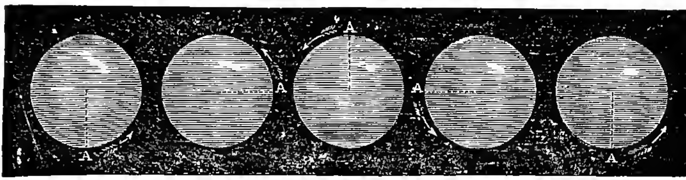

Fig. 40. The motion of rotation of a sphere supposed to be motionless.

If we divide the complete rotation into four periods, Figure 40 shows how the sphere would appear, at the beginning of each of these periods, to a motionless observer. Now, whether or not the sphere rotates about its axis in precisely the same time that it performs the motion of revolution around the motionless observer, it is not less evident that the complete rotation would be performed if the face, of which the point A forms the apparent centre, is successively presented to all the regions of space.

Now, this is exactly the case with the Moon after it has performed a complete revolution in its orbit. The comparison of Figures 40 and 41 shows this indisputably. We see in the second that the point A, which marks the centre of the lunar disc turned towards us at the time of full moon, takes the same positions in the successive phases as the point A, of the first figure, until the following full moon; and this is always the central point of the disc with respect to the Earth.

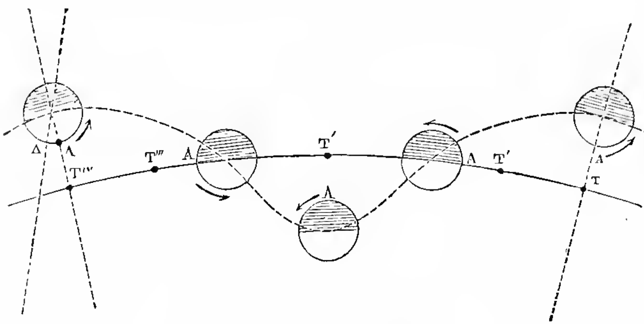

Fig. 41. The lunar rotation.

Fig. 41 shows, also, that the complete rotation is effected before the lunation is entirely accomplished, which explains the duration of $27\frac{1}{3}$ days assigned to the lunar rotation and revolution, instead of the $29\frac{1}{2}$ days necessary to restore our satellite to the same place.

In comparing the duration of the lunar rotation with that of the Earth, we find that the first is about 27.4 times greater than the second. This delay explains perfectly how it happens that any appreciable flatness at the poles of the Moon cannot be established, since it is the centrifugal force developed by the motion of rotation, which is the cause of the equatorial enlargement of celestial bodies.

The angular velocity is the same for all the points of a globe which turns on its axis; but the path described by each depends on its greater or less distance from the axis; nothing at the two poles, it continues to increase as the points have less latitude, till, at the equator, it attains its greatest power. A point of the lunar equator does not travel more than 54,000 feet, or about $10\frac{2}{3}$ miles an hour—that is to say, about 15 feet a second. This is a velocity 100 times less than that of a point of the terrestrial equator, which is 1,522 feet. As the velocity of the Moon in its orbit is about 3,350 feet a second, more than 200 times greater than its velocity of rotation, the result is that the Moon glides through space, according to the expression of M. Saigey, "Comme une roue enrayée par un point se déplaçant lentement sur la circonférence"—like a wheel traversed by a point moving slowly upon the circumference.

But it must not be forgotten, if we wish to have a correct idea of the motion of the Moon in the heavens, that it participates at the same time in the motion which causes the revolution of the Earth around the Sun. Its true velocity is then sometimes equal to that of our planet, (about $18\frac{1}{2}$ miles a second), sometimes greater, sometimes less, according to the relative directions of the two motions.

The axis of rotation of the Moon is nearly perpendicular to the plane of its orbit; but, as this plane does not coincide with that of the terrestrial orbit, (it forms with it an angle of 5° 8′,) the result is that, in consequence of the relative positions of the two bodies, we perceive sometimes the north pole and sometimes the south pole of the lunar globe. The north pole is a little beyond a crater called Gioja; and the south pole occupies a position very near the Dörfel Mountains, which extend a little to the east of this point. Finally, the mean meridian, which gives the direction of the polar axis, traverses the disc, following a line which, to the Earth, never deviates much from a straight line, leaving Tycho in the east, grazing the western rampart of Ptolemæus, traversing the Sinus Medii, cutting the Apennines, the Alps, and the Mare Frigoris, a little distance from the dark cirque of Plato.

As to the equator of the Moon, its position is determined by a diameter perpendicular to the line of the poles; starting at the eastern edge, from the crater Riccioli, the equator traverses the Oceanus Procellarum and the Mare Nubium, leaving the radiant cirques of Copernicus and Kepler a little to the north, passes, like the polar axis, the Sinus

Medii, separates the Mare Tranquillitatis from that of Nectaris, and terminates in the west in the Mare Fœcunditatis.

XXIII.

FORM AND DIMENSIONS OF THE LUNAR GLOBE.

INAPPRECIABLE FLATTENING—FORM ELONGATED TOWARDS THE EARTH—COMPARATIVE DIMENSIONS OF THE EARTH AND MOON—MASS AND DENSITY—WEIGHT AT THE SURFACE.

THE Moon has the form of a sphere, of which we do not perceive much more than half. This proceeds, as we have seen above, from the constantly circular appearance of its disc, and from the elliptic form of the line which separates the regions plunged in darkness from those which receive the solar light. All the diameters of the disc are of equal size, excepting the slight inequalities which arise from the indentations produced on the edges by the profiles of mountains. The lunar globe is not flattened, as is our globe, at its poles, or, if it is, the flattening is insensible and inappreciable to us. That the Moon, like the Earth, was originally fluid, is a very probable hypothesis, but the slowness of its motion of rotation explains sufficiently how it happens that it has not the form of an ellipsoid bulging at the equator.

It appears certain, however, that the lunar globe is not rigorously spherical : the attraction of the Earth has caused its elongation in the direction of the centre of our globe, so that its greatest diameter is always turned towards us. It is to this circumstance, which is, in other respects, a result of the laws of gravitation, that Laplace attributes the perfect equality of the two motions of the rotation and the revolution of our satellite—motions which, without doubt, were originally somewhat unequal. Perhaps a day will come when we can measure the different lunar meridians with sufficient accuracy to render the elongation of which we speak sensible.

It is not enough to know the form of a heavenly body. We desire to know, also its real dimensions. Nothing is easier when we know both its distance and the angle under which we see. We have only to solve the most simple trigonometrical problem.

The radius of the Moon is about three elevenths—a little more than a quarter—of the mean radius of the Earth, or more accurately, the 0.273,125th part of that radius. The lunar diameter is 2,159 miles.

The circumference of a meridian is 6,788½ miles, the length of a degree is 18¾ miles. Such is the distance which those who would make a tour of the lunar world would have to traverse in a straight line. I say in a straight line, because the obstacles presented by the mountainous irregularities would materially increase the length and duration of the journey.

As for the total area, it is a little less than the thirteenth part of the surface of the Earth, (0.0746,) and comprises about 14,685,000 square miles, nearly four times the area of the European continent. This allows 7,342,500 square miles for the area of the hemisphere seen from the Earth. Indeed, owing to the motions, of which we will treat farther on, we can see a little more than the half of our satellite, and, in calculating the area of all the visible parts, we reach the number of 8,000,000 square miles,—about 41 times the extent of France.

If we pass from the linear and superficial dimensions to the volume, we find that the Moon is about 49 times smaller than the Earth. It is even then about 5,750,000,000 cubic miles.

Compared to the volume of the Sun, the size of our satellite is a very small part of the immense globe from which it reflects the light to us. We should have to collect 70,000,000 of Moons to fill the prodigious sphere, yet the discs of the two orbs appear to occupy almost equal portions of the starry vault. But, as we have seen, this arises from the great inequality in the two distances, one of which is 400 times greater than the other.

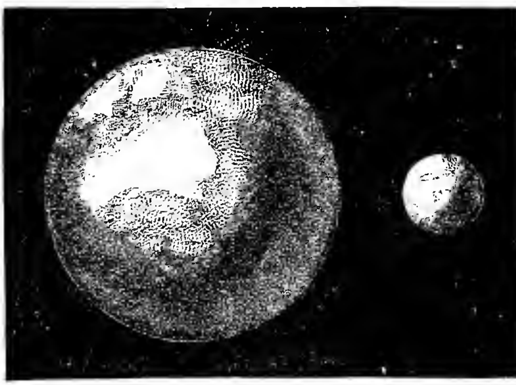

Fig. 42. The dimensions of the Moon and Earth.

The numbers which we have just quoted teach us only the geometrical importance of the lunar globe; we shall say nothing of the material of which it is composed. The telescope shows us what form this material has taken under the influence of internal forces, and how it has accumulated, here in vast plains, there in a multitude of irregularities, hills, circular mountains, pyramidal peaks and points bearing more or less analogy to our terrestrial mountains. But what is the nature of the rocks of which these irregularities are formed, and of the level surface of the valleys and plains? These are questions, the solution of which would be as interesting as it is in reality difficult.

However, the laws of celestial mechanics furnish on this point some data. The accurate knowledge of the motion which draws the Moon around the Earth, and the certainty, since the great discovery of Newton, that it is gravitation which holds the body in its orbit, have permitted us to calculate the mass of our satellite. We have given elsewhere * an idea of the methods which belong to a calculation of this kind; we have explained how astronomers have been able to weigh the celestial bodies, and to measure their masses and their densities. Applied to the Moon, these methods have shown us that the mass of our satellite is the 75th part of the mass of the Earth, and, what consequently follows, that the density of the matter of which it is composed is equal to 653 thousandths of the mean density of our globe.

Change these values into numbers expressing known quantities. The weight of the Moon amounts to nearly 86,310,040,000,000,000,000 tons of 2,000

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* See the chapter which treats of universal gravitation, in our work, *The Heavens*.

pounds. Its mean density, compared with that of water, is 3.55—that is, the lunar globe weighs more than three and a half times a globe of water of the same dimensions. But it must be added that the Moon is without doubt formed, like the Earth, of heterogeneous layers, the density of which increases in going from the surface to the centre. Therefore the strata which form the soil are lighter than indicated by the density of 3.55. How much? We do not know.

Yet this mean density compared with that of some of the minerals of the terrestrial crust permits us to form an idea of the composition of the lunar matter.

The carbonate of manganese, epidote, the glass known by the name of flint, and the diamond have nearly the same specific weight as the lunar matter.

The compound substance of which aerolites are formed is perhaps more fit to furnish us with a term of comparison: and it is interesting to find that the numbers 3.57, 3.54, express the density of some of the meteorites picked up after their fall to the surface of the Earth. Such an identity would be precisely of a nature to sanction the opinion that aerolites are rocks thrown by the volcanoes of the Moon, if the cosmical origin of these bodies was not now well known.

There is still another element which should be taken into consideration when we wish to compare the physical constitution of the Moon with that of our terrestrial globe. I speak of the force of gravity at the surface. This intensity varies in different celestial bodies, being greater in proportion as the total mass is larger, but, at the same time, less as the radius of the orb is greater, or, which amounts to the same thing, as the surface of the body is farther removed from the centre. In applying these principles to the Moon, we arrive at this result, that the weight at its surface is between $\frac{1}{5}$ and $\frac{1}{6}$ of that which bodies at the terrestrial surface weigh. If then we imagine a man transported to our satellite, if we suppose, moreover, that his muscular force remains the same in his new abode, he can there raise, without additional effort, weights five or six times heavier, and his own body would appear five and a half times lighter.

We have seen above what important results we can gather from this fundamental truth, when we consider the forces which could raise the masses of rocks which form the lunar mountains, to heights relatively so immense.

XXIV.

IS THE MOON THE ONLY SATELLITE OF THE EARTH?

THE Moon, we have said at the beginning of this work, is the celestial body nearest to us. Is this assertion quite true? It is what astronomers have long believed, and, indeed, all the planets known to our solar system, all the bodies which have the Sun for the centre or focus of their motions, and with still greater reason, all those luminous points with which the celestial vault sparkles, are at incomparably greater distance. Venus at its least distance from the Earth is yet more than 24,000,000 miles away—that is to say, a hundred times farther removed than the Moon. Mars does not come nearer than 33,000,000 of miles, and this occurs very rarely —a distance 145 times greater than that of the Moon. These are the planets nearest to the Earth.

But besides the celestial bodies individually known whose orbits have been calculated, there are in our solar system immense numbers of small bodies which move around the Sun, at a distance from it which is not far from that of the Earth. These are such as appear on pleasant nights in the form of luminous trains, of sparkling globes: *falling stars* and *bolides*.

Their orbits seem to pass near that of the Earth, sometimes crossing it. When the meeting occurs they either only graze the outer regions of the atmosphere, take fire by their contact and continue their course; or, attracted by the mass of our globe, they fall upon its surface: such are the stones known by the name of meteorites or aerolites.

In this way there are numerous small bodies which periodically approach us much nearer than the Moon does. But what means have we of recognizing them in such an irregular crowd?

Some astronomers, among whom we must cite M. Faye, believe that a certain number of falling stars, those which are seen here and there on every clear night of the year, are so many satellites of the Earth, which are drawn away, so to speak, by the Earth from the more crowded hosts which revolve in troops around the Sun. Is this hypothesis based upon positive observations apart from mere probability?

The following fact shows it. A French astronomer, M. Petit, of the Toulouse observatory, has calculated the orbit of a bolide of which he has been able to obtain a sufficient number of data.

This singular satellite of the Earth, this companion of the Moon, revolves around us in a period which would not exceed 3 hours and 20 minutes, and its distance from the centre of our globe would be at least 9,000,000 miles.*

In such a case the Moon would not be the only companion of the Earth in its journey through the ethereal regions ; and we would have very near to us, at all events much nearer to us than the lunar globe, miniature moons whose illuminated faces would be visible to us whenever they were not eclipsed by the cone of the terrestrial shadow, which would occur quite rarely, since their orbits would not be very much inclined to the orbit of the Earth.

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* I have omitted a passage in the original. If such a body is recognized by astronomers I do not know it.—Ed.

CHAPTER VI.

INFLUENCES OF THE MOON.

XXV.

OCEANIC, ATMOSPHERIC AND SUBTERRANEAN TIDES.

One could fill a large volume with all the nonsense which has been spoken in connection with the Moon and its pretended influences upon our planet and its inhabitants. A still larger book could perhaps be written if one wished to mention all the superstitions of this kind which are current to-day, even among civilized people as well as among the barbarous tribes of which the most unenlightened nations are composed.

Most of these, more or less absurd, have had the honor of a serious discussion, and we will not revert to them. Arago, that generous scientist, so disposed to collect popular traditions, not for the purpose of admitting them into science, but in order to separate those that might contain any truth, and interpret their real meaning, has devoted several chapters to examining the different influences attributed to the Moon. He has shown beyond a doubt that some have no foundation and no probability, that others are exceedingly weak, and bear no proportion to the magnitude of the results attributed to them, although they have been supposed to explain them.

Let us enter into details concerning the only influences which are scientifically established.

The Moon, by its mass, attracts the Earth. The phenomena which are the result of this incessant action are the tides.

All the particles of matter which together form the lunar globe, attract at the same time all the particles composing the terrestrial spheroid, and thus counterbalance in a certain measure their actual weight. But the amount of this attraction is not the same for all particles: it depends both on their distance from the centre of the attracting mass, and on the angle which the direction of the force makes with the direction of the terrestrial gravity.

It is easily understood that the points situated vertically under the Moon are those whose gravity is most diminished, and that this decrease lessens in proportion to the distance of the particles from that position on the whole surface of the terrestrial hemisphere which is turned towards our satellite. There is no change of the solid portion of the globe, but it is not so with the fluid portion, that is to say, with the waters of the ocean nor with the strata of the atmosphere. By reason of their fluidity and their freedom of motion, the liquid and gaseous particles rise under the influence of the lunar attraction, and the liquid sheet of the ocean is extended and heaped up on the side of the Earth towards the Moon. (Fig. 46.) Instead of preserving its form, which is almost spherical, it takes the form of an egg, with all the proportions perfect.*

It is the same with the gaseous sheet which encircles the Earth. It is this elevation of the fluid portions which has received the name of *tide*. If the Earth had not its own particular motion, the tide would be permanent, and the waters would preserve their equilibrium, which purely meteorological influences alone would disturb.

But the Earth in turning presents to the Moon its whole periphery, and the maritime wave thus moves

* Prolate spheroid.

on the ocean, following the parallel which corresponds to the position of our satellite. On the opposite hemisphere the same phenomena take place simultaneously; the liquid sheet is lengthened

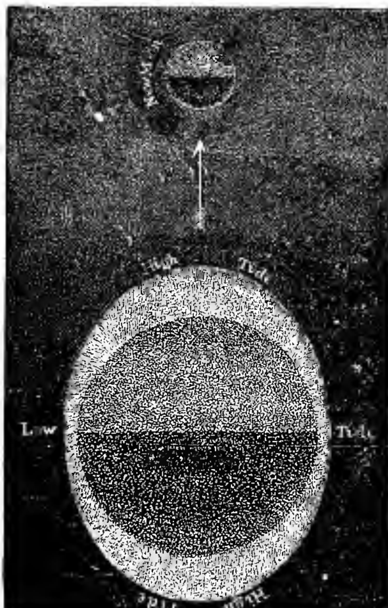

Fig. 43. Attraction of the Moon for the waters of the sea.

in opposition to the Moon, the most distant, and in consequence the least attracted particles are left behind, so that a similar effect is produced by contrary circumstances.

This is not the place to describe all the periods, diurnal, monthly, yearly periods, which the phenomena of the tides present, the multiple causes of which depend upon the simultaneous motions of the Moon and Earth and upon the action of the mass of the Sun.*

But, if you desire to know what the intensity of this force is which produces upon a mass, as large as that of the ocean waters, changes as violent as those of the great tides, you will be surprised undoubtedly to learn that it does not diminish the weight of the bodies on the surface of the Earth more than a sixteen millionth part. Thus a body which weighs 36 pounds exerts a less pressure when the Moon is passing the zenith than when the body is in the horizon, but how much? At most 0.0154 of a grain. This number enables us to form an idea of what the most insignificant force might become when it is repeated and is incorporated in a mass as large as that of the waters of the sea, and accumulates incessantly at each moment of its duration. But to show all that an action of this kind has the powei of producing on the terrestrial globe, it is not by days nor by years, but by centuries and thousands of centuries that one must count.

* Refer on this subject to the chapter devoted to tides, in our astronomical work on *The Heavens*.

Thus we can understand how the structure of continents and the outline of coasts have been slowly but irresistibly modified by this many-headed battering ram, which rushes twice a day with pitiless force upon the downs and the cliffs.

"The Moon," says Humboldt, "by reason of the attraction which it exercises in common with the Sun, sets the ocean in motion, displaces the liquid element on the Earth, and by the periodical risings of the sea and the destructive effect of the tides, changes little by little the outline of the coasts, helps or hinders man's work, and furnishes the greater part of the materials of which the sandstone and conglomerates are composed, covered in their turn by loose and rounded fragments of rocks. The Moon acts incessantly as a source of change upon the geological conditions of our planet.

The Moon, we have said, not only acts by its mass upon the motions of the sea, but also displaces periodically the gaseous strata of which the terrestrial atmosphere is composed. From this we have the *atmospheric tides.*

"In order to reach the ocean," says Laplace, "the action of the Sun and Moon passes through the atmosphere, which should in consequence feel their influence and be subjected to motions similar to those of the sea. Whence result some periodical variations in the height of the barometer, and some winds, the direction and intensity of which are periodical. These winds are inconsiderable, and, indeed, almost imperceptible in an atmosphere already greatly agitated. The extent of the fluctuations of the barometer is not 0.04 of an inch even at the equator, where it is the greatest. At Paris, observations of eight years have confirmed the theoretical deductions of the great geometrician, and have proved that the action of the Moon on the atmosphere does not cause the barometer to fluctuate more than the 2,000th part of an inch.

What is to be said, after these results, concerning the ridiculous theories of our almanac-makers, who, devoid of all knowledge of the mechanism of fluids, lay to the account of the lunar attraction the most violent atmospheric perturbations, and variations of temperature from 20 to 25 degrees.

According to some savants the Moon produces, not only oceanic and atmospheric tides, but, also, subterranean tides. The nucleus of the Earth being, in all probability, fluid, would periodically be raised, being excited by the lunar attraction, and this mass of great density having struck the exterior solid crust would be the cause of the greater part of the earthquakes. Statistical researches have been made for the purpose of proving the accuracy of this theory, and their author, M. Perrey, of the university of Dijon, thought to find in the frequency of seismic phenomena a periodicity which should correspond with the lunar periods of motion.

Opinions differ greatly on this subject. According to M. Babinet, "the attracting force of the Moon would not produce much more effect than the weight of a stratum one foot in thickness," which is to say that this effect is entirely insignificant. Such was the way in which Poisson looked at it, although he did not deny the action of the Moon or the existence of subterranean tides.

All the preceding has referred merely to the influence of the Moon considered as a mass. We have considered before what effect its light and heat could have upon the Earth. They have a power, but it acts within such narrow limits that it hardly explains the popular prejudices on the phases, with which it is necessarily connected. At the time of the new moon the lunar globe sends us neither rays of light nor caloric rays. The full moon, on the contrary, corresponds to the maximum effects of this nature. Between these two periods the influence increases or diminishes by insensible gradations, in such a manner that we cannot understand how sudden changes can be ascribed to it. Before looking elsewhere for the cause of these changes, it would be well for observation to establish them, which has not yet been done.

Does there exist between the Moon and the Earth some hidden mysterious bond of a magnetic nature for instance? Nothing proves or contradicts such a hypothesis, and it is possible that study in this direction might lead to interesting results, but we do not know that such has been undertaken.

This is all that can be said as positively known concerning the influence of the Moon and its connection with our planet.

Beyond this we should pass into the realms of fancy, of mysticism or of ignorance, which would lead us far away.

XXVI.

A LAST WORD ON THE MOON.

THE ANTIQUITY OF THE MOON—ROCKS THROWN OUT BY THE LUNAR VOLCANOES—WHY THE MOON HAS NO ATMOSPHERE—THE MOON DRAWING NEAR TO THE EARTH—WILL IT EVER FALL TO IT?—SUPPOSE THE MOON SHOULD ABANDON US.

In reviewing this work on the satellite of the Earth, we perceive that the reader will not here find the answer to many of the questions which we have heard asked, or which we have read in old and new works. We shall not excuse ourselves by saying that it was for want of space; it was due, rather, to the want of an occasion, and, in certain cases, to the resolution taken to say nothing. Concerning some of these problems, however, we have decided to say, without arrangement, a few words.

And first, is the Moon as old as the Earth? Is there any authority in the tradition of the ancient Arcadians, who believed their ancestors older than the Moon? Writers who have not known more than others on this subject, do not hesitate to say that there is. From this we have the hypothesis that the Moon made its appearance in the form of a comet, which began by causing agitations, and geological revolutions upon our globe—the deluge, for instance, or rather, the deluges—and which finally settled quietly into a regular orbit. All this is purely fancy, put together for the purpose of explaining a fable, and having only the value of a fable.

That which is known of the cometic constitution, of the slight mass of these gaseous agglomerations, of the immense condensation necessary to transform a comet into a globe of the volume and mass of the Moon, of the boundless lapse of time which such a condensation would render necessary, does not permit us to believe for an instant that all these events, besides being mere suppositions, date from an epoch so little removed from our time that they are within the memory of man.

How much more philosophical and probable is the theory of Laplace, which assigns to all the bodies of the solar system, to planets and to satellites, to the Earth and to the Moon, a gaseous origin!

It is then not by thousands but by millions of years that one must count, in order to measure the periods necessary to such transformations.

Another question is, why the Moon, if of gaseous origin, had not the power of preserving its atmosphere? Could it have been deprived of this atmosphere by the Earth? We could answer that the gases of which the lunar atmosphere were composed are chemically fixed, and were absorbed in order to produce its solid crust, the oxidizing power of the substances being considerably increased by the high temperature to which each one of the lunar hemispheres is periodically exposed.

Perhaps even the slight weight of the atmosphere, or rather, of the gases which formed it, enabled it to spread itself to such a distance that it was in part dissipated in space, or, in any case, remained in a state of extreme rarity.

This is a hypothesis which Laplace has admitted as very probable.

This slight weight reminds us of the stones which are said to be hurled from the volcanoes of the Moon, and which we now know to be a quantity of very small bodies, forming planetary rings, which revolve together around the Sun. The hypothesis which has been made is exceedingly improbable. Calculation proves that if we take a point on the line which joins the centres of the Moon and Earth, 217,940 miles distant from the latter, which distance is not more than 20,000 miles from the surface of the Moon, this point marks the respective limits of attraction of the two bodies. According to Laplace, a lunar projectile, having an initial velocity of 8,200 feet a second, would be enabled to reach or pass the point of which we speak. Then either the direction of its primitive impetus would push it into the terrestrial atmosphere, or else, without falling upon our Earth, it would become a satellite. Perhaps this is the origin of some of the meteors of which we have spoken above, an origin which dates from a period at which the lunar volcanoes were at their maximum intensity. Let us say, however, that the great velocity of aerolites, such as have been observed in a large number of cases, does not seem to be reconcilable with this origin unless the projective force of the lunar volcanoes has been greater than that which we have supposed.

The idea of a communication of this nature between the Earth and the Moon is very old; it is from this, without doubt, that we have the fable of the lion of Nemœus and its fall into the midst of Peloponnesus.

The Moon is approaching the Earth. This is another of those facts which excite the imaginations of the lovers of the marvellous. If this diminution of distance continues indefinitely, they say, the Earth is condemned to be destroyed some day by the fall of its satellite, crushed in pieces and dispersed in space. What period must we assign to this terrible event, which would, without doubt, be the end of the universe, or of the solar world, or, at least, the end of our little world? Unfortunately for those who, in the midst of present security, enjoy setting forth the catastrophes of the future, and for those who are eager to take advantage of such prophecies for the benefit of their prejudices, it is not possible to anticipate such an event in human affairs.

The motion of the Moon is indeed accelerated; ancient observations compared with later ones have proved it. Consequently, it approaches the Earth; but, not only is this nearing insensible, but it will also have a limit: in about 25,000 years from this time, this acceleration will cease, and an inverse motion will begin. The cause of this oscillation is understood, and it is known that it is held within narrow limits.

Let us reassure ourselves, then, both for ourselves and for our descendants: the Moon will never fall upon our Earth, to the great disappointment of our hypotheses makers. We return to our task, and inquire: What would become of us, if, for some reason or other, the Moon should abandon us? We now enter the domain of fancy, but what matter! Let us always try to reply, and perhaps this will teach us something.

And first, it is clear that our nights would lose variety, that eclipses would be unknown to us, and that we would need to find another method of counting some intervals of time. But all that is nothing. The most noticeable changes would be a great abatement in the phenomena of tides, since the influence of the Sun does not amount to more than a third in the periodic oscillations of the ocean. Finally, it would cause inevitable modifications in the outline of the maritime coasts, which the motion of the tides insensibly transforms.

This is not all; the gravity of the Moon is felt in another way on the Earth. Our globe is enlarged at the equator, as if covered by a shell or ring, growing thinner and thinner on every side to the poles. Well, it is the action of the Moon upon this enlargement which produces the fluctuation of the axis of the Earth known as Nutation. This motion would be destroyed if the Moon disappeared, and the variations of the equinoxes and of the obliquity of the ecliptic would soon be reduced to those alone which are due to the influence of the Sun.

Finally, the motion of the Earth around the Sun would also be slightly modified, since it is the centre of gravity common to the Earth and the Moon which impels it to move in an ellipse, having the Sun for a focus.

The centre of gravity, which really is in the interior of our globe, at about 750 miles below the surface, would find itself transported to the centre of our spheroid, but the distance from the Earth, and the dimensions of its orbit would not appear to be altered until after long periods.

Enough has been said of a mere conjecture, and we take leave of our readers in begging them to meditate on this great thought, which comes forth so clearly from the study of the laws which govern nature ; it is that she acts only by measure and gradation ; that violent aud sudden changes are repugnant to her, and, as has been said, the cycles, in their slow but irresistible evolutions, are only the seconds of Eternity.

THE END.

APPENDIX.

NOTES.

Page 50.—*On the calorific effect of the Moon's rays on the surface of the Earth.*

The question of the influence of the lunar rays upon thermometric instruments has been taken up of late by various men of science. The son of Lord Rosse, using a reflector with an aperture of three feet and converging the rays upon a thermo-electric pile, has shown that the Moon radiates with a power equal to a surface heated to 360° Fahrenheit. The intensity of the radiation, however, is proportionate to the illuminated surface of the disc.

M. W. Huggins, with an eight inch refractor, has made observations, the different results of which prevent any definite conclusion. But M. Marié-Davy objects, and with reason, that the lenses of the instrument "almost completely arrested the dark heat-rays of the Moon, while the mirror of Lord Rosse reflected them as well as the luminous rays."

M. Marié-Davy began, in 1869, a series of observations, by the aid of which he proposes not only to ascertain and measure the calorific power of the lunar rays, but also to to solve the following questions: 1. What is the proportion of the Moon's diffusive powers in lunar heat? 2. What is the proportion of its absorbent and radiating power, and what are the limits of its variation of temperature in the course of a lunation? 3. How much the diffusive and radiating powers vary on different parts of the lunar surface? 4. What deductions may be drawn concerning the Moon's surface compared to that of the Earth.

The first series of observations has given M. Marié-Davy twelve millionths of a degree centigrade (about 21,500,000ths Fahrenheit) for the direct action of the Moon's luminous rays. "It is," he says, "a sixtieth part of the result obtained by M. Piazzi Smyth on the Peak of Teneriffe, and experimenting with all the lunar rays." M. Marié-Davy received on his instrument only about three fourths of these rays.

M. Baille likewise obtained, in 1869, a positive result, from which he concludes that "the full moon, at Paris, during the summer months throws off as much heat as a smooth black surface maintained at 212° Fahrenheit, at a distance of about 115 feet."

PAGE 54.—*On the ashy light.*

Schrœter has observed the ashy light three days after the first quarter, using a telescope that magnified 160 times.

PAGE 142.—*On volcanic activity upon the Moon's surface.*

To the list of lunar mountains where signs of present volcanic activity are believed to have been recognized, must be added a small crater situated in the middle of the Mare Serenitatis. This crater, which is found indicated on old maps of the Moon, is very distinctly figured on the map of Beer and Mædler, and is known under the name of Linné, was clearly visible even during the full moon. Mr. J. Schmidt, director of the observatory at Athens, who had observed it since the year 1844, was greatly astonished when, in October, 1866, he noticed its disappearance. Different astronomers, advised by Mr. Schmidt of this singular change, directed their attention to this portion of the Moon's disc. By the aid of powerful instruments Messrs. Secchi, Wolf and Huggins recognized that instead of a circular mountain with well-defined borders, as it was represented on the map of Beer and Mædler, there only remained a whitish spot or aureola surrounding a black cavity, indicating the presence of a crater, but a crater much smaller than that known under the name Linné. The edges, instead of projecting above the surrounding plain, appeared now to present nothing more than an insensible declivity. By referring to former observations and anterior drawings, it seems probable that the recent condition of the crater of Linné had already presented itself in former ages ; thus everything would lead us to believe in the reality of successive eruptions, which at various times have caused a partial filling up of the interior cavity of the crater, and, overflowing its exterior, have levelled the surface about its walls. It would result, then, from these interesting observations, that, using the expression of M. Elie de Beaumont, "geologic life still exists in the interior of the Moon as well as in the interior of the Earth."

PAGE 195.—*Duration of a hypothetical falling of the Moon to the Earth.*

In estimating the time it would take our satellite to fall to the Earth—which we have given as six and one fourth days—we had, to abridge the calculation, considered the accelerating force as remaining constant. In reality, it is continually increasing as the distance diminishes, according to the Newtonian law of gravitation. From this it results that the fall of the Moon would be much more rapid. M. Flammarion, to whom we are indebted for this observation, finds the time required to be only eighteen hours, employing the complete formula given by Poisson.

PAGE 225.—*Influence of the Moon on the time of the Earth's rotation.*

The attractive force of the Moon's mass acting on the waters of the ocean raises them, we have stated, in such a manner as to give their total mass a constant ellipsoidal form, the principal axis of which would continually follow the radius vector that unites the centres of the Moon and the Earth, if the movement of the water encountered no resistance. As the liquid ellipsoid turns to the Moon in proportion to the movement of the Earth's daily rotation, this continual displacement of water cannot be accomplished without the results of friction and resistance arising from the liquid molecules themselves, and from inequalities of all kinds presented by the surface upon which the seas repose. Hence a retardation, which daily observations of the tides prove, and in consequence of which high tides never occur till a little while after the Moon passes the meridian.

Setting aside local irregularities, the effect is as if the Moon were situated in the heavens a little back of the place it really occupies, having reference to its daily movement. We have, then, a fact the explanation of which is easy, but which borrows nothing from hypothesis. The two liquid protuberances, the successive movement of which produces the tides, are not in the direction of the radius vector of the Moon, but follow a line constantly situated to the east of that satellite.

This action of the Moon—not now on the mass of our globe, supposed to be spherical, but on these two protuberances, at unequal distances from that body—according to M. Delaunay produces a retardation of the Earth's rotation. "If we refer to the mode of lunar action which causes the phenomenon of the tides, it will be seen that the first of these protuberances (that nearest the Moon) is, as it were, attracted by the Moon ; while the second, on the contrary, is repulsed, as it were, by that body. From this there results a double force,* applied to the mass of the terrestrial globe which tends to make it turn in a contrary direction to that in which it really turns—a force which must hence produce a retardation of the rotation of our planet."

Such, in substance, is the new theory. We shall not follow M. Delaunay in the provisory calculations by means of which he shows that this action of the Moon on the tidal protuberances is far from being insensible, and may, indeed, explain the excess of secular acceleration given by ancient observations. It suffices to admit that the mass of water formed by each protuberance is equivalent to a stratum forty inches in thickness, resting on a circular basis, with a radius of 420 miles. Such a stratum applied

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* *Couple* is the word used by M. Delaunay. This word is applied, in French, in the science of Mechanics, to any system of two equal forces, parallel and contrary, acting at the extremities of the same right line.

to the surface of the Earth would have a diameter of about twelve degrees at the equator.

In truth, the learned astronomer has, to effect this calculation, assumed a hypothesis much simpler than that of reality; but it cannot be doubted that the actual effect produced by the Moon's action on the waters of the ocean is sufficient to cause the necessary retardation.

M. Delaunay's views have undergone, of course, various more or less well-founded criticisms; but none controvert the principle that serves as their basis. The supposition that the movement of the tides is of a nature to retard the Earth's rotation is not a new one. The originator of the dynamic theory of heat, Dr. Mayer, expressed it in one of his works, and Tyndall has reproduced it since. But what constitutes the merit and originality of M. Delaunay's labor is, to use his own expressions, to have shown, 1st, that the retardation due to this cause is far from being insensible; 2nd, that therein lies the explanation of the discrepancy existing between the observation of ancient eclipses and the theory of gravitation, relative to the secular acceleration of the mean motion of the Moon.

Finally, the duration of the sidereal day is not invariable if the theory of M. Dulaunay—so entirely sanctioned by the distinguished director of the Greenwich observatory, Mr. Airy—is adopted. This duration diminishes, in the lapse of time, about one second in a hundred thousand years.

If this diminution preserved the same rate indefinitely, it would be easy to calculate the time when the motion of rotation would be entirely overcome, and when the length of the day would be confounded with that of the year. The sidereal day, consisting of 86,400 seconds, it would require 8,640,000,000 years to produce a complete stoppage of the Earth's rotation. Eighty-six million four hundred thousand centuries! Truly, between this time and then we and our great-great-grandsons may rest easy.

But, to tell the truth, things will not come to that pass, and for this reason: the velocity of the Earth's rotation, constantly diminishing, will come to be equal to that of the Moon in its orbit, so that the Earth will always present the same hemisphere to its satellite, exactly as the latter now does to the Earth. But then the tidal protuberances will no longer have a progressive movement; they will at last, then, be constantly in the direction of the Moon, and the power of the latter will cease to act as a retarding force. M. Delaunay likewise reassures us in another way. As the temperature of the Earth is constantly becoming less in consequence of the diminution of the Sun's heat, and the excess of the Earth's radiation over the heat received, the time will arrive when the temperature will be so low that all the seas will become frozen. "The phenomenon of the tides will no longer exist, the cause of the retardation of rotation will disappear, and the Earth will then continue to move with a constant velocity."