I

THE ROMANCE OF THE HEAVENS

THE SCALE OF THE UNIVERSE—THE SOLAR SYSTEM

LAPLACE.
One of the greatest mathematical astronomers of all time and originator of the nebular theory.

§ 1

THE story of the triumphs of modern science naturally opens with Astronomy. The picture of the Universe which the astronomer offers to us is imperfect; the lines he traces are often faint and uncertain. There are many problems which have been solved, there are just as many about which there is doubt, and, notwithstanding our great increase in knowledge, there remains just as many which are entirely unsolved. "The problem of the structure and duration of the universe," said the great astronomer Simon Newcomb, "is the most far-reaching with which the mind has to deal. Its solution may be regarded as the ultimate object of stellar astronomy, the possibility of reaching which has occupied the minds of thinkers since the beginning of civilisation. Before our time the problem could be considered only from the imaginative or the speculative point of view. Although we can to-day attack it to a limited extent by scientific methods, it must be admitted that we have scarcely taken more than the first step toward the actual solution. . . . What is the duration of the universe in time? Is it fitted to last for ever in its present form, or does it contain within itself the seeds of dissolution? Must it, in the course of time, in we know not how many millions of ages, be transformed into something very different from what it now is? This question is intimately associated with the question whether the stars form a system. If they do, we may suppose that system to be permanent in its general features; if not, we must look further for our conclusions."

The Heavenly Bodies.

The heavenly bodies fall into two very distinct classes so far as their relation to our Earth is concerned; the one class, a very small one, comprises a sort of colony of which the Earth is a member. These bodies are called *planets*, or wanderers. There are eight of them, including the Earth, and they all circle round the sun. Their names, in the order of their distance from the sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and of these Mercury, the nearest to the sun, is rarely seen by the naked eye. Uranus is practically invisible, and Neptune quite so. These eight planets, together with the sun, constitute, as we have said, a sort of little colony; this colony is called the Solar System.

The second class of heavenly bodies are those which lie *outside* the solar system. Every one of those glittering points we see on a starlit night is at an immensely greater distance from us than is any member of the Solar System. Yet the members of this little colony of ours, judged by terrestrial standards, are at enormous distances from one another. If a shell were shot in a straight line from one side of Neptune's orbit to the other it would take five hundred years to complete its journey. Yet this distance, the greatest in the Solar System, is insignificant compared to the distances of the stars. One of the nearest stars to the earth that we know of is Alpha Centauri, estimated to be some twenty-five billions of miles away. Sirius, the brightest star in the firmament, is double this distance from the earth.

We must imagine the colony of planets to which we belong as a compact little family swimming in an immense void. At distances which would take our shell, not hundreds, but millions of years to traverse, we reach the stars—or rather, a star, for the distances between stars are as great as the distance between the nearest of them and our Sun. The Earth, the planet on which we live, is a mighty globe bounded by a crust of rock many miles in thickness; the great volumes of water which we call our oceans lie in the deeper hollows of the crust. Above the surface an ocean of invisible gas, the atmosphere, rises to a height of about three hundred miles, getting thinner and thinner as it ascends.

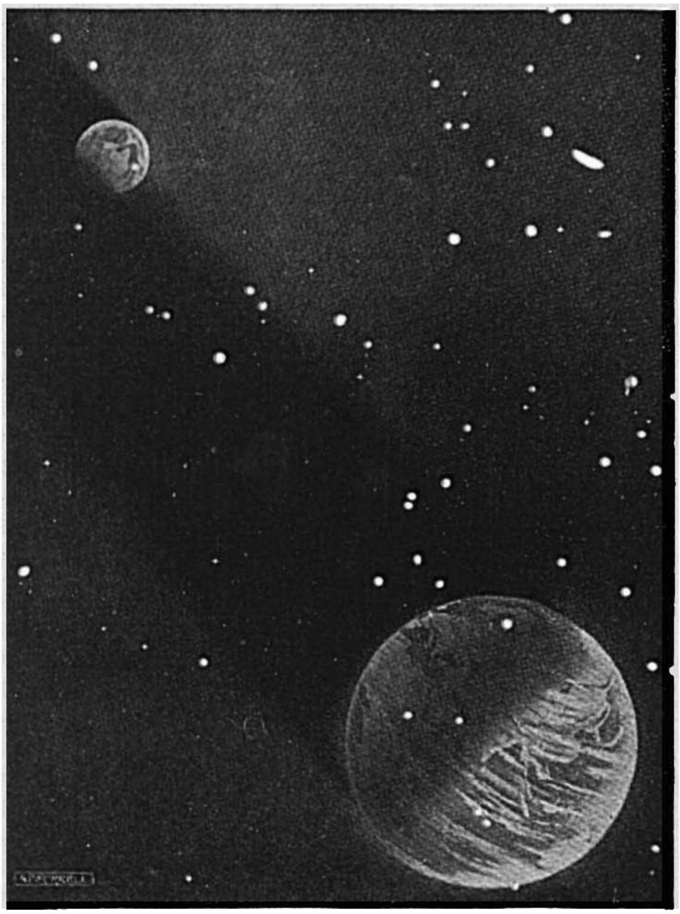


FIG. 1.—THE MOON ENTERING THE SHADOW CAST BY THE EARTH.
The diagram shows the Moon partially eclipsed.

Except when the winds rise to a high speed, we seem to live in a very tranquil world. At night, when the glare of the sun passes out of our atmosphere, the stars and planets seem to move across the heavens with a stately and solemn slowness. It was one of the first discoveries of modern astronomy that this movement is only apparent. The apparent creeping of the stars across the heavens at night is accounted for by the fact that the earth turns upon its axis once in every twenty-four hours. When we remember the size of the earth we see that this implies a prodigious speed.

In addition to this the earth revolves round the sun at a speed of more than a thousand miles a minute. Its path round the sun, year in year out, measures about 580,000,000 miles. The earth is held rigidly to this path by the gravitational pull of the sun, which has a mass 333,432 times that of the earth. If at any moment the sun ceased to exert this pull the earth would instantly fly off into space straight in the direction in which it was moving at the time, that is to say, at a tangent. This tendency to fly off at a tangent is continuous. It is the balance between it and the sun's pull which keeps the earth to her almost circular orbit. In the same way the seven other planets are held to their orbits.

Circling round the earth, in the same way as the earth circles round the sun, is our moon. Sometimes the moon passes directly between us and the sun, and cuts off the light from us. We then have a total or partial eclipse of the sun. At other times the earth passes directly between the sun and the moon, and causes an eclipse of the moon. The great ball of the earth naturally trails a mighty shadow across space, and the moon is "eclipsed" when it passes into this.

The other seven planets, most of which have moons of their own, circle round the sun as the earth does. The sun's mass is immensely larger than that of all the planets put together, and all of them would be drawn into it and perish if they did not travel rapidly round it in gigantic orbits. So the eight planets, spinning round on their axes, follow their fixed paths round the sun. The planets are secondary bodies, but they are most important, because

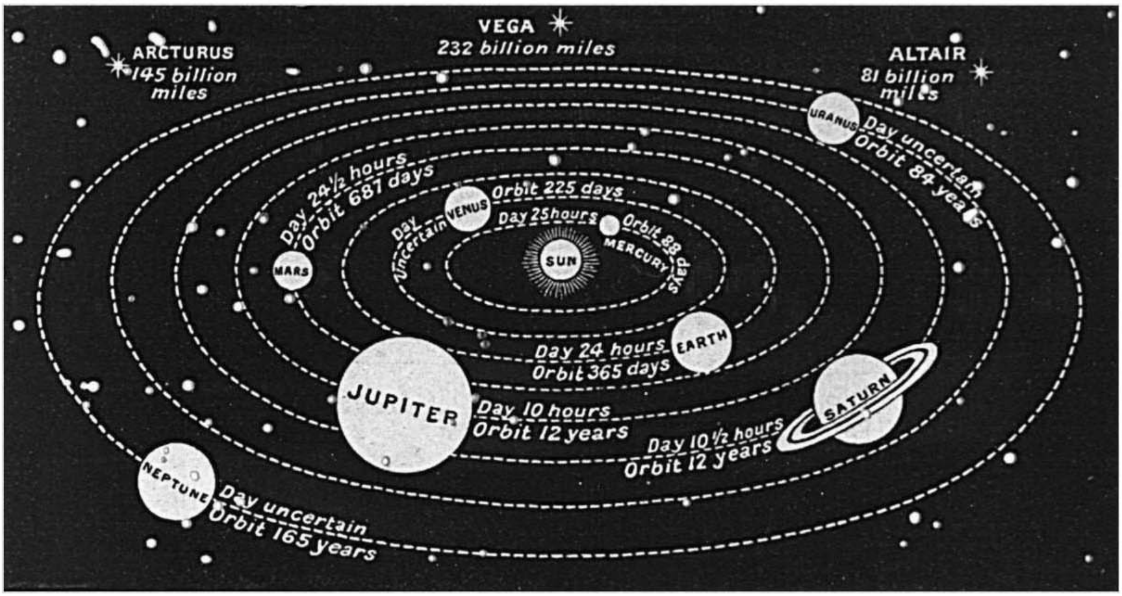


FIG. 2.—A DIAGRAM OF THE SOLAR SYSTEM.

Neptune's "year," it will be noted, is 165 times our year. It will be seen that the Stars in the diagram are at enormous distances, showing the great isolation in space of the Solar System.

they are the only globes in which there can be life, as we know life.

If we could be transported in some magical way to an immense distance in space above the sun, we should see our Solar System as it is drawn in the accompanying diagram (Fig. 2), except that the planets would be mere specks, faintly visible in the light which they receive from the sun. If we moved still farther away, billions of miles away, the planets would fade entirely out of view, and the sun would shrink into a point of fire, a star. And here you begin to realise the nature of the universe. *The sun is a star. The stars are suns.* Our sun looks big simply because of its comparative nearness to us. The universe is a stupendous collection of millions of stars or suns, many of which may have planetary families like ours.

The Scale of the Universe.

How many stars are there? A glance at a photograph of star-clouds will tell at once that it is quite impossible to count them. The fine photograph reproduced on the next page (Fig. 3) represents a very small patch of that pale-white belt, the Milky Way, which spans the sky at night. It is true that this is a particularly rich area of the Milky Way, but the entire belt of light has been resolved in this way into masses or clouds of stars. Astronomers have counted the stars in typical districts here and there, and from these partial counts we get some idea of the total number of stars. There are estimated to be between two and three thousand million stars.

Yet these worlds are separated by inconceivable distances from each other, and it is one of the greatest triumphs of modern astronomy to have mastered, so far, the scale of the universe. For several centuries astronomers have known the relative distances from each other of the sun and the planets. If they could discover the actual distance of any one planet from any other, they could at once tell all the distances within the Solar System.

The sun is, on the latest measurements, 92,830,000 miles from the earth. This means that in six months from now the earth will be right at the opposite side of its path round the sun, or 185,000,000 miles away from where it is now. Viewed or photographed from two positions so wide apart, the nearest stars show a tiny "shift" against the background of the most distant stars, and that is enough for the mathematician. He can calculate the distance of any star near enough to show this "shift." We have found that the nearest star to the earth, a recently discovered star, is twenty-two billion miles away. Only thirty stars are known to be within a hundred billion miles of us.

This way of measuring does not, however, take us very far away in the heavens. There are only a few hundred stars within five hundred billion miles of the earth, and at that distance the "shift" of a star against the background (parallax, the astromer calls it) is so minute that figures are very uncertain. At this point the astronomer takes up a new method. He learns the different types of stars, and then he is able to deduce more or less accurately the distance of a star of a known type from its faintness. He, of course, has instruments for gauging their light. As a result of twenty years work in this field, it is now known that the more distant stars of the Milky Way are at least a hundred thousand billion miles away from the sun.

Photo: Harvard College Observatory.

FIG. 3.—THE MILKY WAY.
Note the cloud-like effect.

Our sun is in a more or less central region of the universe, or a few hundred billion miles from the actual centre. The remainder of the stars, which are all outside our Solar System, are spread out, apparently, in an enormous disc-like collection, so vast that even a ray of light, which travels at the rate of 186,000 miles a second, would take 50,000 years to travel from one end of it to the other. This, then, is what we call our universe.

Are there other Universes?

Why do we say "our" universe"? Why not *the* universe? It is now believed by many of our most distinguished astronomers that our colossal family of stars is only one of many universes. By a universe an astronomer means any collection of stars which are close enough to control each other's movements by gravitation; and it is clear that there might be many universes, in this sense, separated from each other by profound abysses of space. Probably there are.

For a long time we have been familiar with certain strange objects in the heavens which are called "spiral nebulæ" (Fig. 4). We shall see at a later stage what a nebula is, and we shall see that some astronomers regard these spiral nebulæ as worlds "in the making." But some of the most eminent astronomers believe that they are separate universes—"island-universes" they call them—or great collections of millions of stars like our universe. There are certain peculiarities in the structure of the Milky Way which lead these astronomers to think that our universe may be a spiral nebula, and that the other spiral nebulæ are "other universes."

Vast as is the Solar System, then, it is excessively minute in comparison with the Stellar System, the universe of the Stars, which is on a scale far transcending anything the human mind can apprehend.

THE SOLAR SYSTEM

THE SUN

§ 1

But now let us turn to the Solar System, and consider the members of our own little colony.

Within the Solar System there are a large number of problems that interest us. What is the size, mass, and distance of each of the planets? What satellites, like our Moon, do they possess? What are their temperatures? And those other, sporadic members of our system, comets and meteors, what are they? What are their movements? How do they originate? And the Sun itself, what is its composition, what is the source of its heat, how did it originate? Is it running down?

These last questions introduce us to a branch of astronomy which is concerned with the physical constitution of the stars, a study which, not so very many years ago, may well have appeared inconceivable. But the spectroscope enables us to answer even these questions, and the answer opens up questions of yet greater interest. We find that the stars can be arranged in an order of development—that there are stars at all stages of their life-history. The main lines of the evolution of the stellar universe can be worked out. In the sun and stars we have furnaces with temperatures enormously high; it is in such conditions that substances are resolved into their simplest forms, and it is thus we are enabled to obtain a knowledge of the most primitive forms of matter. It is in this direction that the spectroscope (which we shall refer to immediately) has helped us so much. It is to this wonderful instrument that we owe our knowledge of the composition of the sun and stars, as we shall see.

Photo: Royal Observatory, Greenwich.

FIG. 4.—NEBULA IN ANDROMEDA, SEPT. 23, 1898.
A famous Spiral Nebula, sometimes visible to the naked eye.

"That the spectroscope will detect the millionth of a milligram of matter, and on that account has discovered new elements, commands our admiration; but when we find in addition that it will detect the nature of forms of matter billions of miles away, and moreover, that it will measure the velocities with which these forms of matter are moving with an absurdly small per cent. of possible error, we can easily acquiesce in the statement that it is the greatest instrument ever devised by the brain and hand of man."

Such are some of the questions with which modern astronomy deals. To answer them requires the employment of instruments of almost incredible refinement and exactitude and also the full resources of mathematical genius. Whether astronomy be judged from the point of view of the phenomena studied, the vast masses, the immense distances, the æons of time, or whether it be judged as a monument of human ingenuity, patience, and the rarest type of genius, it is certainly one of the grandest, as it is also one of the oldest, of the sciences.

The Solar System.

In the Solar System we include all those bodies dependent on the sun which circulate round it at various distances, deriving their light and heat from the sun—the planets and their moons, certain comets and a multitude of meteors: in other words, all bodies whose movements in space are determined by the gravitational pull of the sun.

The Sun.

Thanks to our wonderful modern instruments and the ingenious methods used by astronomers, we have to-day a remarkable knowledge of the sun.

Look at the figure of the sun in the frontispiece. The picture represents an eclipse of the sun; the dark body of the moon has screened the sun's shining disc and taken the glare out of our eyes; we see a silvery halo surrounding the great orb on every side. It is the sun's atmosphere, or "crown" (corona) stretching for millions of miles into space in the form of a soft silvery-looking light; probably much of its light is sunlight reflected from particles of dust, although the spectroscope shows an element in the corona that has not so far been detected anywhere else in the universe and which in consequence has been named Coronium.

We next notice in the illustration that at the base of the halo there are red flames peeping out from the edges of the hidden disc. When one remembers that the sun is 866,000 miles in diameter, one hardly needs to be told that these flames are really gigantic. We shall see what they are presently.

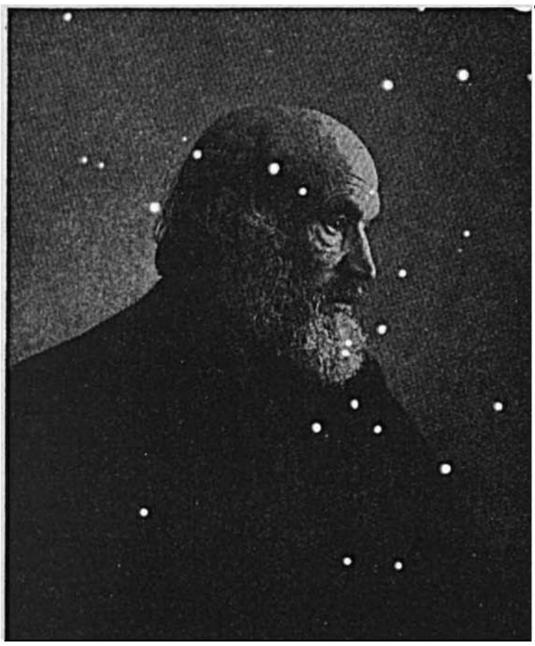


Photo: Royal Astronomical Society.
PROFESSOR J. C. ADAMS,
who, anticipating the great French mathematician, Le Verrier, discovered the planet Neptune by calculations based on the irregularities of the orbit of Neptune. One of the most dramatic discoveries in the history of Science.

Regions of the Sun.

The astronomer has divided the sun into definite concentric regions or layers. These layers envelop the nucleus or central body of the sun somewhat as the atmosphere envelops our earth. It is through these vapour layers that the bright white body of the sun is seen. Of the innermost region, the heart or nucleus of the sun, we know almost nothing. The central body or nucleus is surrounded by a brilliantly luminous envelope or layer of vaporous matter which is what we see when we look at the sun and which the astronomer calls the photosphere.

Above—that is, overlying—the photosphere there is a second layer of glowing gases, which is known as the reversing layer. This layer is cooler than the underlying photosphere; it forms a veil of smoke-like haze and is of from 500 to 1,000 miles in thickness.

A third layer or envelope immediately lying over the last one is the region known as the chromosphere. The chromosphere extends from 5,000 to 10,000 miles in thickness—a "sea" of red tumultuous surging fire. Chief among the glowing gases is the vapour of hydrogen.

The intense white heat of the photosphere beneath shines through this layer, overpowering its brilliant redness. From the uppermost portion of the chromosphere great fiery tongues of glowing hydrogen and calcium vapour shoot out for many thousands of miles, driven outward by some prodigious expulsive force. It is these red "prominences" which are such a notable feature in the picture of the eclipse of the sun already referred to.

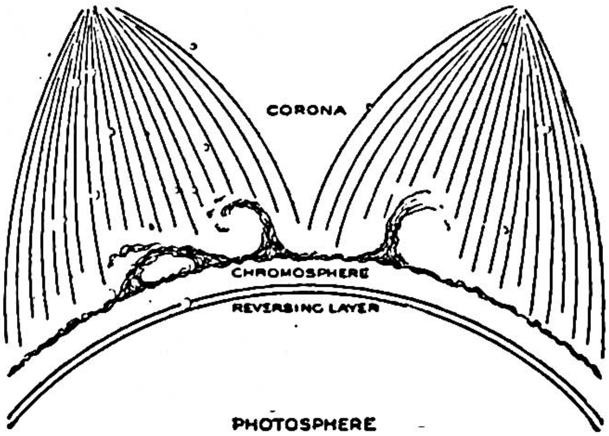


FIG. 5.—DIAGRAM SHOWING THE MAIN LAYERS OF THE SUN. Compare with frontispiece.

During the solar eclipse of 1919 one of these red flames rose in less than seven hours from a height of 130,000 miles to more than 500,000 miles above the sun's surface. This immense column of red-hot gas, four or five times the thickness of the earth, was soaring upward at the rate of 60,000 miles an hour.

These flaming jets or prominences shooting out from the chromosphere are not to be seen every day by the naked eye; the dazzling light of the sun obscures them, gigantic as they are. They can be observed, however, by the spectroscope any day, and they are visible to us for a very short time during an eclipse of the sun. Some extraordinary outbursts have been witnessed. Thus the late Professor Young described one on September 7, 1871, when he had been examining a prominence by the spectroscope:

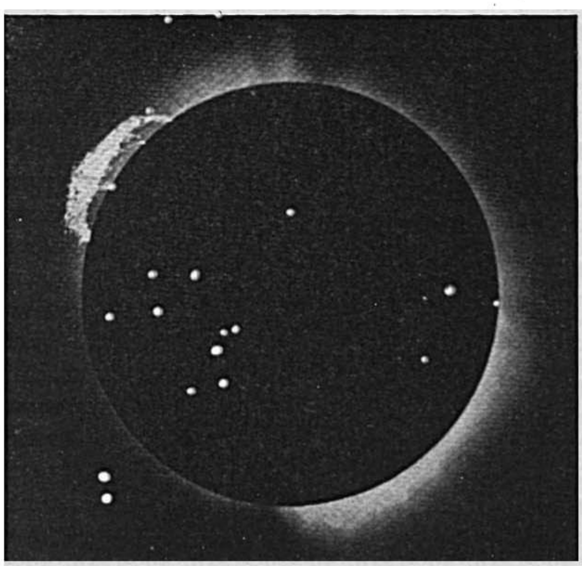


Photo: Royal Observatory, Greenwich.

FIG. 6—SOLAR PROMINENCES SEEN AT TOTAL SOLAR ECLIPSE, MAY 29, 1919.

The small Corona is also visible.

"It had remained unchanged since noon of the previous day—a long, low, quiet-looking cloud, not very dense, or brilliant, or in any way remarkable except for its size. At 12.30 a.m. the Professor left the spectroscope for a short time, and on returning half an hour later to his observations, he was astonished to find the gigantic Sun flame shattered to pieces. The solar atmosphere was filled with flying debris, and some of these portions reached a height of 100,000 miles above the solar surface. Moving with a velocity which, even at the distance of 93,000,000 miles, was almost perceptible to the eye, these fragments doubled their height in ten minutes. On January 30, 1885, another distinguished solar observer, the late Professor Tacchini of Rome, observed one of the greatest prominences ever seen by man. Its height was no less than 142,000 miles—eighteen times the diameter of the earth. Another mighty flame was so vast that supposing the eight large planets of the solar system ranged one on top of the other, the prominence would still tower above them."[1]

The fourth and uppermost layer or region is that of the corona, of immense extent and fading away into the surrounding sky—this

[1] *The Romance of Astronomy*, by H. Macpherson.

we have already referred to. The diagram (Fig. 5) shows the dispositions of these various layers of the sun. It is through these several transparent layers that we see the white light body of the sun.

§ 2

The Surface of the Sun.

Here let us return to and see what more we know about the photosphere — the sun's surface. It is from the photosphere that we have gained most of our knowledge of the composition of the sun, which is believed not to be a solid body. Examination of the photosphere shows that the outer surface is never at rest. Small bright cloudlets come and go in rapid succession, giving the surface, through contrasts in luminosity, a granular appearance. Of course, to be visible at all at 92,830,000 miles the cloudlets cannot be small. They imply enormous activity in the photosphere. If we might speak picturesquely the sun's surface resembles a boiling ocean of white-hot metal vapours. We have to-day a wonderful instrument, which will be described later, which dilutes, as it were, the general glare of the sun, and enables us to observe these fiery eruptions at any hour. The "oceans" of red-hot gas and white-hot metal vapour at the sun's surface are constantly driven by great storms. Some unimaginable energy streams out from the body or nucleus of the sun and blows its outer layers into gigantic shreds, as it were.

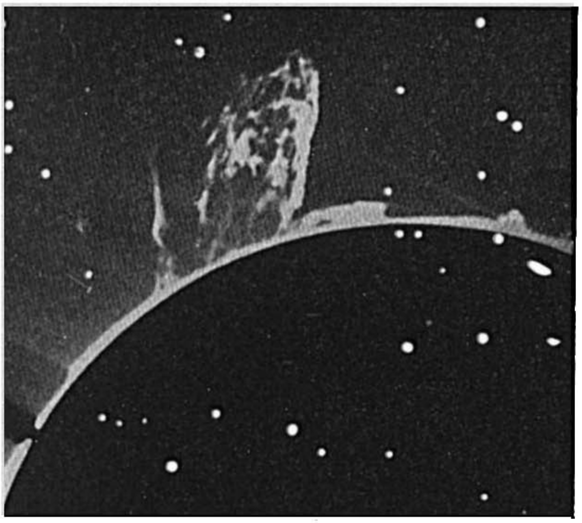


Photo: Kodaikanal Observatory, South India.

FIG. 7.—SOLAR PROMINENCES, MAY 26, 1916.

These flames are sometimes hundreds of thousands of miles high.

The actual temperature at the sun's surface, or what appears to us to be the surface—the photosphere—is, of course, unknown, but careful calculation suggests that it is from 5,000° C. to 7,000° C. The interior is vastly hotter. We can form no conception of such temperatures as must exist there. Not even the most obdurate solid could resist such temperatures, but would be converted almost instantaneously into gas. But it would not be gas as we know gases on the earth. The enormous pressures that exist on the sun must convert even gases into thick treacly fluids. We can only infer this state of matter. It is beyond our power to reproduce it.

Sun-spots.

It is in the brilliant photosphere that the dark areas known as sun-spots appear. Some of these dark spots—they are dark only by contrast with the photosphere surrounding them—are of enormous size, covering many thousands of square miles of surface. What they are we cannot positively say. They look like great cavities in the sun's surface. Some think they are giant whirlpools. Certainly they seem to be great whirling streams of glowing gases with vapours above them and immense upward and downward currents within them. Round the edges of the sun-spots rise great tongues of flame.

Perhaps the most popularly known fact about sun-spots is that they are somehow connected with what we call magnetic storms on earth. These magnetic storms manifest themselves in interruptions of our telegraphic and telephonic communications, in violent disturbances of the mariner's compass, and in exceptional auroral displays. The connection between the two sets of phenomena cannot be doubted, even although at times there may be a great spot on the sun without any corresponding "magnetic storm" effects on the earth.

A surprising fact about sun-spots is that they show definite periodic variations in number. The best-defined period is one of about eleven years. During this period the spots increase to a maximum in number and then diminish to a minimum, the variation being more or less regular. Now this can only mean one thing. To be periodic the spots must have some deep-seated connection with the fundamental facts of the sun's structure and activities. Looked at from this point of view their importance becomes great.

It is from the study of sun-spots that we have learned that the sun's surface does not appear to rotate all at the same speed. The "equatorial" regions are rotating quicker than regions further north or south. A point forty-five degrees from the equator seems to take about two and a half days longer to complete one rotation than a point on the equator. This, of course, confirms our belief that the sun cannot be a solid body.

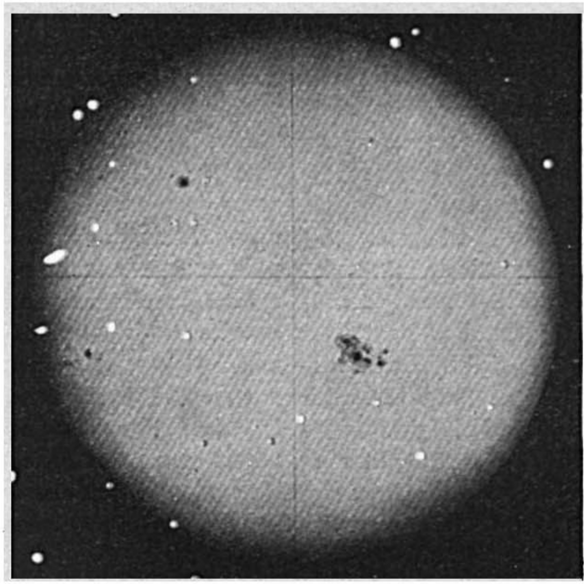


Photo: Royal Observatory, Greenwich.

FIG. 8.—SUN, FEB. 5, 1905.

A general view of the Sun showing Sun-spots.

What is its composition? We know that there are present, in a gaseous state, such well-known elements as sodium, iron, copper, zinc, and magnesium; indeed, we know that there is practically every element in the sun that we know to be in the earth. How do we know?

It is from the photosphere, as has been said, that we have won most of our knowledge of the sun. The instrument used for this purpose is the spectroscope; and before proceeding to deal further with the sun and the source of its energy it will be better to describe this instrument.

A WONDERFUL INSTRUMENT, AND WHAT IT REVEALS

The spectroscope is an instrument for analysing light. So important is it in the revelations it has given us that it will be best to describe it fully. Every substance to be examined must first be made to glow, made luminous; and as nearly everything in the heavens *is* luminous the instrument has a great range in Astronomy. And when we speak of analysing light, we mean that the light may be broken up into waves of different lengths. What we call light is a series of minute waves in ether, and these waves are—measuring them from crest to crest, so to say—of various lengths. Each wave-length corresponds to a colour of the rainbow. The shortest waves give us a sensation of violet colour, and the largest waves cause a sensation of red. The rainbow, in fact, is a sort of natural spectroscope. (The meaning of the rainbow is that the moisture-laden air has sorted out these waves, in the sun's light, according to their length.) Now the simplest form of spectroscope is a glass prism—a triangular-shaped piece of glass. If white light (sunlight, for example) passes through a glass prism, we see a series of rainbow-tinted colours. Anyone can notice this effect when sunlight is shining through any kind of cut glass—the stopper of a wine decanter, for instance. If, instead of catching with the eye the coloured lights as they emerge from the glass prism, we allow them to fall on a screen, we shall find that they pass, by continuous gradations, from red at the one end of the screen, through orange, yellow, green, blue, and indigo, to violet at the other end. *In*

FIG. 9.—A SUN-SPOT AS THE 100-INCH TELESCOPE ON MOUNT WILSON SHOWS IT. Notice the flaky appearance of the surface of the Sun surrounding the spot.

other words, what we call white light is composed of rays of these several colours. They go to make up the effect which we call white. And now just as water can be split up into its two elements, oxygen and hydrogen, so sunlight can be broken up into its primary colours, which are those we have just mentioned.

This range of colours, produced by the spectroscope, we call the solar spectrum, and these are, from the spectroscopic point of view, primary colours. Each shade of colour has its definite position in the spectrum. That is to say, the light of each shade of colour (corresponding to its wave-length) is reflected through a certain fixed angle on passing through the glass prism. Every possible kind of light has its definite position, and is denoted by a number which gives the wave-length of the vibrations constituting that particular kind of light.

Now, other kinds of light besides sunlight can be analysed. Light from any substance which has been made incandescent may be observed with the spectroscope in the same way, and each element can be thus separated. It is found that each substance (in the same conditions of pressure, etc.) gives a constant spectrum of its own. *Each metal displays its own distinctive colour. It is obvious, therefore, that the spectrum provides the means for identifying a particular substance.* It was by this method that we discovered in the sun the presence of such well-known elements as sodium, iron, copper, zinc, and magnesium.

Every chemical element known, then, has a distinctive spectrum of its own when it is raised to incandescence, and this distinctive spectrum is as reliable a means of identification for the element as a human face is for its owner. Whether it is a substance glowing in the laboratory or in a remote star makes no difference to the spectroscope; if the light of any substance reaches it, that substance will be recognised and identified by the characteristic set of waves.

The spectrum of a glowing mass of gas will consist in a number of bright lines of various colours, and at various intervals; corresponding to each kind of gas, there will be a peculiar and distinctive arrangement of bright lines. But if the light from such a mass of glowing gas be made to pass through a cool mass of the *same* gas it will be found that dark lines replace the bright lines in the spectrum, the reason for this being that the cool gas absorbs the rays of light emitted by the hot gas. Experiments of this kind enable us to reach the important general statement that every gas, when cold, absorbs the same rays of light which it emits when hot.

Crossing the solar spectrum are hundreds and hundreds of dark lines. These could not at first be explained, because this fact of discriminative absorption was not known. We understand now. The sun's white light comes from the photosphere, but between us and the photosphere there is, as we have seen, another solar envelope of relatively cooler vapours—the reversing layer. Each constituent element in this outer envelope stops its own kind of light, that is, the kind of light made by incandescent atoms of the same element in the photosphere. The "stoppages" register themselves in the solar spectrum as dark lines placed exactly where the corresponding bright lines would have been. The explanation once attained, dark lines became as significant as bright lines. The secret of the sun's composition was out. We have found practically every element in the sun that we know to be in the earth. We have identified an element in the sun before we were able to isolate it on the earth. We have been able even to point to the coolest places on the sun, the centres of sun-spots, where alone the temperature seems to have fallen sufficiently low to allow chemical compounds to form.

It is thus we have been able to determine what the stars, comets, or nebulæ are made of.

A Unique Discovery.

In 1868 Sir Norman Lockyer detected a light coming from the prominences of the sun which was not given by any substance known on earth, and attributed this to an unknown gas which he called helium, from the Greek *helios*, the sun. *In 1895 Sir William Ramsay discovered in certain minerals the same gas identified by the spectroscope.* We can say, therefore, that this gas was discovered in the sun nearly thirty years before it was found on earth; this discovery of the long-lost heir is as thrilling a chapter in the detective story of science as any in the sensational stories of the day, and makes us feel quite certain that our methods really tell us of what elements sun and stars are built up. The light from the corona of the sun, as we have mentioned, indicates a gas still unknown on earth, which has been christened Coronium.

But this is not all; soon a new use was found for the spectroscope. We found that we could measure with it the most difficult of all speeds to measure, speed in the line of sight. Movement at right angles to the direction in which one is looking is, if there is sufficient of it, easy to detect, and, if the distance of the moving body is known, easy to measure. But movement in the line of vision is both difficult to detect and difficult to measure. Yet, even at the enormous distances with which astronomers have to deal, the spectroscope can detect such movement and furnish data for its measurement. If a luminous body containing, say, sodium is moving rapidly towards the spectroscope, it will be found that the sodium lines in the spectrum have moved slightly from their usual definite positions towards the violet end of the spectrum, the amount of the change of position increasing with the speed of the luminous body. If the body is moving away from the spectroscope the shifting of the spectral lines will be in the opposite direction, towards the red end of the spectrum. In this way we have discovered and measured movements that otherwise would probably not have revealed themselves unmistakably to us for thousands of years. In the same way we have watched, and measured the speed of tremendous movements on the sun, and so gained proof that the vast disturbances we should expect there actually do occur.

Measuring the Speed of Light.

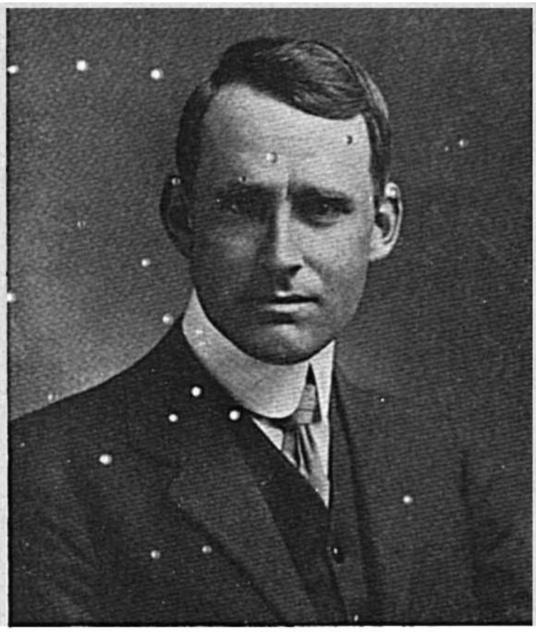


Photo: Elliott & Fry, Ltd.

PROFESSOR EDDINGTON.

Professor of Astronomy at Cambridge. The most famous of the English disciples of Einstein.

IS THE SUN DYING?

§ 3

Now let us return to our consideration of the sun.

To us on the earth the most patent and most astonishing fact about the sun is its tremendous energy. Heat and light in amazing quantities pour from it without ceasing.

Where does this energy come from? Enormous jets of red glowing gases can be seen shooting outwards from the sun, like flames from a fire, for thousands of miles. Does this argue fire as we know fire on the earth? On this point the scientist is sure. The sun is not burning, and combustion is not the source of its heat. Combustion is a chemical reaction between atoms. The conditions that make it possible are known and the results are predictable and measurable. But no chemical reaction of the nature of combustion as we know it will explain the sun's energy, nor indeed will any ordinary chemical reaction of any kind. If the sun were composed of combustible material throughout and the conditions of combustion as we understand them were always present, the sun would burn itself out in some thousands of years, with marked changes in its heat and light production as the process advanced. There is no evidence of such changes. There is, instead, strong evidence that the sun has been emitting light and heat in prodigious quantities, not for thousands, but for millions of years. Every addition to our knowledge that throws light on the sun's age seems to make for increase rather than decrease of its years. This makes the wonder of its energy greater.

And we cannot avoid the issue of the source of the energy by saying merely that the sun is gradually radiating away an energy that originated in some unknown manner, away back at the beginning of things. Reliable calculations show that the years required for the mere cooling of a globe like the sun could not possibly run to millions. In other words, the sun's energy must be subject to continuous and more or less steady renewal. However it may have acquired its enormous energy in the past, it must have some source of energy in the present.

The best explanation that we have to-day of this continuous accretion of energy is that it is due to shrinkage of the sun's bulk under the force of gravity. Gravity is one of the most mysterious forces of nature, but it is an obvious fact that bodies behave as if they attracted one another, and Newton worked out the law of this attraction. We may say, without trying to go too deeply into things, that every particle of matter attracts every other throughout the universe. If the diameter of the sun were to shrink by one mile all round, this would mean that all the millions of tons in the outer one-mile thickness would have a straight drop of one mile towards the centre. And that is not all, because obviously the layers below this outer mile would also drop inwards, each to a less degree than the one above it. What a tremendous movement of matter, however slowly it might take place! And what a tremendous energy would be involved! Astronomers calculate that the above shrinkage of one mile all round would require fifty years for its completion, assuming, reasonably, that there is close and continuous relationship between loss of heat by radiation and shrinkage. Even if this were true we need not feel over-anxious on this theory; before the sun became too cold to support life many millions of years would be required.

It was suggested at one time that falls of meteoric matter into the sun would account for the sun's heat. This position is hardly tenable now. The mere bulk of the meteoric matter required by the hypothesis, apart from other reasons, is against it. There is undoubtedly an enormous amount of meteoric matter moving about within the bounds of the solar system, but most of it seems to be following definite routes round the sun like the planets. The stray erratic quantities destined to meet their doom by collision with the sun can hardly be sufficient to account for the sun's heat.

Recent study of radio-active bodies has suggested another factor that may be working powerfully along with the force of gravitation to maintain the sun's store of heat. In radio-active bodies certain atoms seem to be undergoing disintegration. These atoms appear to be splitting up into very minute and primitive constituents. But since matter may be split up into such constituents, may it not be built up from them?

The question is whether these "radio-active" elements are undergoing disintegration, or formation, in the sun. If they are undergoing disintegration—and the sun itself is undoubtedly radio-active—then we have another source of heat for the sun that will last indefinitely.

THE PLANETS

LIFE IN OTHER WORLDS?

§ 1

It is quite clear that there cannot be life on the stars. Nothing solid or even liquid can exist in such furnaces as they are. Life exists only on planets, and even on these its possibilities are limited. Whether all the stars, or how many of them, have planetary families like our sun, we cannot positively say. If they have, such planets would be too faint and small to be visible tens of billions of miles away. Some astronomers think that our sun may be exceptional in having planets, but their reasons are speculative and unconvincing. Probably a large proportion at least of the stars have planets, and we may therefore survey the globes of our own solar system and in a general way extend the results to the rest of the universe.

In considering the possibility of life as we know it we may at once rule out the most distant planets from the sun, Uranus and Neptune. They are probably too hot. We may also pass over the nearest planet to the sun, Mercury. We have reason to believe that it turns on its axis in the same period as it revolves round the sun, and it must therefore always present the same side to the sun. This means that the heat on the sunlit side of Mercury is above boiling-point, while the cold on the other side must be between two and three hundred degrees below freezing-point.

The planet Venus, the bright globe which is known to all as the morning and evening "star,"

The Planet Venus.

seems at first sight more promising as regards the possibility of life. It is of nearly the same size as the earth, and it has a good atmosphere, but there are many astronomers who believe that, like Mercury, it always presents the same face to the sun, and it would therefore have the same disadvantage—a broiling heat on the sunny side and the cold of space on the opposite side. We are not sure. The surface of Venus is so bright—the light of the sun is reflected to us by such dense masses of cloud and dust—that it is difficult to trace any permanent markings on it, and thus ascertain how long it takes to rotate on its axis. Many astronomers believe that they have succeeded, and that the planet always turns the same face to the sun. If it does, we can hardly conceive of life on its surface, in spite of the cloud-screen.

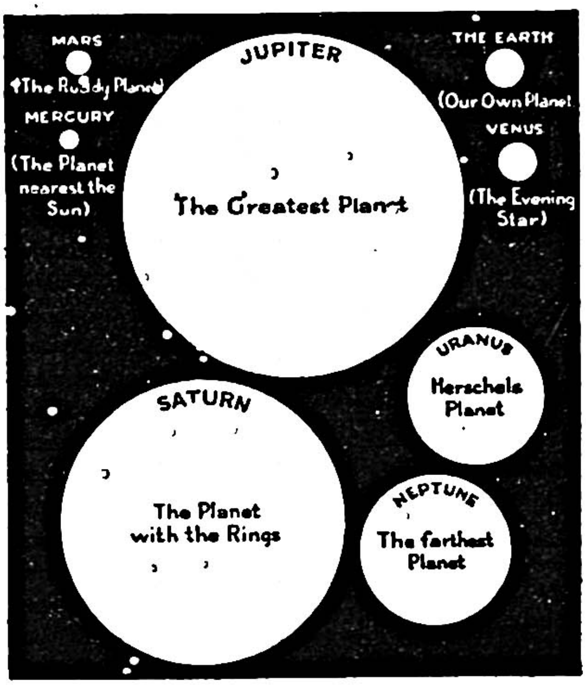


FIG. 10.—THE PLANETS, SHOWING THEIR RELATIVE DIMENSIONS

We turn to Mars; and we must first make it clear why there is so much speculation about life on Mars, and why it is supposed that, if there *is* life on Mars, it must be more advanced than life on the earth.

The basis of this belief is that if, as we saw, all the globes in our solar system are masses of metal that are cooling down,

Is there Life on Mars?

the smaller will have cooled down before the larger, and will be further ahead in their development. Now Mars is very much smaller than the earth, and must have cooled at its surface millions of years before the earth did. Hence, if a story of life began on Mars at all, it began long before the story of life on the earth. We cannot guess what sort of life-forms would be evolved in a different world, but we can confidently say that they would tend toward increasing intelligence; and thus we are disposed to look for highly intelligent beings on Mars.

But this argument supposes that the conditions of life, namely air and water, are found on Mars, and it is disputed whether they are found there in sufficient quantity. The late Professor Percival Lowell, who made a lifelong study of Mars, maintained that there are hundreds of straight lines drawn across the surface of the planet, and he claimed that they are beds of vegetation marking the sites of great channels or pipes by means of which the "Martians" draw water from their polar ocean. Professor W. H. Pickering, another high authority, thinks that the lines are long, narrow marshes fed by moist winds from the poles. There are certainly white polar caps on Mars. They seem to melt in the spring, and the dark fringe round them grows broader.

Other astronomers, however, say that they find no trace of water-vapour in the atmosphere of Mars, and they think that the polar caps may be simply thin sheets of hoar-frost or frozen gas. They point out that, as the atmosphere of Mars is certainly scanty, and the distance from the sun is so great, it may be too cold for the fluid water to exist on the planet.

If one asks why our wonderful instruments cannot settle these points, one must be reminded that Mars is never nearer than 34,000,000 miles from the earth, and only approaches to this distance once in fifteen or seventeen years. The

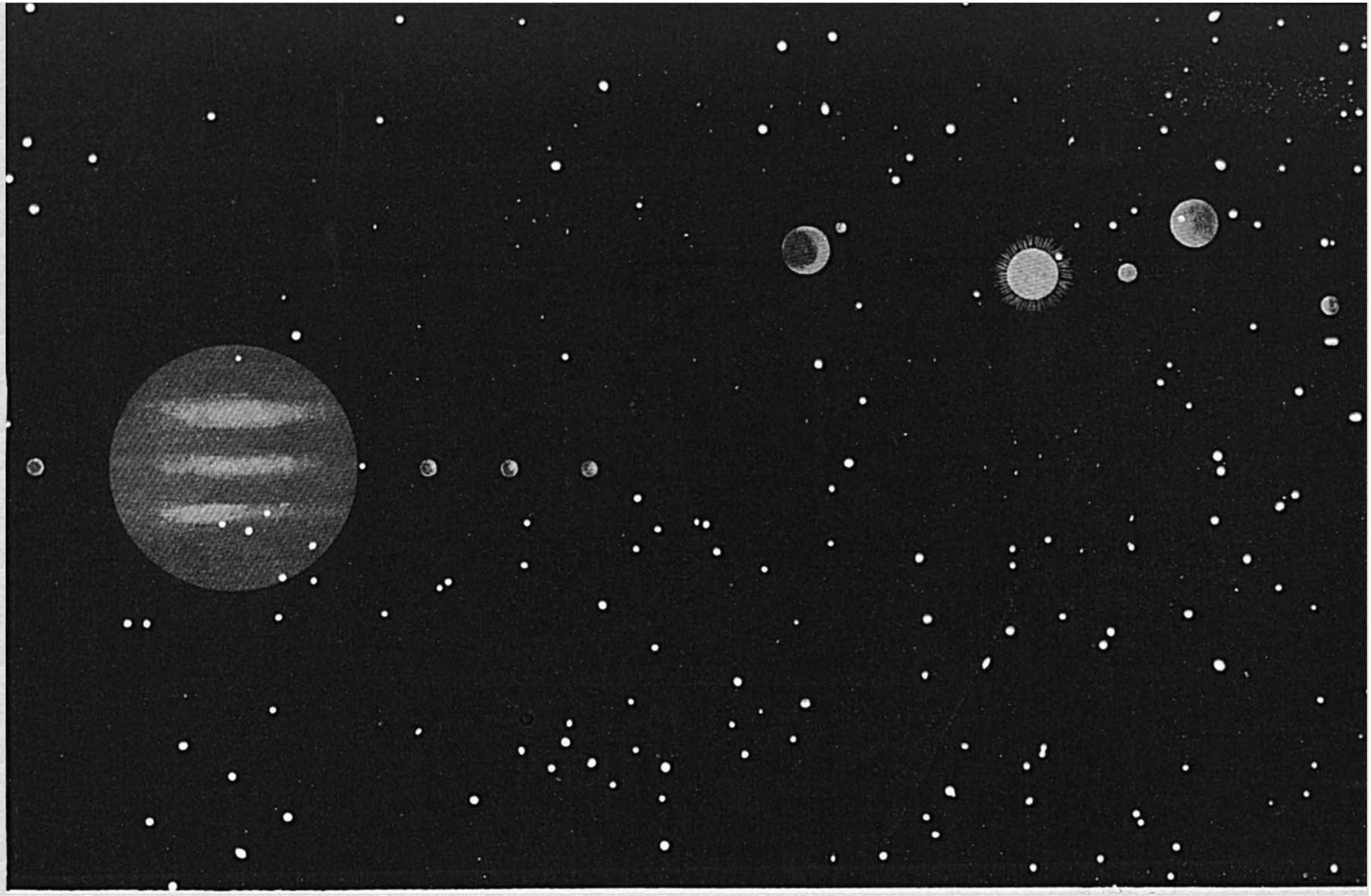


FIG. 11.—A PICTORIAL REPRESENTATION OF PART OF THE SOLAR SYSTEM.
Reading from left to right: Jupiter and four of its satellites, Earth, Moon, Sun, Mercury, Venus, and Mars.

image of Mars on the photographic negative taken in a big telescope is very small. Astronomers rely to a great extent on the eye, which is more sensitive than the photographic plate. But it is easy to have differences of opinion as to what the eye sees, and so there is a good deal of controversy.

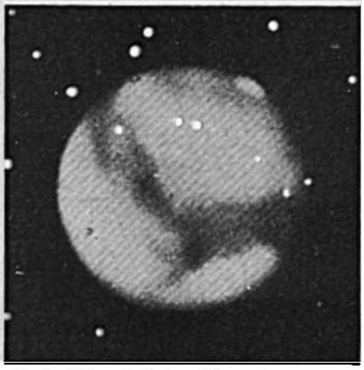


Photo: Mount Wilson Observatory.

FIG. 12.—MARS, OCTOBER 5, 1909.
Showing the dark markings and the Polar Cap.

In August 1924 the planet will again be well placed for observation, and we may learn more about it. Already a few of the much disputed lines, which people wrongly call "canals," have been traced on photographs. Astronomers who are sceptical about life on Mars are often not fully aware of the extraordinary adaptability of life. There was a time when the climate of the whole earth, from pole to pole, was semi-tropical for millions of years. No animal could then endure the least cold, yet now we have plenty of Arctic plants and animals. If the cold came slowly on Mars, as we have reason to suppose, the population could be gradually adapted to it. On the whole, it is possible that there is advanced life on Mars, and it is not impossible, in spite of the very great difficulties of a code of communication, that our "elder brothers" may yet flash across space the solution of many of our problems.

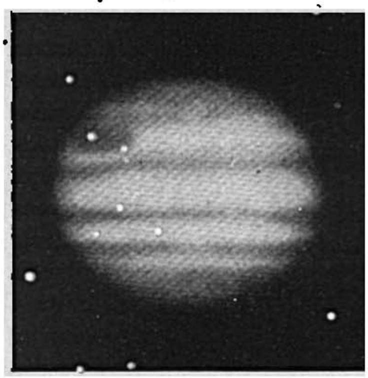


FIG. 13.—JUPITER.
Showing the belts which are probably cloud formations.

§ 2

Jupiter and Saturn.

Next to Mars, going outward from the sun, is Jupiter. Between Mars and Jupiter, however, there are more than three hundred million miles of space, and the older astronomers wondered why this was not occupied by a planet. We now know that it contains about nine hundred "planetoids," or small globes of from five to five hundred miles in diameter. It was at one time thought that a planet might have burst into these fragments (a theory which is not mathematically satisfactory), or it may be that the material which is scattered in them was prevented by the nearness of the great bulk of Jupiter from uniting into one globe.

For Jupiter is a giant planet, and its gravitational influence must extend far over space. It is 1,300 times as large as the earth, and has nine moons, four of which are large, in attendance on it. It is interesting to note that the outermost moons of Jupiter and Saturn revolve round these planets in a direction contrary to the usual direction taken by moons round planets, and by planets round the sun. But there is no life on Jupiter.

The surface which we see in photographs (Fig. 13) is a mass of cloud or steam which always envelops the body of the planet. It is apparently red-hot. A red tinge is seen sometimes at the edges of its cloud-belts, and a large red region (the "red spot"), 23,000 miles in length, has been visible on it for half a century. There may be a liquid or solid core to the planet, but as a whole it is a mass of seething vapours whirling round on its axis once in every ten hours. As in the case of the sun, however, different latitudes appear to rotate at different rates. The interior of Jupiter is very hot, but the planet is not self-luminous. The planets Venus and Jupiter shine very brightly, but they have no light of their own; they reflect the sunlight.

Photo: Professor E. E. Barnard, Yerkes Observatory.

FIG. 14.—SATURN, NOVEMBER 19, 1911.
Showing the rings, mighty swarms of meteorites.

Saturn is in the same interesting condition. The surface in the photograph (Fig. 14) is steam, and Saturn is so far away from the sun that the vaporisation of its oceans must necessarily be due to its own internal heat. It is too hot for water to settle on its surface. Like Jupiter, the great globe turns on its axis once in ten hours—a prodigious speed—and must be a swirling, seething mass of metallic vapours and gases. It is instructive to compare Jupiter and Saturn in this respect with the sun. They are smaller globes and have cooled down more than the central fire.

Saturn is a beautiful object in the telescope because it has ten moons (to include one which is disputed) and a wonderful system of "rings" round it. The so-called rings are a mighty swarm of meteorites—pieces of iron and stone of all sorts and sizes, which reflect the light of the sun to us. This ocean of matter is some miles deep, and stretches from a few thousand miles from the surface of the planet to 172,000 miles out in space. Some astronomers think that this is volcanic material which has been shot out of the planet. Others regard it as stuff which would have combined to form an eleventh moon but was prevented by the nearness of Saturn herself. There is certainly no life in Saturn.

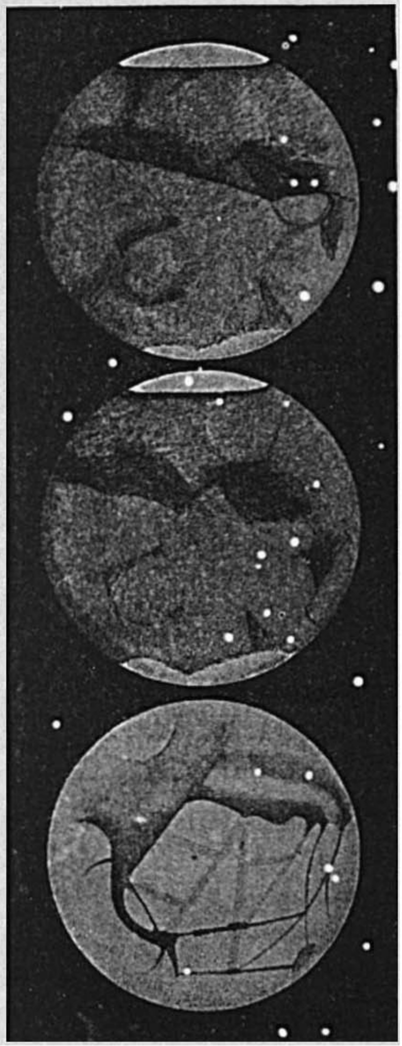


FIG. 15.—THE PLANET MARS.

The two uppermost drawings are by Professor Lowell, July 8 and 12, 1907.

The lower drawing is by Professor Schiaparelli, May 1890. On each the polar caps and the famous canals are visible.

THE MOON

Mars and Venus are therefore the only planets, besides the earth, on which we may look for life; and in the case of Venus, the possibility is very faint. But what about the moons which attend the planets? They range in size from the little ten-miles-wide moons of Mars, to Titan, a moon of Saturn, and Ganymede, a satellite of Jupiter, which are about 3,000 miles in diameter. May there not be life on some of the larger of these moons? We will take our own moon as a type of the class.

A Dead World.

The moon is so very much nearer to us than any other heavenly body that we have a remarkable knowledge of it. In Fig. 16 you have a photograph, taken in one of our largest telescopes, of part of its surface. In a sense such a telescope brings the moon to within about fifty miles of us. We should see a city like London as a dark, sprawling blotch on the globe. We could just detect a Zeppelin or a *Diplodocus* as a moving speck against the surface. But we find none of these things. It is true that a few astronomers believe that they see signs of some sort of feeble life or movement on the moon. Professor Pickering thinks that he can trace some volcanic activity. He believes that there are areas of vegetation, probably of a low order, and that the soil of the moon may retain a certain amount of water in it. He speaks of a very thin atmosphere, and of occasional light falls of snow. He has succeeded in persuading some careful observers that there probably are slight changes of some kind taking place on the moon.

But there are many things that point to absence of air on the moon. Even the photographs we reproduce tell the same story. The edges of the shadows are all hard and black. If there had been an appreciable atmosphere it would have scattered the sun's light on to the

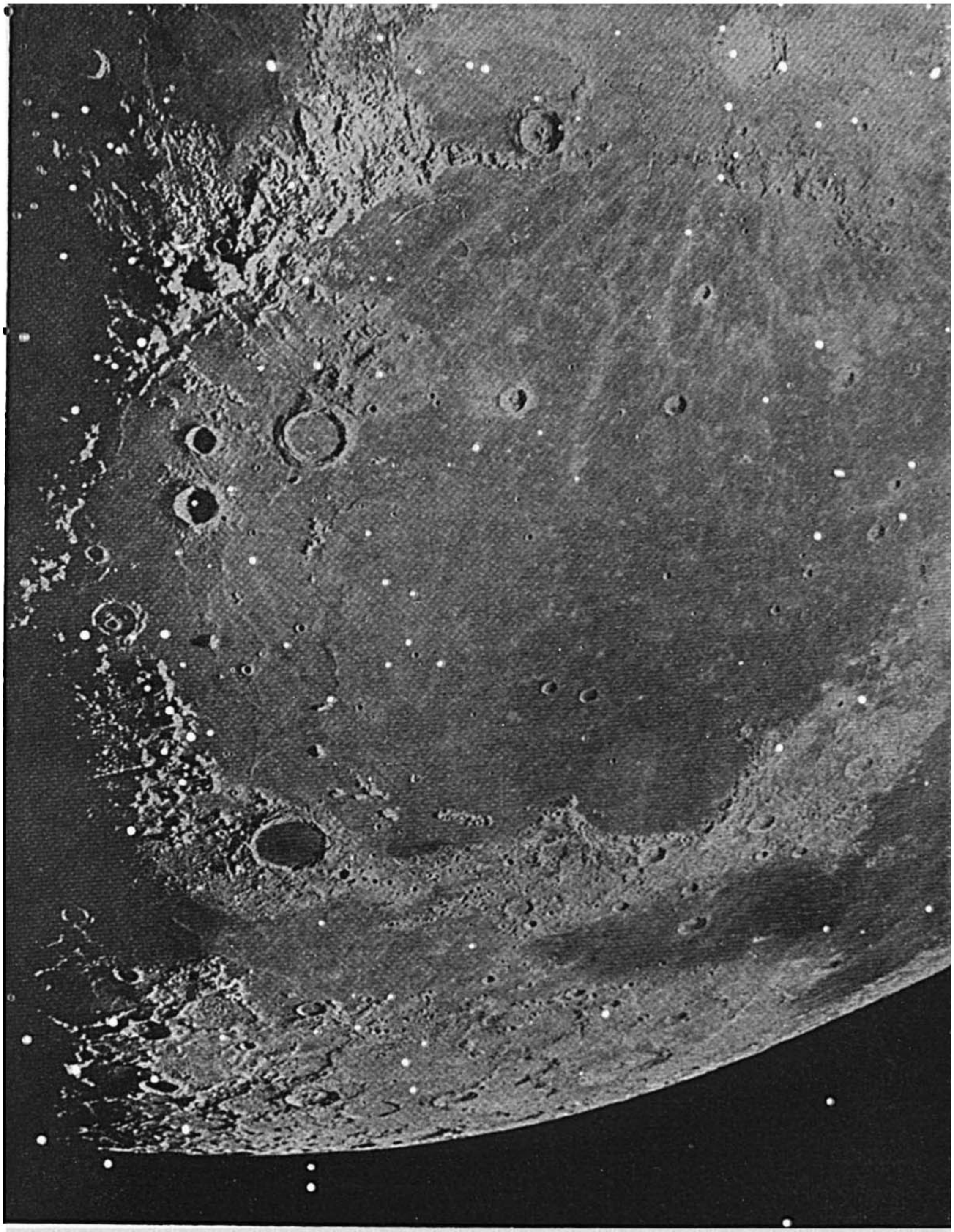


FIG. 16.—THE MOON.

Showing a great plain and some typical craters. There are thousands of these craters, and some theories of their origin are explained on the following page.

edges and produced a gradual shading off such as we see on the earth. This relative absence of air must give rise to some surprising effects. There will be no sounds on the moon, because sounds are merely air waves. Even a meteor shattering itself to a violent end against the surface of the moon would make no noise. Nor would it herald its coming by glowing into a "shooting star," as it would on entering the earth's atmosphere. There will be no floating

Photo: Observatoire, Paris.

FIG. 17.—THE MOON, SEPTEMBER 12, 1903.

Note the mysterious "rays" diverging from the central crater, and also the mountain peaks, with the dawn breaking on them, to the left of the photograph.

dust, no scent, no twilight, no blue sky, no twinkling of the stars. The sky will be always black and the stars will be clearly visible by day as by night. The sun's wonderful corona, which no man on earth, even by seizing every opportunity during eclipses, can hope to see for more than two hours in all in a long lifetime, will be visible all day. So will the great red flames of the sun. Of course, there will be no life, and no landscape effects and scenery effects due to vegetation.

The moon takes approximately twenty-seven of our days to turn once on its axis. So for fourteen days there is continuous night, when the temperature must sink away down towards the absolute cold of space. This will be followed without an instant of twilight by full daylight. For another fourteen days the sun's rays will bear straight down, with no diffusion or absorption of their heat, or light, on the way. It does not follow, however, that the temperature of the moon's surface must rise enormously. It may not even rise to the temperature of melting ice. Seeing there is no air there can be no check on radiation. The heat that the moon gets will radiate away immediately. We know that amongst the coldest places on the earth are the tops of very high mountains, the points that have reared themselves nearest to the sun but farthest out of the sheltering blanket of the earth's atmosphere. The actual temperature of the moon's surface by day is a moot point. It may be below the freezing-point or above the boiling-point of water.

The Mountains of the Moon.

The lack of air is considered by many astronomers to furnish the explanation of the enormous number of "craters" which pit the moon's surface. There are about a hundred thousand of these strange rings, and it is now believed by many that they are spots where very large meteorites, or even planetoids, splashed into the moon when its surface was still soft. Other astronomers think that they are the remains of gigantic bubbles which were raised in the moon's "skin," when the globe was still molten, by volcanic gases from below. A few astronomers think that they are, as is popularly supposed, the craters of extinct volcanoes. Our craters, on the earth, are generally deep cups, whereas these ring-formations on the moon are more like very shallow and broad saucers. Clavius, the largest of them, is 123 miles across the interior, yet its encircling rampart is not a mile high.

The mountains on the moon (Fig. 17) rise to a great height, and are extraordinarily gaunt and rugged. They are like fountains of lava, rising in places to 26,000 and 27,000 feet. The lunar Apennines have three thousand steep and weird peaks. Our terrestrial mountains are continually worn down by frost acting on

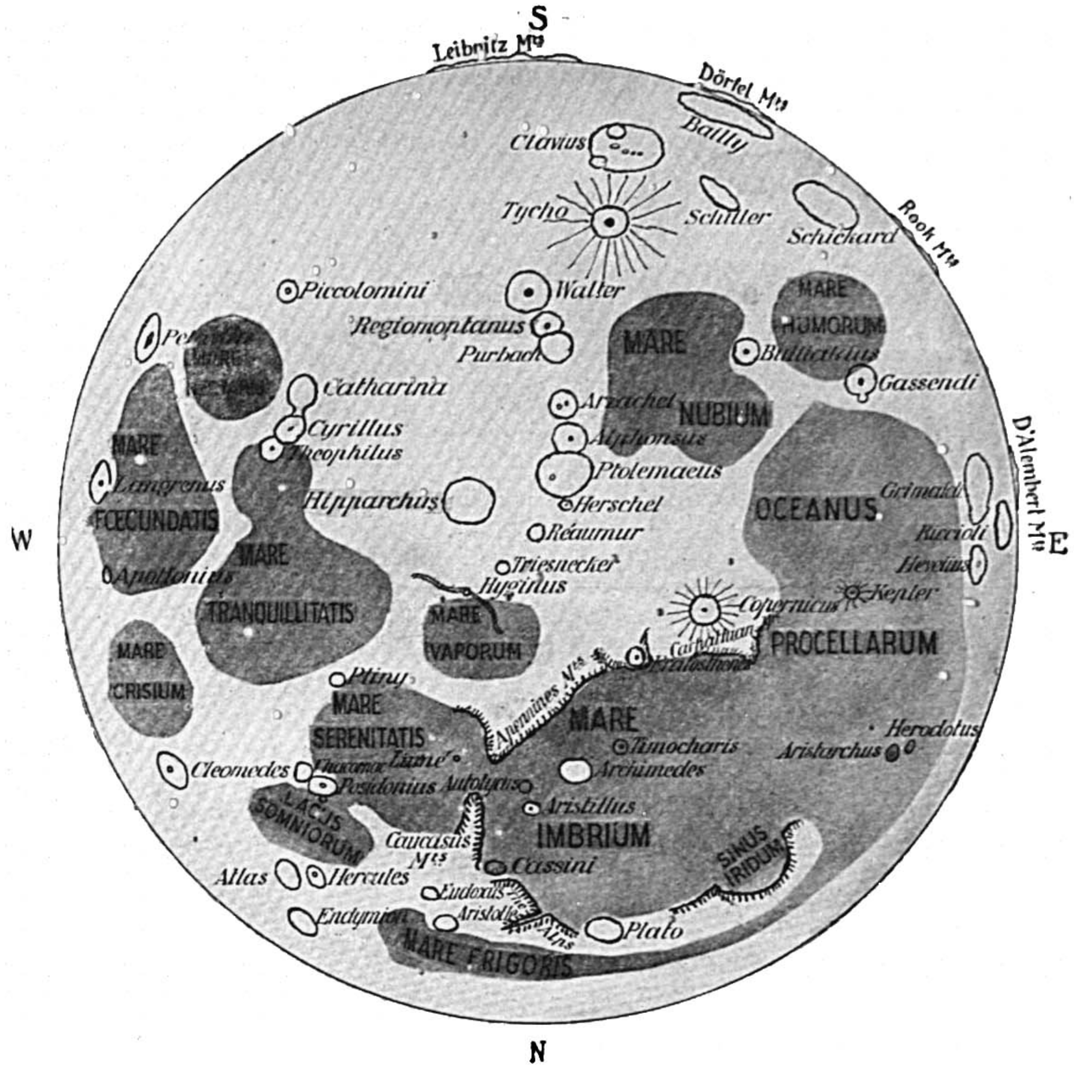


FIG. 18.—A MAP OF THE CHIEF PLAINS AND CRATERS OF THE MOON.
The plains were originally supposed to be seas: hence the name "Mare."

moisture and by ice and water, but there are none of these agencies operating on the moon. Its mountains are comparatively "everlasting hills."

The moon is interesting to us precisely because it is a dead world. It seems to show how the earth, or any cooling metal globe, will evolve in the remote future. We do not know if there was ever life on the moon, but in any case it cannot have proceeded far in development. At the most we can imagine some strange lowly forms of vegetation lingering here and there in pools of heavy gas, expanding during the blaze of the sun's long day, and frozen rigid during the long night.

METEORS AND COMETS

We may conclude our survey of the solar system with a word about "shooting stars," or meteors, and comets. There are few now who do not know that the streak of fire which suddenly lights the sky overhead at night means that a piece of stone or iron has entered our atmosphere from outer space, and has been burned up by friction. It was travelling at, perhaps, twenty or thirty miles a second. At seventy or eighty miles above our heads it began to glow, as at that height the air is thick enough to offer serious friction and raise it to a white heat. By the time the meteor reached about twenty miles or so from the earth's surface it was entirely dissipated, as a rule in fiery vapour.

Millions of Meteorites. It is estimated that between ten and a hundred million meteorites enter our atmosphere and are cremated, every day. Most of them weigh only an ounce or two, and are invisible. Some of them weigh a ton or more, but even against these large masses the air acts as a kind of "torpedo-net." They generally burst into fragments and fall without doing damage.

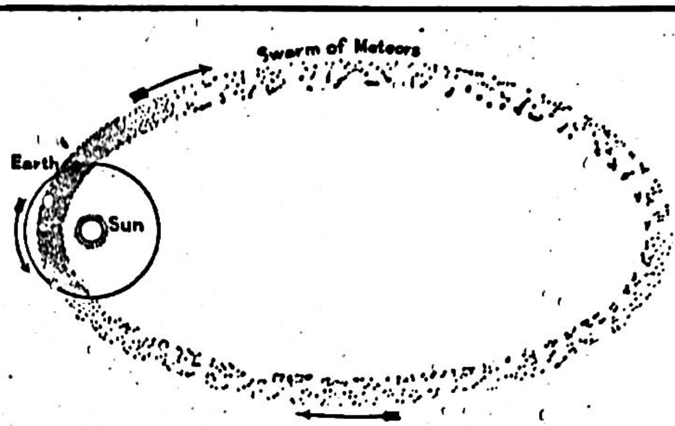


FIG. 19.—A DIAGRAM OF A STREAM OF METEORS SHOWING THE EARTH PASSING THROUGH THEM.

It is clear that "empty space" is, at least within the limits of our solar system, full of these things. They swarm like fishes in the seas. Like the fishes, moreover, they may be either solitary or gregarious. The solitary bit of cosmic rubbish is the meteorite, which we have just examined. A "social" group of meteorites is the essential part of a comet. The nucleus, or bright central part, of the head of a comet (Fig. 20) consists of a swarm, sometimes thousands of miles wide, of these pieces of iron or stone. This swarm has come under the sun's gravitational influence, and is forced to travel round it. From some dark region of space it has moved slowly into our system. It is not then a comet, for it has no tail. But as the

Photo: Royal Observatory, Greenwich.

FIG. 20.—COMET, SEPTEMBER 29, 1908.

Notice the tendency to form a number of tails. (See photograph on next page.)

crowded meteors approach the sun, and the speed increases, mutual friction raises at least a large part of them to a white heat. They give off fine vapour-like matter and the fierce flood of light from the sun sweeps this vapour out in an ever-lengthening tail. Whatever way the comet is travelling, the tail always points away from the sun.

A Great Comet.

The vapoury tail often grows to an enormous length as the comet approaches the sun. The great comet of 1843 had a tail two hundred million miles long. It is, however, composed of the thinnest vapours imaginable. Twice during the nineteenth century the earth passed through the tail of a comet, and nothing was felt. The vapours of the tail are, in fact, so attenuated that we can hardly imagine them to be white-hot. They may be lit by some electrical force. However that may be, the comet dashes round the sun, often at three or four hundred miles a second, then may pass gradually out of our system once more. It may be a thousand years, or it may be fifty years, before the monarch of the system will summon it again to make its fiery journey round his throne.

Photo: Royal Observatory, Greenwich.

FIG. 21.—COMET, OCTOBER 3, 1908.

The process has gone further and a number of distinct tails can now be counted.

THE STELLAR UNIVERSE

§ 1

The immensity of the Stellar Universe, as we have seen, is beyond our apprehension. The sun is nothing more than a very ordinary star, perhaps an insignificant one. There are stars enormously greater than the sun. One such, Betelgeux, has recently been measured, and its diameter is more than 300 times that of the sun.

The proof of the similarity between our sun and the stars has come to us through the spectroscope. The elements that we find by its means in the sun are also found in the same way in the stars. Matter, says the spectroscope, is essentially the same everywhere, in the earth and the sun, in the comet that visits us once in a thousand years, in the star whose distance is incalculable, and in the great clouds of "fire-mist" that we call nebulæ.

The Evolution of Stars.

In considering the evolution of the stars let us keep two points clearly in mind. The starting-point, the nebula, is no figment of the scientific imagination. Hundreds of thousands of nebulæ, besides even vaster irregular stretches of nebulous matter, exist in the heavens. But the stages of the evolution of this stuff into stars are very largely a matter of speculation. Possibly there is more than one line of evolution, and the various theories may be reconciled. And this applies also to the theories of the various stages through which the stars themselves pass on their way to extinction.

The light of about a quarter of a million stars has been analysed in the spectroscope, and it is found that they fall into about a dozen classes which generally correspond to stages in their evolution (Fig. 22).

The Age of Stars.

In its main lines the spectrum of a star corresponds to its colour, and we may roughly group the stars into red, yellow, and white. This is also the order of increasing temperature, the red stars being the coolest and the white stars the hottest. We might therefore imagine that the white stars are the youngest, and that as they grow older and cooler they become yellowish, then red, and finally become invisible—just as a cooling white-hot iron would do. But a very interesting recent research shows that there are two kinds of red stars; some of them are amongst the oldest stars and some are amongst the youngest. The facts appear to be that when a star is first formed it is not very hot. It is an immense mass of diffuse gas glowing with a dull-red heat. It contracts under the mutual gravitation of its particles, and as it does so it grows hotter. It acquires a yellowish tinge.

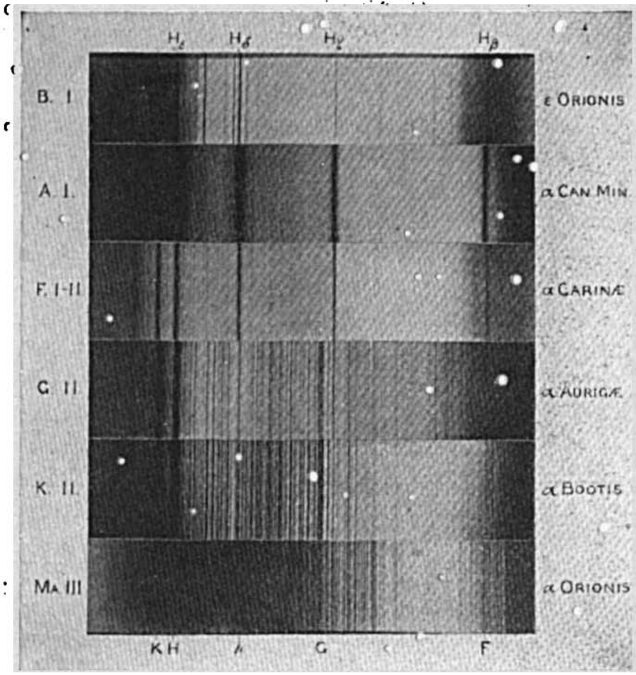


Photo: Harvard College Observatory.

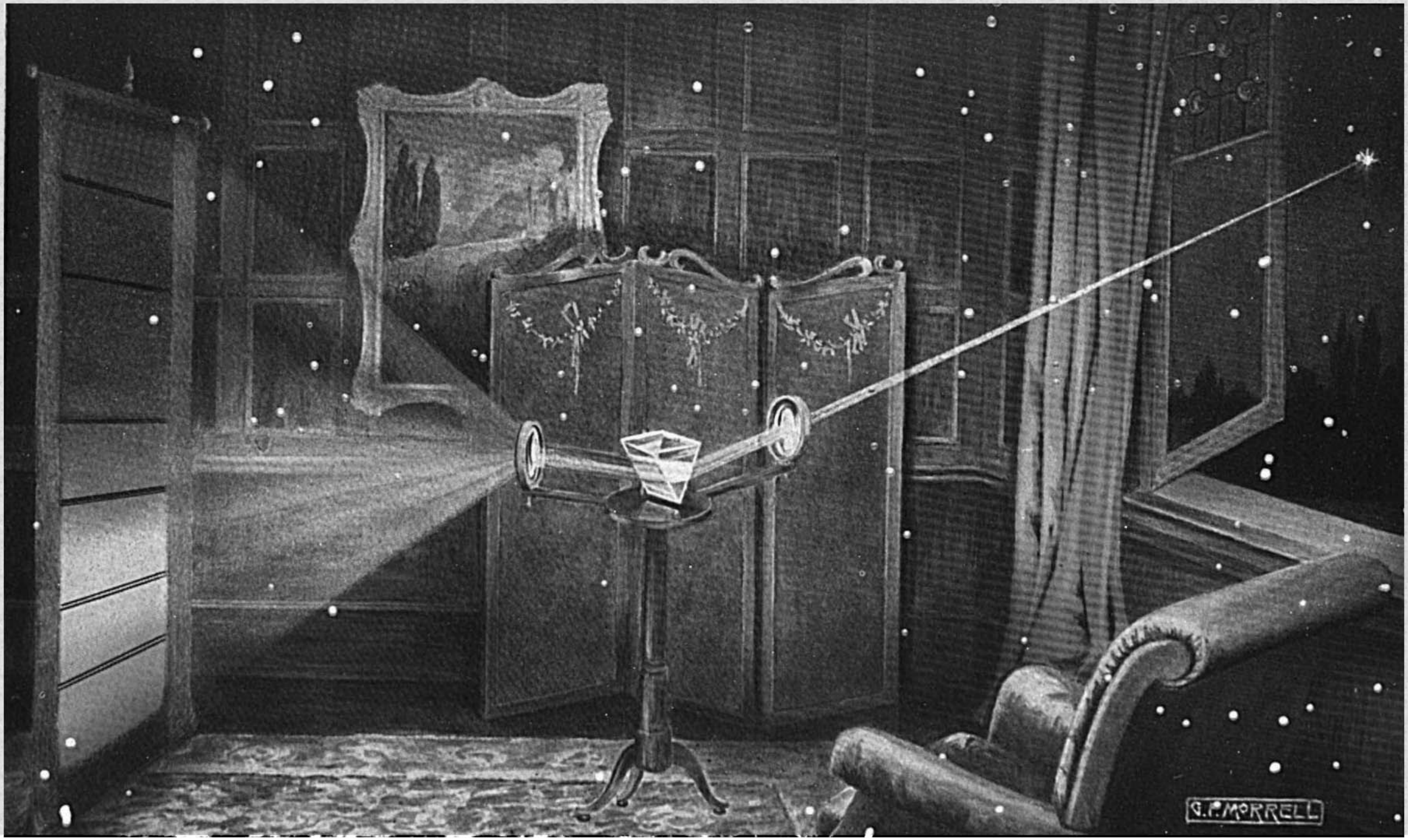
FIG. 22.—TYPICAL SPECTRA.

Six main types of stellar spectra. Notice the lines they have in common, showing what elements are met with in different types of stars. Each of these spectra corresponds to a different set of physical and chemical conditions.

As it continues to contract it grows hotter and hotter until its temperature reaches a maximum as a white star. At this point the contraction process does not stop, but the heating process does. Further contraction is now accompanied by cooling, and the star goes through its colour changes again, but this time in the inverse order. It contracts and cools to yellow and finally to red. But when it again becomes a red star it is enormously denser and smaller than when it began as a red star. Consequently the red stars are divided into two classes called, appropriately, Giants and Dwarfs. This theory, which we owe to an American astronomer, H. N. Russell, has been successful in explaining a variety of phenomena, and there is consequently good reason to suppose it to be true. But the question as to how the red giant stars were formed has received less satisfactory and precise answers.

The most commonly accepted theory is the nebular theory.

The nebular theory is dealt with in a later chapter.



THE SPECTROSCOPE (see page 11) IS AN INSTRUMENT FOR ANALYSING LIGHT; IT PROVIDES THE MEANS FOR IDENTIFYING DIFFERENT SUBSTANCES.

This pictorial diagram illustrates the principle of Spectrum Analysis, showing how sunlight is decomposed into its primary colours. What we call white light is composed of seven different colours. The diagram is relieved of all detail which would unduly obscure the simple process by which a ray of light is broken up by a prism into different wave-lengths. The spectrum rays have been greatly magnified.