THE END OF THE WORLD

THE NEW STAR IN AURIGA (1892)

(In centre of circle) (*see p.* 224)

THE END OF THE WORLD

BY

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PREFACE

THIS is an account of the recent discoveries and the present position of science, chiefly astronomical science, in relation to the interesting subject announced in the title.

The science of astronomy has for some years been distinguished by an intense and fruitful research and a large disturbance of received opinions. Great new eyes have opened upon the universe in all parts of our planet. New improvements have added power and penetration to our marvellous instruments. A splendid and superbly equipped body of observers have scanned afresh the features of the universe, and behind them a critical body of mathematicians have digested their reports and restrained their speculations. Man's vision has grown sharper and larger, and theories which hardly ten years ago were generally accepted, and still fascinate the reader of popular literature, are shaking on their insecure foundations.

This is a piece of popular literature. It avoids technical language as far as possible, and seeks only to convey interesting results or conjectures to an inexpert reader. But it is largely based upon the papers and notes which have appeared in expert journals down to the month in which I write; and it will be understood that, starting from this critical literature, I have proceeded cautiously. The inexpert reader, who once found astronomy as interesting as romance, is less amiably disposed toward it to-day. On the one hand, an astronomical treatise repels him by its inevitable array of mathematical symbols and technical names: which have, on the less adventurous, the effect of the broken bottles and iron spikes of an orchard wall. On the other hand, there are sophists who would persuade us that science is always changing: that the guesses of one generation are but the amusement of the next. Therefore I set out to reintroduce the general reader to some of the grand permanent truths of the astronomical revelation and explain the real incidence of the new views. Here and there, as in Chapters III. and XI., I enlarge on novel or more speculative aspects of the subject; but the text is still based on the most recent and critical literature of the sciences implicated. Since, however, the book is not intended for students, I have felt it useless to load it with references to the mass of recent literature from which its contents have been distilled.

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The End of the World

CHAPTER I

WHAT IS THE WORLD?

BEFORE the stupendous revelation of modern science burst upon the mind it was possible to express in a few simple words one's belief, or conjecture, about the end of the world. The earth was generally regarded as the prime reality: the remainder of the universe was an overarching structure which might crack under its own weight and topple upon the great plain on which man played his human comedy. Did not stars fall nightly from the skies? They, and the sun and the moon and the planets, were the lamps of the theatre, set in a great scaffolding or dome, which might rest on the higher mountains of the earth. The gods might, in a fit of anger, loosen the foundations of the scaffolding, and fling sun and moon and stars fierily upon the earth.

At one point, more than two thousand years ago, the mind of man outsoared this puny conception, and obtained strange glimpses of the real universe. When the pioneers of the northern race, the Greeks, reached the frontiers of civilisation, and heard the wisdom of Persia and Babylonia and Egypt, their vigorous mind, unchecked by sacred traditions, entered upon a wonderful avenue of speculation. The sun might be a great central fire, so much vaster than the earth, and so remote, that no conceivable vault could sustain it. The stars might be similar suns scattered over an area that enfolded what was called the world much as the wide waters of the sea enfolded Crete. The universe might be an absolutely boundless desert of dust, gathering here and there into the large balls that we call worlds . . . We talk of "the wisdom of the East," but nothing in all the dreamy contemplations of the East approaches these brilliant guesses of the earlier Greek thinkers. They were, however, mere guesses, not scientific deductions; and Greece turned away from Nature to other things, and perished.

Apart from this audacious strain in Greek thought, "the world" was a measureable structure, lying at the feet of the gods, and from all time men have wondered how it would end.

Usually it was thought that the gods would, in a mood of anger, destroy it, and the manner of its destruction was not difficult to imagine. There were, within experience, two great destructive powers, fire and flood; and one or both of these would some day put an end to the world. Long ago, a great many nations thought a flood had almost buried the Earth. Some day the destruction would be complete. So the guesses passed from father to son: from barbarism to civilisation.

In Asia Minor, four thousand years ago, dwelt the united fathers of the Hindus and Persians, the tribe whose traditions would dominate the greater part of Asia and southern Europe. They had—it becomes a great dogma in the Hindu and Persian sacred books, and even in the Stoic teaching—a legend that this world, as we know it, will end in a mighty conflagration, with tempests and earthquakes, and the moon and the stars falling from their shrivelled scaffolding. In the forests of the north of Europe was another large parental tribe, or group of tribes, the Teutons. They held that some day the Sun and the stars would be darkened, and vast flames would break out, and the Earth would be swallowed up in the ocean. In the western continent, among the unknown Amerinds, was the same belief that the world would come to a catastrophic end in flame. It was naive and natural. The gods would surely destroy the world some day, because man was so wicked; and fire was the most terrible instrument of their wrath. Few people had not in those days seen a village or a town perish in flames. Some of them knew volcanoes. Where flood was more dreaded, it replaced fire as the destroyer. Where the earthquake was painfully known, it, in the final catastrophe, opened the bowels of the earth and shook the stars from their places.

These dreams fitted a small world; and the few Greeks who saw something of a larger universe did not believe in angry gods, and had no thought of an end. But now that we have proved the truth of the vision of the Greeks, we set aside the simple speculations of our fathers and ask the question afresh. Will the world end? And how will it end?

We must settle what we mean by "the world." The word itself hardly fits our larger conceptions. It lingers among us as a glove that the hand has outgrown. Fifty years ago we began—heatedly, as in the case of all innovations—to discuss the plurality of worlds, though even then it was known that there were millions of stars. Scientific men spoke of the "universe," but the great Rosse telescope, with its six-foot mirror, had already raised the question of "other universes than ours." Now we speak of "stellar systems," perhaps widely separated from each other, in a vast vague area, possibly without limits, which may be called *the* universe, or the sum of material things.

"The world" we may still take to mean our earth. Men may seek to intimidate us with learned proof of its negligible minuteness in the totality of things, but we are unmoved. What chiefly interests us is to know if, and how, and when, this globe will cease to be the home of man. It might matter no more to the universe than the crushing of an ant if this globe were blotted out, but the catastrophe would put an end to the existence of two thousand million representatives of the highest form of life known to us—man. We have as yet no definite and accepted proof that there are living and intelligent beings on any other globe in our solar family, and probably the most sanguine astronomer would say at once that no conceivable enlargement of our powers will ever detect a planet in any other solar system. So we may take a "world" in the old sense of an inhabited globe.

There are, broadly, three conceivable ways in which the Earth may come to an end. Modern research has discovered certain broad features which these great globes, the citizens of the universe, have in common with living things. They are born, they have a vigorous prime, and they slowly die. There are, apparently, embryo-worlds, sleeping in the dark womb of the universe; and it is quite accepted that there are dead worlds. We may follow the analogy a little more closely and say that our Earth may conceivably, like a human being, come to an end in one of the three general ways. It may die prematurely of disease, it may be cut off by violent accident, or it may pass through the slow and chilling phases of old age into the rigor of death.

On all these lines of possibility there are suggestions which it is interesting to consider. Our globe is assuredly not in a perfect state of health. Earthquakes remind us at times that the appalling energy with which it turns on its axis once in twenty-four hours imposes a severe strain on its strong shell, and that the shell is full of faults and weaknesses of structure. Volcanic eruptions tell us that it has a vast internal "inflammation," and when we regard the face of the moon, which has gone the way of death before us, we seem to see a world whose fiery bowels burst through the skin, in some phase, on a stupendous scale. We will consider it; also the suggestions that a day will come when men will have no air to breathe, or no water to mix with their blood and plasm, or no dry land to live upon. Then there is the increasing cold of the planet, in connection with which I draw attention to a singular feature of Ice-Ages which is generally overlooked.

It may be said at once that the discussion of these possibilities will not lead to any alarming conclusions. A planet that has survived the weaknesses of its constitution for fifty million years, at least, has not grave reason to fear premature death.

The same consideration will nerve us to discuss cheerfully the second possibility. May not our globe come to a violent and premature end by accident in the streets of space? Once more we may reflect that a globe which has escaped accident for fifty or a hundred million years, or more, will sustain its luck for the few million years of natural life that remain to it. But, since my chief purpose is to convey the large and interesting truths about the universe which an inquiry into this point incidentally discovers, I discuss the possibility of collision, even the old fear that a comet may menace us. Modern science has discussed collisions, or violent encounters or catastrophes in space, more seriously, and we may survey the large field of interesting possibilities which it opens to us.

There remains, assuming that we conclude to set aside these chances of premature disaster, the question of natural death—death from old age, as people used to say. From the astronomical point of view our globe is already dead, or has at the most a feeble pulse of vitality. But it is the cosmic law that what we call life shall arise only on a dead world, and it is possible because here the analogy with living things fails. The heart of our world is 92,000,000 miles away. As long as the Sun maintains its vitalising stream above a certain level, we live. Will the heart fail? Will the cold rigor of death one day rob Earth of its colour and movement? That this will happen no one doubts for a moment. The question here is not *if*, but *when*; and we will discuss the many lines of modern research on which any answer must be based.

And this will lead us on to a vastly wider consideration. We shall find the Sun obeying a cosmic law of life and death, and our eye will instinctively turn to survey the general rise and ebb of vitality, the vaster drama of extinction which broods over the entire universe. In order to understand aright the story of our own world, we must get the scale of the universe.

The familiar aspect of the heavens prepares us for this. Round the Earth, scattered more or less evenly over a mighty area, are the few thousand stars which the telescope discovers to be the nearer or the more brilliant members of a vast population; and girding this stupendous cluster, at a colossal distance, is the great belt of the Milky Way, in which hundreds of millions of widely separated suns blend into a narrow arch of faint light. All our research encourages us to believe that this structure is not illusory. The Milky Way is a giant ring of worlds, probably thousands of millions of miles in depth, in the centre of which is the large cluster, or group of clusters, of worlds to which our sun belongs. The Sun, in fact, has a fairly central position (on a cosmic scale); though recent calculations would make it as much as 500 million miles from the actual centre of our starry system.

But the precise structure of this enormous aggregate of worlds we do not yet know. One imagines that if we were suddenly removed far outside the system, and were able to look down from an appalling distance upon the more or less flattened ring of the Milky Way, we should see, traced in light, something like the circle of a coral-island, with a large fainter island within the circle. A very remote astronomer might see our system as a ring-nebula, like that which the telescope perceives in the constellation Lyra, though with a more thickly peopled centre, and great ragged streamers at the outer edge. But the ring-structure is rare in the heavens; there is reason to believe that even the object in Lyra is a spiral viewed edgeways. The spiral is the more familiar form, and there is a growing feeling that our system more probably resembles in structure a spiral nebula, such as that in Canes Venatici, where the remarkable prolongation (see the photograph on Plate) of one of the two great arms of the spiral might even, roughly, stand for our Magellanic Clouds. Our Milky Way is forked in places, and one branch seems more remote than another.

Of recent years it has been discovered that the stars of our system have, above their

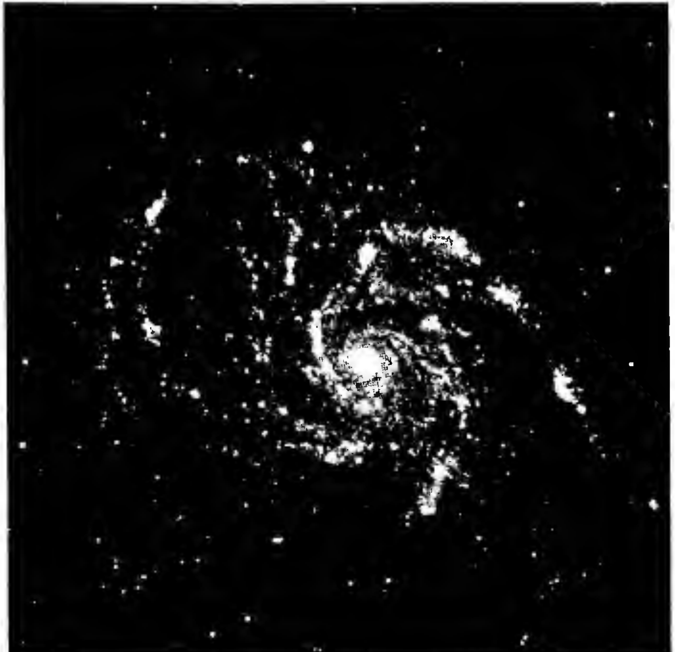
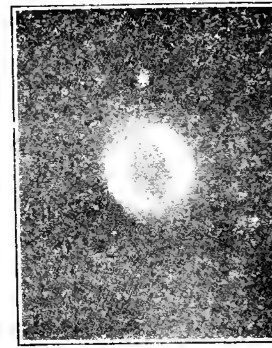


Photo by] [*H. J. Shepstone.*

A SPIRAL NEBULA

Lying a little south-west of the bright star Eta in the Great Bear.



THE RING NEBULA IN LYRA.

Photographed by Sullivan at the Yerkes Observatory with the 40-inch telescope

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individual peculiarities of movement, a tendency to travel in two great streams, running in opposite directions: one at about thirty-four, and one at about nineteen, kilometers a second. This singular race has tempted some to recognise in the opposing streams the distant outlying arms of the spiral. A close examination of the photograph of a spiral nebula will show that the structure does not resemble the single coil of a watch-spring. Two arms start from opposite sides of the central mass and trail round it, in widening circles, billions of miles into space. But the streams of our system do not seem to be separated; they pass through each other on every side. In fact, there is a third stream, or class, and the meaning of the phenomenon is still obscure. Possibly it means only that our stars revolve round a centre. The whole question of the *structure* of our system is at present under acute discussion, and we do well to cultivate patience.

Fortunately it is the *magnitude* of the system that chiefly concerns us here, and on this we can speak more confidently. We know, in very round numbers, the distance of only about seven hundred stars out of the hundreds of millions which make up our system, and astronomers merely express a hope that this direct determination may yet extend to about three thousand. But when we regard the principle of measurement, our very ignorance becomes instructive. When a nearer star is photographed from opposite sides of the earth's orbit it is slightly displaced against the background of the more distant stars; just as two observers, at some distance from each other, will see a house in the middle ground of their view projected against different points of the more distant hills—or just as two spectators, on opposite sides of the theatre, will see the figure of the actor projected against different portions of the scenery. When we accurately measure the distance between the observers and the apparent amount of the displacement against the background, the mathematician can deduce the distance of the intermediate object. But the measure of the displacement, or the "parallax," is so minute in the case of a star that a fraction too slight to be determined accurately may mean a hundred billion miles. The star must not be distant more than five hundred billion miles if we are to measure its shift with any confidence. At 900 or 1000 billion miles it ceases to show any displacement, even if the observations are made millions of miles apart; and, as the overwhelming majority of the stars which have as yet been examined show "no parallax," they are something more than a thousand billion miles away.

This is, however, a minimum figure. Have we any indirect means of enlarging it? That it must be enormously enlarged we can say without hesitation. The stars are crowded so thickly on some of our photographic plates of parts of the Milky Way, especially in the southern sky, that they blend into clouds of light, and no man can affect to count them. We may say at least that our stellar system contains hundreds of millions of stars: between one and two thousand millions, it is generally calculated, though a recent estimate runs to 3360 millions. Now, although the nearest star to us is only twenty-five billion miles away, the average distance from each other of the stars we have measured is about forty or fifty billion miles. It would be very unsafe to make a cosmic law out of so few measurements, but probably the average distance from star to star is a matter of tens of millions of miles, and we have to imagine a thousand million or more suns scattered at this distance from each other.

Indirect methods of calculating are now being used, or tried, by astronomers, and more satisfactory results may soon be announced.

The mere faintness of a star cannot measure its remoteness, as stars differ in size, and especially in intrinsic brightness. Sirius, the brightest star, is comparatively near to us ; but its rival, Canopus, is hopelessly beyond the limit of measurement, and is conspicuous only because it is thousands of times more powerful a light-giver than our Sun. Yet astronomers feel that when the stars fall into classes we may have more definite clues to their distance. Quite recently (1916) it has been found that a method of measuring the relative intensity of certain lines in the spectra of the stars proves, where we can check it by finding a parallax, a very hopeful line of inquiry. A distinguished astronomer has said that indirect methods take us more or less confidently as far as 10,000 billion miles away from the Sun. Hertzsprung has calculated that the Lesser Magellanic Cloud, which is thought to be an outlier of our system, must be twenty thousand billion miles away, and the calculation is received with respect. More recently Mr. Shapley has estimated that a certain cluster of stars is a trillion miles away.

These figures feebly suggest the scale of our universe : a system of stars which few imagine to have a diameter of less than 50,000 billion miles, and many would assign a diameter of 100,000 billion or more. The astromer has, in fact, invented a unit of measurement which dispenses him from handling these colossal figures. He measures in "parsecs"—the expression for a parallax of one second of an arc, or about nineteen billion miles—or in "light-years." But, convenient as these terms are in science, lecturing experience convinces me that the best way to convey to the inexpert some dull sense of the vastness of the universe is to express oneself in billions and trillions. We are citizens of a universe which measures some tens of thousands of billions of miles in extent.

But is this vast system *the* universe, or are there "other universes than ours?" There is very strong reason to think that our system is definitely limited in size. As we count the stars according to their magnitudes, the number increases rapidly up to a certain point and then, in the fainter classes, decreases in a remarkable manner. We must allow for the obstruction or scattering in space of the light of the more distant suns, but astronomers are now generally convinced that the system has limits.

Just in the same proportion, however, astronomers are returning to the older idea of "other universes," or other stellar systems.

Herschel long ago concluded, though he modified the belief in later years, that the dim patches of light we call nebulae were such universes, or other stellar systems. Some of these are now definitely known to be masses of luminous gas (or gas and other cosmic rubbish), but the spiral nebulae are not gaseous, or are gas under great pressure; and they are at present the subject of acute controversy. They were long thought to be, and many still think them to be, masses of glowing metal: a phase of condensation between the thin gaseous nebulae and the completed system of stars. I return to this view later, but it is necessary to note here that an increasing number of astronomers regard them as distinct and remote stellar systems, or "island universes." They lie far away from the plane of our system, while the undoubted nebulae are associated with it; and they are moving with great speed.

Since we know about 120,000 of these spiral nebulae, the speculation that they are "other universes" is fascinating, but it is contested, and the reader should regard it with reserve.[1] Certainly these objects are of stupendous size,

[1] The evidence, or arguments, on both sides may conveniently be consulted in a couple of articles in *The Observatory*, March and April, 1916.

and we may be confident that, if they are not independent stellar systems, they are such systems in the way of evolution.

Let us return to the facts. We occupy a fairly central position in a mighty system of hundreds, possibly thousands, of millions of stars; and it is suggested that this system is one of tens of thousands of such systems which faintly glow on the very limit of the eye's range. Our system is in a condition of terrific movement. Some have thought, indeed, that a vast central sun compels the others to circle round its throne. An older astronomer gave this royal position to Alcyone, of the Pleiades, which is neither central enough nor massive enough for such a rank. Some recent astronomers have been disposed to regard Canopus, a sun of appalling power, as the central body; though if Canopus is, as they say, 30,000 billion miles away, the centre of our system is awkwardly placed. It is the general opinion that the system is not monarchic, but collectivist. Its members follow the general will—the gravitational power of the whole system—and we must not be misled by the analogy of our little solar system.

It is interesting to note that the system seems to be not without its "anarchists."

Arcturus, a star equal in light-giving power to 200 or 300 suns like ours, and presumably much vaster, moves at 150 kilometers a second, and seems to be beyond control. Others move at 250 or 260, and one even at 325 kilometers, a second. These velocities are exceptional, but I defer until a later stage the question of the possibility of collisions or encounters.

This is the universe over which the great eyes of our telescopes range to-day. I have given here only a meagre outline of it, and I will return at various stages to the points I have summarised, and make clearer the processes and instruments by which man can put his measurement on so vast a configuration. But enough has been said to prepare the reader to see that the question of the end of the world presents an entirely different aspect to our generation from any that it presented to the narrow and feeble outlook of our fathers. We must think cosmically. We must feel ourselves citizens of the universe, not merely of a planet. The law of death which we shall gradually detect is a law for the hundreds of millions of shining inhabitants of space, and there is scarcely a more impressive discovery among the many which we owe to modern science than this apprehension of hundreds of millions of stars moving towards extinction.

Yet we will proceed, as I indicated, from the near and familiar to the dim vastness beyond. We will learn what science can tell or conjecture about the future of our earth, then about the future of the central luminary, on whose largesse we are dependent. From that point we may go on gradually to bring the vast and varied contents of the universe under the single aspect of it which we are considering.

CHAPTER II

THE MUMMY AT THE FEAST

ONE of the most curious effects of what we may call the new cosmic outlook, the attitude engendered by the study of astronomy, is that we can regard our globe with a spirit of cold detachment. The man of science seems to transfer himself a quarter of a million miles away—say, to the moon—and describe the earth as if it were the possession of an alien race. Essentially, he says, a large metal globe, measuring about 7,900 miles in diameter, and weighing about (here one likes the "about") 6,000,000,000,000,000,000,000 tons. Being surrounded by a shell of gases, some of which have formed great oceans of water, the metal has rusted and disintegrated at the surface; and the rubbish, and the molten matter squeezed from below, have, under pressure, formed a tough skin of rock between forty and fifty miles in thickness which binds the globe.

This would give us a very solid and durable structure but for two circumstances. The metal interior must have a very high temperature and be subject to an enormous pressure. The temperature rises one degree (Fahrenheit) with every fifty feet of descent into the crust, and the boiling point of water must be reached about two miles from the surface. At fifty miles the metal should have a temperature of about 5,000° F. The terrific pressure no doubt prevents the metal from taking a fluid or molten form, but when we reflect that the belt of rock is, in comparison with the fierce interior, hardly thicker than the shell of an egg, we are not surprised that molten matter bursts or oozes from below through every pore and fissure. If the Earth is still contracting, as is generally believed, the pressure must increase and the strain on the rocky shell become more severe.

The second great condition of instability is that the globe whizzes—it is almost absurd to say "turns"—on its axis once in twenty-four hours. At the Equator, in other words, the surface of the ball gyrates at a thousand miles an hour. It is a great "fly-wheel," and a hundred things indicate its sensitiveness under the strain. Only a short time ago a very wet week-end poured 6,000,000,000 tons of water upon the district of London, and it can be proved that such a sudden load actually depresses the solid crust It is believed that the shifting of the North Pole means that the earth wobbles under the shock of heavy local falls of snow and rain. That it shudders and trembles habitually is registered infallibly by our sensitive modern instruments, and to lie awake on the fifth floor of an hotel during even a moderate earth-quake, as I have done in New Zealand, is a peculiar experience. Sometimes a great fault or dislocation in the seams of rock discovers itself, and the masses of rock snap together with a jolt that shakes large cities into bloody ruins.

It is intimated that 13,000,000 people have met their deaths by earthquake and volcano during the last three thousand years. This is, however, a small toll of the thousands of millions of human beings who have trodden the Earth during that period, and it merely indicates, for the present, a condition of what we should call "comparative stability." The question of interest is whether there is any danger of the malady increasing as the Earth contracts.

When we study the face of our Moon we get the impression that the danger is worth considering. It is related that the ancient Egyptians had an unpleasant habit of checking the

THE MOON.

[Face p. 22.

THE CRATER THEOPHILUS (*see p.* 28).

[*Face p.* 23.

flow of mirth at a banquet by introducing a mummy and sending the thoughts of the guests forward to an unattractive future. The Moon is the mummy at the feast of humanity. "Such you will one day become," its livid face seems to call to the astronomer. It will be realised in the course of this work that the period of cosmic life depends on size or mass. Heat is life in the case of these globes, and smaller bodies lose their heat sooner than large bodies. Hence, though the Moon is not older than the Earth, and is indeed generally believed to be a daughter of the Earth, it has—with certain reserves which I will discuss presently—reached the state of cosmic death long before us. The Sun, a globe of 2,000 trillion tons, is in, or not long past, the prime of life. The Earth, 332,000 times less in volume, has almost lost internal life, but may maintain a surface-life for millions of years. The Moon, with less than 1/80th the volume of the Earth, is a dead and rigid world.

So one asks with interest how the Moon died, and at first sight, as I said, the inquirer may be alarmed. The face which the Moon presents to us is almost entirely blotched with what seem to be the craters of extinct volcanoes. It looks as if at some date the heated metal interior had revolted at length against the pressure of the shell, and had oozed out, by 200,000 pores, some of gigantic dimensions, upon the surface of the globe.

In the days of feeble telescopes the volcanic nature of these dark rings was undoubted, but with the enlargement of the power of the instruments many astronomers began to interpret the features differently. The telescope consists essentially of two parts; a great lens or mirror for gathering as much light as possible from the distant object and a magnifying glass, or small microscope, for enlarging the image of the object at the intensified focus of the lens or mirror. The more light you get—the larger the diameter of the lens or mirror—the greater the power of magnification you can apply, and, virtually, the nearer you bring the object. With the Lick telescope, which has a 36 inch lens, or the Yerkes telescope, which has a 40-inch lens, or the Mt. Wilson reflecting telescope, which has a 60-inch mirror, a magnifying power of 1,000 can profitably be applied. Larger powers may of course be used, but photographs taken with these larger powers will show that you lose in detail what you gain in size. We, are, however, not so near the end of telescopic development as men thought ten years ago. The Canadian Government has now, in its

Astrophysical Observatory, a reflecting telescope with a 72-inch mirror, and the Mt. Wilson Observatory has erected one with a mirror 100 inches in diameter. New principles of construction also are being tried, and we may before many years see the Moon as one sees landscapes in a mountainous region.

As it is, a powerful telescope has, in a sense, the effect of bringing the moon so close to us that we can detect single objects 440 feet long. With the larger and dimmer power, indeed, an object only 295 feet long could be individualised. The range of our eye on Earth must not mislead us. Here we gaze horizontally through the thick strata of the atmosphere, but in examining the Moon we gaze through the shortest depth of the dense layers, and there is no air (or a negligible quantity of air) on the Moon to dim its features. We have therefore a remarkable knowledge of the surface of the Moon, and the excellent photographs that have been published, especially by the Lick Observatory, make it familiar far beyond the range of amateur astronomy.

And the first impression one has is, as a vivid astronomical writer has said, that one is gazing upon a "volcanic charnelhouse." The sharp line between light and darkness, as the

Sun rises, and the unfading brilliance of the stars when they pass behind the disk, show that the Moon has no appreciable atmosphere. Whether it may have an inappreciable atmosphere, or wisps and pools of thick gases lying in the hollows, it is not worth our while to seek. Gases surrounding a globe tend to drift away into space, unless the mass of the globe is sufficient to hold them by its gravitational power. It is doubted by many if the mass of the Moon is great enough to exert that control, and they therefore doubt if it ever had an atmosphere. However that may be, a number of delicate tests convince us that the Moon is to-day practically airless and waterless, and its aspect encourages the belief that this has been its condition for ages.

Its isolated hills and its ranges of mountains rise, steeply, to a height which, relatively to the size of the moon, makes them More majestic than our Andes and Himalaya. Gravitation is, on the Moon, one sixth feebler than it is on the Earth, and the masses of molted rock which have boiled through the crust have risen like stupendous fountains turned into ice. There has, moreover, been no "weathering"—no corrosive action of gas and water—and the frozen masses of metal rise into innumerable cones and peaks, and fling sharp and weird shadows over the levels. The lunar Apennines, 450 miles long, soar into some three thousand steep and rugged peaks, touching a height of 18,000 feet. The Alps have 700 peaks, rising to 10,760 feet. The peaks of the Doerfel Mountains reach 26,000 feet; of the Leibnitz Mountains 27,000 feet.

In addition to these colossal outbursts of igneous matter, which have congealed into lofty mountain ranges, there are other features which are generally interpreted as volcanic. The dark large areas which were once thought to be the bottoms of evaporated seas and oceans are now generally regarded as lava-plains. Possibly the thin crust succumbed, in an early stage of development, and the molten lava flowed evenly over the vast areas. There are also bright rays or streaks, radiating far over the disk from some of the craters, and, since they are brightest at full moon, it is thought that they are ancient lava-streams, on the surface of which a fine ash or crystalline layer has gathered. In fine, there are the craters, but the nature of these is the subject of a warm debate in actual astronomy.

The name "crater" was, as I said, given to them in the early days of the telescope, when their real natnre and size were not appreciated. Accurate measurement and closer acquaintance with their structure led to a general abandonment of the idea that they were the cups of extinct volcanoes, though no clear and widely accepted theory of their nature was substituted. They are, on close examination, very different in many respects from our terrestial volcanoes. "Crater" means cup, but these ring-shaped depressions are comparatively shallow, and they would be more aptly compared to a saucer then to a cup, when we bear in mind the enormous size of many of them. Copernicus, one of the favourite objects of the amateur astronomer, is a deep circular pit, with a central peak rising 11,000 feet above the bottom of the pit, though only 2,600 feet above the average level of the moon's surface. The pit is surrounded by a broken circular rampart which reaches a height of 13,000 feet above the moon's surface: a circular range of hills, in effect, torn and scattered, as if by successive land-slides, into great ridges and terraces. But when we learn that the internal diameter of the "cup" is forty-six miles, we see that the cavity is twenty times as spacious as the height of the walls, and our familiar volcano fades out of comparison. And Copernicus is by no means one of the largest or shallowest of these singular constructions. Plato is sixty miles in diameter, and the highest peaks of its rampart rise to only about 7500 feet. Ptolemaeus is 115 miles across the circular depression, and its walls do not rise (and this only on one side) more than 9000 feet. In fine, Clavius measures 140 miles from rampart to rampart, yet attains a height of only 16,000 feet. It was therefore thought that the attempt to liken these structures to what we know as volcanoes failed, and some new interpretation must be found.

The chief rival to the volcanic theory is a theory that the markings are due to a bombardment of the surface of the moon at a time when it was still plastic, or the crust was very thin. I have explained that the mass and therefore the gravitational "pull" of the moon is so small that many doubt if it ever had an atmosphere. Gases there would undoubtedly be among its original constituents, and they would be found at its surface, but it is presumed by many that they would quickly depart into space. Now the moon must be, like the earth, subjected to a heavy bombardment by those blocks of iron or stone which, rapidly traversing space, are burned up and become "shooting stars" in our atmosphere. These wanderers in space may be of all sizes, from minute grains to blocks of metal weighing many tons, as will be seen later, but our planet is protected from their fierce onrush by a "torpedo-net"—the atmosphere. Since the moon has no appreciable atmosphere, its surface has been exposed for ages to this meteoritic bombardment. If we suppose that it was thus unprotected at a time when its crust was still thin, or even plastic, we can understand that the occasional impact, at twenty or thirty miles a second, of a mass of metal weighing many tons would pit its surface in some such form as that we behold.

But the size of the "craters" is a serious difficulty. The tens of thousands of these structures which stud our photographs of the moon are miles in diameter, some of them more than a hundred miles, It is impossible to conceive meteors causing such pits as Herschel (90 miles in diameter), Petavius (100 miles), Gauss (110 miles), Humboldt (112 miles), Hipparchus (125 miles), and Clavius (123 miles, in the inner ring.) A very much larger shell is required, and to meet this Professor See has put forward an ingenious theory. He holds that the ball of the moon was drawn toward the sun from a distant region of our system and "captured," or domesticated, by the earth; and that in its journey toward us it passed through the zone of our numerous "minor planets," or planetoids, and numbers of them smashed into its surface.

Here assuredly, are large enough projectiles, but the suggestion is not widely accepted. The general belief is that the moon was born of the earth in an early phase of its development. There is very strong reason to believe that in that early age, when the earth was still viscous, it gyrated on its axis very much more rapidly than it does to-day. The tidal action of the sun's gravitational power is slowing down the rotation of our planet, just as the earth has reduced that of the moon. Something between a thousand and two thousand million years ago—the theory estimates—the earth spun round on its axis once in four or five hours, and the terrific strain gradually detached from the semi-fluid globe a mass of 74 million billion tons, which rounded into our moon and gradually moved away.

This is the generally received speculation about the moon's origin, and, while it affords an excellent foundation for the volcanic features of the moon, it offers less room for the play of large projectiles. The moon would be for ages a cooling molten mass. Its thin growing skin would be repeatedly disrupted by the compressed volcanic mass below, and there would be, as on the earth, vast floods of lava. The larger meteors might play some part. It is calculated that they strike the moon with 100,000 times the energy of fulminate, and in those early ages at least they would cause great volcanic outpours. When the moon still lingered near the earth it might further sustain the shock of masses shot out from the earth itself.

On the whole modern astronomers lean to the older theory, the volcanic theory, though they warn us that the very conditions of the moon make any comparison with earthly structures precarious, and for the moment we must be reserved. The earliest rocks of the earth clearly indicate that our globe at one time passed through a great volcanic phase. Tens of thousands of feet of igneous rock underlie our strata of sedimentary rock. What the earth was then like we cannot imagine, for the wear and tear of millions of years—the action of gas and water and frost—have obliterated or buried the early features. On the moon, where no such weathering and wearing-down occurred, we seem to see the volcanic age petrified, but what the process was that formed particular structures we cannot confidently say. Some have suggested that the ring-structures may mark sites where gigantic bubbles were blown in the molten or viscous surface by gases from below, the ramparts and inner peaks representing the ruins of the burst bubble. Here again the size is a difficulty. The thin atmosphere and feebler gravitation of the moon would permit the formation of blisters on a scale unknown to us, but it is not easy to conceive the rise of tens of thousands of bubbles having a diameter of several miles each. The larger "craters" are clearly refractory to the theory.

Whether there was ever life on such a globe we have no means of determining. The late Professor Pickering, having in mind certain changes of colour which are at times observed in parts of the moon, maintained that there is vegetal life on its surface to-day. The conditions would be peculiar. The tidal influence of the earth has slowed down the rotation of the moon on its axis until the period has become identical with the period of its revolution round the earth. Its day and night are therefore each about a fortnight in length. During 354 hours its surface sustains the full flood of the sun's rays, untempered by cloud or atmosphere. Except in the direct rays of the sun the cold even at noon would be severe, for the heat is reflected at once into space. And when the sun goes down, instantaneously, without the least twilight, the moon's surface passes quickly into a coldness beyond our power of imagining and an utter darkness. The darkness is, however, tempered by the light reflected from the earth. "Earth-shine" must be about fourteen times as brilliant as "moonshine" is with us, on account of the greater size of our globe.

Other astronomers think that life once covered the surface of the moon, but does so no longer. This belief is fairly grounded upon our experience that life appears wherever the conditions are found. Life passes into the deep abysses of the ocean, and climbs beyond the snow-line of the loftier mountains. But in this we must assume that the moon once had an atmosphere and water, and many astronomers think that its mass is insufficient to hold these at its surface, or that whatever water there was would quickly be frozen upon its surface. Certainly if the conditions of life were ever present, they cannot have lasted long enough to enable life to reach the higher levels we know, and romances about "men in the moon" are mere flights of fancy. No undisputed movement—though quite lately movements have been announced—has ever been seen on the moon, though thousands of eyes have scanned it nightly for several generations. With a reserve in regard to the opinion of Professor Pickering, we may say that the moon seems an air-less, water-less, unchanging desolation; our predecessor in the way of cosmic death.

But we must conclude that the manner, or the attendant circumstances, of its death contain no clear lesson for us. From earth also the air and water are slowly going, particle by particle, into space, but the departure is so slow that it will not affect humanity. Other causes will have drawn a shroud about the earth long before it is materially robbed of its mantle of gas. It does not share the particular weaknesses of the moon. Although we seem to see various phases of disturbance of the moon, where crater encroaches upon crater, the great mass of its features point to an early age. Possibly our earth similarly spluttered and burst in its earlier period, and the grinding and scouring and redistributing of millions of tons of material have concealed the fact. We may trust that the crust has now set firm over the heated interior, and our volcanoes are but the "safety-valves" by which the pressure is eased. The scarred face of the moon need not intimidate us.

CHAPTER III

THE MENACE OF THE ICE-AGE

I have incidentally noticed in the course of the last chapter one of the ways in which, it is suggested, our globe may cease to be the theatre of life. Physicists tell us that gas and water are continually escaping into outer space, owing to the feebler gravitational control of the earth over their particles at great altitudes. This fact has been made the basis of a theory that a time will come when an atmosphere too thin to breathe, and an inadequate supply of water, will be left at the earth's surface. Again we have the fate of the moon before us; and it seems to be reinforced by the state of the planet Mars, on which water is, to say the least, scanty, and the atmosphere is thin. But we need not linger on this point. In the case of so much heavier a globe as ours the period of time required for the escape of water and air is so vast and vague that these conditions are practically permanent. The lamps of the theatre will have been extinguished, and the actors departed, long before these vital conditions fail.

Another suggestion of a malady that may prematurely close the drama of life is that in time the dry land may disappear beneath the waves. Our coasts are crumbling age by age. Within the life-time of man it was possible to walk afoot from Africa to Europe, from France to Britain, from Asia to America. Little earlier the coast of Europe was flung a hundred miles beyond the present western shore of Ireland. In places every year sees a few yards of the coast slide into the water; and even when granite walls face the fury of the waves they are being undermined. A twenty-foot wave, a not uncommon wave on some coasts in the winter, strikes the rocks with a force of one ton to the square foot. Then there are the rain and the rivers, which scour millions of tons from the solid land every year. Even beyond the range of water the devastation continues, as if angry demons tore at the earth. It is calculated that fourteen thousand feet have been worn from the great Alpine hill, of which Mont Blanc is the diminished stump to-day, during the time that horses have trodden the earth.

To this it is usual to reply that the sea gives as much as it takes. I have stood on a part of the English coast (Blackpool) while an aged native pointed out to me the spot, far out at sea, where his father had kept a public-house; and ten miles away, during the same period, the sea had receded about the same distance. So it has been throughout all geological time. Once a continent stretched across what is now the North Atlantic Ocean, and the animals walked from Africa to America; but Europe and the United States and Central America hardly existed in those days. Once there was a continent connecting Australia, Antarctica, South Africa, and South America; but the bulk of *our* Asia, Africa, and South America did not then exist. On the whole, the land has gained on the water. Once only in the history of the earth does there seem to have been as much solid land as there is to-day.

However, we need not conjure up a vision of the future race flitting from continent to continent. There is a spot on the eastern coast of England, Dunwich, where the last relic of a prosperous medieval town totters on the edge of the cliffs. The sea has swallowed the remainder. But a few miles away a small town, with feeble resources, defends itself successfully against the destroyer. Modern engineering can preserve any part of the earth that is worth preserving. The engineers of the future will certainly not fear an end of the world by flood. Even the scouring by rain and river, which removes about six cubic miles every year of the solid land, is not intimidating. Lapparent estimated that at this rate, it would take the waters 3,500,000 years to destroy the land. What will human engineering be like in three million years?

Strangely enough, even geologists have, in their speculations about "the last things," overlooked a very interesting fact. Since they have overlooked it—I mean in this connection—the reader will understand that the theme of this chapter must be taken with reserve. But the fact to which I draw attention is not in dispute. Certain limitations and reserves will be duly noted, but enough is known to suggest a very interesting aspect of the future of humanity on this globe. I refer to the Ice-Ages which have periodically chilled and devastated the earth; and the particular point I would discuss is whether we have any indications that a permanent Ice-Age may settle upon our planet long before the sun has reached the critical stage which is generally assigned by astronomers.

In the early part of the nineteenth century it was discovered—Goethe was one of the first to discover it—that Europe had, at no distant geological period, passed through an Ice-Age. In the latter part of the century it was found that there were traces of an earlier Ice-Age, which had followed the great Coal-Forests. There arose a crop of speculations as to the cause of Ice-Ages, and it was generally believed that certain eccentricities of the earth's orbital path around the sun led to recurrent Ice-Ages, at widely separated intervals. As time went on, further traces of periods of intense cold were discovered, but they corresponded neither with a theory of a wandering of the Polar circle nor any other form of the astronomical speculation. At the present moment we have admitted traces of five such periods of glaciation: including one which, as will be seen, has left few traces of glaciation, but was admittedly a period of severe cold following a long genial period. What I propose to show is that, although these Ice-Ages do not seem to be consistent with any astronomical theory of a recurrent period of cold, there is a certain rhythm in their occurrence which has not attracted the attention it deserves; and this feature is closely connected with the theme of my book.

For many years scientific men have treated with genial disdain those possibilities of premature disaster which I have already considered or will presently consider. The belief has become general that, barring accident, our planet will continue to be the home of man, or superman, until the fires of the sun sink to a certain degree of temperature; and this is not believed to threaten us until something more than ten million years have passed. The discovery of a heat-supply in radium has tended to lengthen the lease of planetary life in the mind of scientific men, and the end is put off indefinitely. But there is reason to wonder whether, long before the fires of the sun sink to the point in question, the earth may not pass into a permanent Ice-Age. This may not mean the end of the drama of terrestrial life, but it is, clearly, a point of some interest.

A general observation on the chronicle of the earth's climate may usefully be inserted here. The inexpert reader who at times glances at the literature of our geological experts may have noticed a certain sharp antagonism of sentiment. Not infrequently one reads that "the climate of the earth has always been much the same," yet the majority of geological works describe the earth lingering for ages in semi-tropical conditions which are now confined to its equatorial and adjoining regions. The chief reason for this clash of expressions is that there are two very different theories of the earth's origin. These will be described in a later chapter. Here they can be noticed only in so far as it is necessary to explain certain statements which may seem to be at variance with the contents of this chapter.

The Nebular Hypothesis, in its modern form, conceives the material of the earth to be part of the immense gaseous nebulae out of which, it supposes, our solar system was formed. It seems to be a consequence of this view that the early atmosphere of the earth was densely loaded with carbon dioxide ("carbonic acid gas"), and the luxuriance of the Coal-Forests is held to indicate this condition; just as the coldness of the earth in the next geological period indicates that the absorption of the gas by the dense forests thinned the atmosphere. But the rival hypothesis of the origin of the sun and the planets, the Planetesimal Hypothesis (to be explained later), does not imply more carbon dioxide in the primitive atmosphere than the early volcanoes would eject into it, and its followers read the geological record in a very different spirit. These contradictory expressions may seem to imply that there is grave uncertainty about the story of the earth's climate which I propose briefly to tell.

In point of fact, there is no uncertainty about the facts on which I rely, though it is very far from certain that they are *all* the facts, as I will eventually consider. There have been five Ice-Ages alternating with long periods of genial climate. I need not rely on the particular hypothesis of either school. It will be enough to quote the geological manual of a recent and able writer of the Planetesimal school, which is quite in accord with the splendid manual published by the leaders of the school, Professors Salisbury and Chamberlin. In his recent "Text-Book of Geology" (Part II, 1915) Professor Schuchert repeatedly observes that the climate of the earth has always been much the same, and in one place (p. 329) he explains that this means "warm mild climates, continuing for a very long time, separated from one another by cooler to cold climates of short duration." His language smacks of defiance to the geologists of the rival school, with which, he says, these facts are inconsistent, and it needs modification. But that the earlier periods between Ice-Ages were much longer and warmer than the later similar periods, neither he nor Professor Chamberlin, nor any other geologist, contests; and that is the fact on which I build. Indeed, in a later work, Professor Schuchert, we shall see, entirely confirms my position.

The evidence of former glacial action need not be described here. In the glaciated districts of Switzerland or Canada one sees to-day how the river of ice records itself. It brings down from the higher level and flings together blocks and pieces of stone which have fallen upon it from the rocks which overhang its passage. It scars and scours the hardest rocks as it flows over them, for a moderately thick glacier exerts a pressure of 500,000 pounds to the square yard on its rocky bed. It deposits mounds of fine and coarse rubbish, which has an unmistakable glacial character, in the valley where it melts. It gouges out large basins in the solid earth, which will become lakes when it retreats. By these imperishable signs we know the action of the glacier, no matter how ancient. Boulder stones, till (glacial rubbish), and scratched or grooved rocks tell, millions of years afterwards, of its passage. In Australia to-day snow and ice are known, in the depth of winter, in only two or three restricted localities. The nearest glacier is two thousand miles away. Yet I have seen in pretty gorges thirty miles from Melbourne the marks by which every geologist recognises the passage of a glacier; and in this case it must be about ten million years or more since a river of thick ice scarred the granite of the Werribee Gorge.

The geological scrutiny of the rocks is still very imperfect, but during two generations at least quite an army of investigators, scattered over the globe, have studied the texture and the comparative age of the rocks. The upper sections of rock, the compressed material which represents the millions of years during which life has been on earth, are now so well known that new discoveries can add only sub-sections to our scheme of classification. That scheme is, as is well-known, chronological. The rocks are arranged in the order of their formation in time, beginning, at the lower level, with the vast masses of igneous rock which represent great floods of lava poured out through and upon the comparatively thin crust of the early earth. For my purpose it is not necessary to give the whole scheme of classification, but it will be useful to give a scheme presenting the chief divisions of the geological scale according to their relative duration.

This can be done only roughly and tentatively. We estimate the duration of a geological period or era chiefly by the thickness of its rocks. The conditions being equal, it will take twice as much time to scour or deposit 50,000 feet of material from the land as to take 25,000 feet. But the conditions are *not* equal in the various periods. There have been periods of sluggish life followed by periods of mountain-rise and rapid denudation. The rocks, moreover, are by no means all composed of material scoured of the land; nor are they all formed at the same rate. In fine we are not at all sure that we have yet discovered the full thickness of the rocks of any particular period.

Yet something may be said to inspire a degree of interest in the suggestion I am making. As I am dealing only with large stretches of time, or what are called Eras, the inequality of conditions, and the gaps in the known record, will be equitably distributed over each Era. This is at all events true of the later Eras, and the fact that it is untrue of the earlier

Eras is of material consequence to my inquiry. The rocks of the earlier Eras are not only much less explored, and more difficult to explore, than the rocks of the later Eras, but, as will at once be realised, they have themselves been used up to a great extent in the making of the later rocks. A geological period lives to a great extent on its predecessors. The record of the earlier times is therefore not only imperfectly known, since those rocks are apt to be buried deepest, but it is itself a partially destroyed record; and the further we go back in geological time the more necessary it is to remember this.

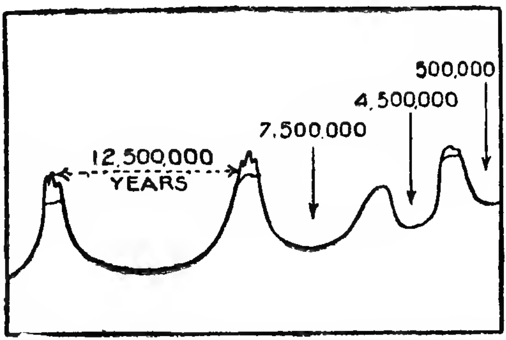
Other reserves must be made in estimating geological time from the thickness of the strata, but since I am concerned here only with the *comparative* length of the Eras, they need not be examined. I draw up a table (based chiefly on the data given by Professors Chamberlin, Salisbury, and Schuchert) of the later geological Eras, the known thickness of their rocks, an estimate of their duration, and the position of the Ice-Ages; and, in order to convey my point the more effectively, I roughly indicate the comparative lengths of the Eras, and recurrence of the Ice-Ages, by giving to each Era a space proportionate to its length:

Eras	Thickness	Duration	Cold Periods
Cenozoic	45,000 ft.	4,500,000 years	Pleistocene
Mesozoic	75,000 ft.	7,500,000 years	Cretaceous
Paleozoic	125,000 ft.	12,500,000 years	Permian Cambrian

The student of geology may notice that the estimate given for the first period differs considerably from that given by Sollas and Joly, and said to based on Chamberlin. I do not recognise in Chamberlin some of the data given by Sollas for the Cenozoic. Schuchert, the latest authority, gives 45,000 feet. I base the estimate of age on the widely accepted rate of one foot per century, and, since I am concerned only with *comparative* estimates, need not discuss its value. The current and conflicting estimates have much the same proportion. In his latest work (a chapter in *The Evolution of the Earth and its Inhabitants*, 1918, edited by Professor Lull for Yale Usnversity), Professor Schuchert fully confirms my estimate. His diagrams (pages 53 and 111) show the incidence of Ice-Ages (with one or two minor periods of chill) as I have described it, and he estimates the Cenozoic as 5 per cent. the Mesozoic as 12 per cent., and the Palaeozoic as 28 per cent. of the whole of geological time. He adds that the physicists, on radio-active estimates, give much the same proportion (4, 11, and 30 per cent), In examining this table the reader should bear in mind that the older record is farther from completeness than the more recent. Great gaps (or "unconformities"), which Professor Sollas takes to represent millions of years, occur in the Paleozoic Era. The Mesozoic record also is regarded as very, though less, imperfect. The Cenozoic record is regarded as much nearer completeness. In other words the interval between the Cambrain or Proterozoic and the Permian Ice-Ages may yet be very considerably extended: the interval between the Permian Ice-Age and the Cretaceous chill somewhat less, but greatly, extended: while the interval between the Creaceous chill and the last, or Pleistocene, Ice-Age is less liable to be enlarged. The suggestiveness of these admitted facts leaps to the eye, as the French say. Ice-Ages are, apparently, coming upon the earth at intervals which lessen by about fifty per cent at each recurrence.

The earlier geological Eras and the one known earlier Ice-Age I have not represented in the table. The "Huronian" Ice-Age occurs about the beginning of the Proterozoic Era, the length of which no geologist cares to estimate. Earlier still was the Archeozoic Era, a vast and dim age, usually said to be, probably, as long as all the subsequent Eras put together. In these Eras even relative chronology becomes too difficult to attempt. The relation of the four later periods of cold suffices for my purpose.

This suggestion is enforced when we reflect that, apart from Ice-Ages, the general climate of the earth has grown steadily cooler. Of the climate during the earlier Eras we know nothing, but the animal-life and the Coal-Forests of the Paleozoic indicate at that time a warm climate from Pole to Pole. In the succeeding Era the plants of the Coal-Forests could live no longer, but the earth still enjoyed a genial climate from Pole to Pole. There was no winter : there were no zones of climate : there were no polar caps. With the Cretaceous chill winter set in as a permanent institution, as the rise of our deciduous trees tells, and the earth soon began to grow colder at the poles. Since the last Ice-Age we have permanent ice-sheets at the Poles, broad temperate latitudes, and marked changes of seasons. We may therefore represent the general evolution of the Earth's temperature in some such way as in the following diagram, in which the Proterozoic Ice-Age and a few minor local chills are omitted. The three peaks are definite Ice-Ages : the blunted elevation is the very pronounced and considerable chill (with some glaciation) of the Cretaceous Period. But a further explanation of this singular development must be given before we proceed.



Variations of Climate in Past Time.

A much more precise and valuable diagram is as I said, given in Dr. Lull's recent *Evolution of the Earth*, but I had used the above diagram for several years in lectures before 1918. It more accurately conveys the general fall of temperature.

The Archæozoic and Proterozoic Eras we must dismiss briefly. The vast and unknown thickness of the rocks which represent them shows that they make up at least half the earth's geological record, possibly much more than half; and the enormous proportion of igneous rock tells us that the Earth was in a very unsettled condition, In the midst of this chaotic period a great Ice-Age occurred. In Canada there have been found immense glacial deposits which seem to indicate that an Ice-Age as great as, or even greater than, the last glacial period, then spread its mantle over the American continent. As it is useless to attempt any time-estimates for this early age, I will be content to notice that the American geologists speak of a vast rise of mountains before the Ice-Age occurred.

The next Ice-Age is plainly indicated by glacial beds discovered in South Australia, Tasmania, Norway, China, India, and South-East Africa. These scattered traces seem to show that a great ice-sheet spread over an immense area, the greater part of which is now below the waves. The glacial beds belong to the Lower Cambrian, or the series immediately preceding it. For my purpose it is enough to note that a great Ice-Age occurred at the time which we assign as the limit of the Proterozoic and the Palæozoic Eras.

And it is undoubted that this period of cold was followed by millions of years of a warm, winterless climate, Life now crept from the oceans to the land, and the vegetation at least gives us fair indications of the climate. Forests, rising in the Devonian Period and culminating in the Carboniferous, covered the Earth with such a growth of timber and ferns as it has never borne since. They, it is agreed, indicate a warm climate, and their spread from Spitzbergen to the Antarctic shows that the climate was uniform. The majority of geologists prefer to put it that the climate, which spread from Pole to Pole for millions of years, was "hot moist, muggy;" but there are certain deposits of salt which indicate areas or phases of dryness. These, however, imply heat rather than cold, and they do not conflict with my point. After the Cambrian Ice-Age the Earth enjoyed, for some millions of years, a hot and perpetual summer.

This was closed by the Permian Ice-Age. Glacial beds and markings in Australia, India, and South Africa, and a gradual and entire change in the nature of the fossil organisms, show that an ice-sheet spread over and between these regions, covering several million square miles of the Earth's surface. In fact, glacial beds of this age are now claimed in South and

North America, England, and Germany. There was a terrific destruction of the old warm-loving plants and animals, and life moved on to a higher level.

But it is further undoubted that, after its prolonged chill, which may have lasted hundreds of thousands of years, the Earth returned to a perpetual summer. The characteristic trees and great insects and amphibians of the Coal-Forests spread over the earth no longer. The climate seems to have been less warm and moist. But there were still no trees which shed their leaves once a year, and reptiles—whose indifference to their eggs and young demands a hot climate—wandered over Central Europe and the north of the United States.

This period was, whatever its actual length in millions of years may have been, little more than half the length of the preceding period. It closed in the Chalk Period, when the reptiles were slain or driven south, and deciduous trees—trees which shed their leaves in the winter-time—made their first appearance. This phase of cold does not seem to have been so acute as the earlier Ice-Ages, and I have in my diagram represented it accordingly. There are traces of glaciers of the period in Colorado, and others are claimed in Bavaria, but one can hardly speak of an Ice-Age. That there was a period of great and general chill, however, it is impossible to question. There was a considerable rise of mountain-ranges and the aspect of life on the earth was transformed. The warm-blooded and warm-coated mammals and birds spread prodigiously: the deciduous trees conquered the Earth.

Yet the general climate again returned to a more genial height than it enjoys to-day. The palm, bamboo, and magnolia flourished in Greenland. Monkeys overran England, and large man-like apes lived in France. But warm-loving plants and animals gradually retreated southward, and the period did not last half as long as its predecessor. Our Rocky Mountains and Andes, our Alps and Atlas and Himalaya, were rising, and the temperature fell steadily. The period closed with an Ice-Age, which covered about seven million square miles of the northern hemisphere with permanent ice and snow, and sent rivers of ice down from most of the great mountain-ranges of the Earth. Four or five times at least the ice-sheet spread from the northern mountains, with intervals of milder climate. The whole period may have lasted hundreds of thousands of years.

I have discussed elsewhere the question of

FOSSIL-LEAF FROM SPITZBERGEN OF A WARM-ZONE PLANT.

HALLEY'S COMET, 29th May, 1910.
Photo. by Barnard at the Yerkes Observatory.
(*See p.* 67.)

[*Face p.* 57

the cause of Ice-Ages, and will say here only that I believe the periodic rise of mountain-chains to be the fundamental and predominant cause.* Whatever the cause may be, the facts which I have briefly summarised are interesting. The Earth is assuredly growing colder. Winter set in—on current geological estimates—between three and five million years ago. The chilling of the Polar circles began between one and two million years ago. We have for the first time a great area of the Earth at sea-level (apart from the discharge of glaciers) permanently glaciated. And it is scarcely possible to doubt that Ice-Ages occur at much shorter periods as the Earth grows older. Whatever corrections geological research may bring in the future, it is unthinkable that they should alter the relative lengths of the Palæozoic, Mesozoic, and Cenozoic Eras. We may therefore be fairly confident that the four Ice-Ages with which I am concerned succeeded each other at intervals decreasing by more than forty per cent. in each case.

*The diagrams of Professor Schurchert, to which I have referred on p. 49 ; prove this. They show an almost perfect co-incidence of Ice-Ages and rise of land.

If there is a permanent principle at the base of this phenomenon, it is obvious that the Earth will endure a permanent Ice-Age long before the millions of years of which astronomers speak are run out. Unfortunately the geological estimates of time are still so conflicting that it is useless to attempt to predict the time when this condition may be reached, supposing that the progression is maintained.

Opinions differ to-day as widely as they did twenty years ago. In the last generation geologists, calculating the rate of formation of the rocks, were disposed to claim a hundred million years at least. Biologists, vaguely estimating the ages that were needed for the development of life, were inclined to demand hundreds of millions of years. But physicists, estimating the age of the sun from its expenditure of energy, would not allow more than 25 million years since the earth was a molten globe.

In the course of the last twenty years geologists and biologists have generally moderated their demands, and there was a pretty widespread belief that from fifty to seventy million years might suffice. This was confirmed by a calculation of the time it has aken to impregnate the ocean (which was originally fresh) with its salts. But the whole prospect of something like agreement has now been disturbed. First Sir G. Darwin found very large support for his theory of the origin of the moon, according to which it may be a thousand million years since the moon was born of the earth. Then the discovery of radio-active elements, releasing immense energy from within their own atoms, was said to destroy the whole foundation of Lord Kelvin's calculation. Recently Dr. Jeffreys has put forward (*Nature*, vol. 101, pp. 447-9) a theory of the origin of our solar system which gives it an age of 3,000,000,000 years.

There are, it is true, eminent astronomers who slight these developments, but the study of the radio-active elements had more to say. It is claimed that the age of our radio-active minerals can be estimated, and we are told to return to the idea of hundreds, if not thousands, of millions of years! Strutt, one of the most esteemed authorities, calculates that the minerals of some of the older strata have an age of 710,000,000 years, and this is not the beginning of terrestrial time. Others claimed for the same minerals an age of 1000 to 1600 million years.

I am not at all concerned to specify even an approximate date for the end of the world, and am content to relate that scientific men are in a very undecided frame of mind on these material points. There are, for instance, able geologists who will not admit more than two million years since the Eocene Period, yet Strutt assigns an age of 31,000,000 years to minerals of that period. One's faith in the latter calculation is somewhat strained when one reflects that it would give man himself a life, up to the present date, of something more than ten million years! For man is now known to have been fully developed in the Pliocene Period, and he must, as Professor Keith shows, go back to the Miocene or earlier. Professor Schuchert, while accepting the radio-active method, thinks the estimates should be cut down by fifty per cent.

Professor Joly states that an application of the radio-active method to uranium found in very ancient rocks gave results lying between the extreme of 20 and 400 million years. The method seems to be precarious, and perhaps one does better to cling, provisionally, to the geological estimates. These, as I said, are far from concordant. But the most authoritative estimates now, as a rule, range between 80 and 100 million years, and are more favourable to the former. On this estimate of 80,000,000 years for the sedimentary rocks, we must allow a period of about five million years between the Cretaceous chill and the last Ice-Age; and if the rate of progress of the Ice-Ages is maintained as in the past, if the intervals between them diminish by about forty or fifty per cent, the earth ought, some five or six million years hence, to fall into the grip of a permanent Ice-Age. It must be remembered that these cold periods are very protracted, probably extending over hundreds of thousands of years, and short intervals between them would be mere interglacial episodes.

But I will not be tempted to enlarge upon a vision of mankind crowding into a shrinking equatorial belt, nor is it necessary to observe that, even if the earth becomes wholly glaciated, this will not necessarily mean the end of the human drama. A great synthetic chemist, Berthelot, believed that the twentieth century would inaugurate the change from natural to artificial food. At least we may be sure that the men of some millions of years hence will not laboriously breed cattle and grow corn in in order to secure the few daily grains of carbon, nitrogen, etc. that they need.

These, however, are matters for the scientific story-writer. I am anxious that the reader should grasp the limitations and uncertainties of the calculation. To demand a positive result in such matters is to invite deception. We are far from agreed as to the rate of formation of the rocks, on which the estimate of the duration of geological Eras is based, and our knowledge of their thickness is incomplete. On the other hand, as I said, the later record, which is more to my purpose, is the better known, and fresh discoveries ought not materially to alter the relative lengths of the Eras. It may be added that we are not at all likely to discover in the later record further Ice-Ages which would disturb the scheme I have set forth. Such discoveries do not depend merely on the chance finding of scratched rocks and beds of glacial rubbish. Ice-Ages eat into the living population of the earth as profoundly as they eat into the rocks, and the record of life on land since the Devonian Period is now very well known. It shows three of these "revolutions" only, and they coincide with the known traces of glaciation.

The suggestion is therefore much more than a fanciful interpretation of a few scattered facts. The earth is growing colder. In the present age it may actually be growing warmer, and there is some evidence of the shrinking of our glaciers and ice sheets. This is because we are still in the penumbra of the last Ice-Age, which some would bring down to about twenty or thirty thousand years ago. But if we use the great standard of geological time, the Earth is growing colder, though we do not yet know the reason. There is ground to think that it will be locked in a permanent Ice-Age long before the millions of years promised by the astronomer, and the tens of millions of years vaguely suggested by the new physics, come to their appointed term.

CHAPTER IV

THE CHANCES OF COLLISION

In the last two chapters we seem to have exhausted the possibilities of what we may call the premature death of our world from disease. There is, in reality, a further suggestion, of recent appearance. Here and there, in the preceding chapters we have found the speculations of modern physicists, based upon the discovery of radio-active bodies, crossing the lines of the other sciences. Now we have a new development of this very intererresting vein of research. It is suggested that the enormous and increasing pressure of the crust of the earth upon the contents of the globe may lead to so appalling an explosion that our planet would be shattered.

This must not be confused with the volcanic theory which we have already discussed. The idea is not that the compressed matter of the earth may some day revolt and tear the confining crust of rock. It is that the colossal energy which we now know to be imprisoned in the atoms of the heavier elements may be so hampered in its liberation that it may seek release in a terrific explosion. The energy of these minute atomic systems is, as we know, stupendous, and if there are large quantities of such metals as uranium imprisoned under the thickening and contracting crust, there seems to be ground for such a speculation.

But the basis of this speculation is doubly insecure, and I will not enlarge upon it. We do not know what proportion of these substances there may be in the interior of our globe, and we do not know that they would explode under pressure, or under what pressure. The idea was primarily put forward as a purely conjectural explanation of certain outbursts seen in stars, which we will consider later. It was then suggested that possibly a similar explosion might at some stage shatter the Earth; and the myriads of fragments which make up the rings of the planet Saturn, which some take to be the debris of a shattered satellite, and others (the majority) take to be material that has failed to make a globe, was held to give the speculation some sort of basis. It is not without interest, and I may return to it later. The catastrophe is generally imagined as likely to occur long after man has left this planet, and we need not consider it among the suggestions of premature disaster.

We have, in sum, no serious ground to fear such disaster from a study of the constitution of our globe. It becomes more stable as it grows older. The worst that we can anticipate is that the inevitable chilling of its surface may come earlier than is generally believed. That would not, for reasons which I will develop presently, mean the end of life on Earth, and we may turn to the second section of our inquiry. How far is it likely, or possible, that our world may come to a premature end by violent accident in the streets of space?

In this connection one naturally considers first the ancient fear of a comet. The idea of our incurring any disaster by an encounter with one of these unsubstantial monsters has not, in fact, yet entirely disappeared. When the last conspicuous comet, Halley's Comet, spread its ghostly tail across our skies in 1910, the nervousness was not confined to Russian peasants and uneducated negroes. There was some drawing of curtains even in enlightened Chicago and other cities. The astronomer complains that the popular writer is responsible for this revival of a mediæval superstition. We have discovered cyanogen in the tails of comets, and the theory which caused some flutter of modern nerves in 1910 was that, as we passed through the tail of the comet, some quality of this deadly substance might enter into and impregnate our atmosphere.

In point of fact, more than one astronomer has given colour to this apprehension. M. Flammarion in his scientific romance, "La Fin du Monde," imagines our Earth sustaining a very grievous disaster by passing through the tail of a comet. Mr. H. G. Wells may be presumed to have based his story, "In the Days of the Comet," on the less sober work of the French astronomer; but while he makes the gases of the comet's tail play a most beneficent part in the economy of human life, M. Flammarion imagines them destroying or driving insane the greater part of the human race. Indeed, I happened to be in Sydney at the time of the last visit to Halley's comet, and I saw that in the journals of that liberal city a scientific official—not of the Sydney Observatory, I hasten to add—warned his townsmen to remain indoors, discreetly screened, on the day on which, it was calculated, we should pass through the tail.

The overwhelming majority of astronomers, however, now treat the comet, from this point of view, with genial disdain. We have no more reason to fear a passage through the tail of a comet, than a locomotive has to fear an encounter with a trail of smoke; and an encounter with the "head" of a comet is probably something to be desired. A consideration of this change of attitude will introduce us, along a fresh avenue, to the modern astronomical view of the cosmos.

In the Middle Ages comets were vaguely conceived by the learned men as a collection of noxious vapours which arose from the Earth and gathered in the "upper air." The popular fear that the monster shook pestilence from its "hair" thus had a "scientific" foundation. Some of the mediæval scholars went further, and they have left us drawings of the dire and terrible details (bloody heads, daggers, etc.) which, even before the telescope was invented, they descried in the heads of comets. With the progress of science, and of the common sense habit of checking such beliefs statistically, the comet lost its terrors. The "head" was, however, still conceived to be an immense solid mass, with which it would be dangerous to collide. Buffon imagined the rush of a comet through the outer layers of the sun to have torn off and cast into space enough material to form the Earth.

The astronomer of the nineteenth century put the comet definitively into its place. There then came into use a mathematical process by which the man of science could weigh the various members of our solar family, and, when the comet was put into the balance, it was found that, so to say, it would not turn the scale. It was therefore certainly less than a million tons in weight, while the earth itself weighed some 6000 million billion tons. A solid ball weighing some hundreds of thousands of tons could, however, cause prodigious damage to the earth by colliding with it at the speed at which heavenly bodies commonly travel, and the next step was to render the mass innocuous. The tail, it was soon perceived, was the thinnest of phantasms. Stars shine through thousands of miles of thickness of the silvery stuff, as it stretches across the heavens. But the luminous mass of the "head," which may be more than a hundred thousand miles in diameter, long eluded the astronomer.

We do not positively know to-day the nature of the head of a comet, but the accepted theory has received no check during a half century of careful study of comets, and it is regarded with confidence. The "shooting star" gave the clue. What had been called "empty space' was, it was realised, largely filled, within our solar system at least, by small material bodies in enormous numbers. The larger of these are, when they enter our atmosphere at a prodigious speed—the actual speed is much disputed—rendered incandescent and generally reduced to ash. At one hundred and twenty miles above the surface of the Earth they begin, although the air is at that height millions of times thinner than at sea-level, to feel the resistance. The air is compressed in front of them, and, as it grows denser, the energy of their motion is converted into heat, and they become white-hot. The larger meteors may explode, or may even in their entirety (less the melted quantity) reach the earth. Masses of iron weighing many tons have reached us in this way. There is, in fact, at the Devil's Canyon in Arizona a crater three quarters of a mile in diameter, and more than four hundred feet deep, which there is some reason to regard as the result of the impact of a large meteor.

These are but the larger representatives of an invisible army that assails our globe day after day. The telescope and the photographic plate discover smaller masses burning up in our atmosphere, and it is believed that the size may run down to the smallest grains. There is naturally much difference of opinion as to the number of these particles or blocks of iron or stone that our atmospheric net captures daily. The figure is usually represented as something between twenty and a hundred millions a day; Sir Norman Lockyer puts the total at 400 millions, and Professor See, on the basis of his own observation, at 1200 millions. On any hypothesis the number travelling within the limits of our solar system must be prodigious.

Where the meteors come from is, by the way, a matter of interesting speculation in modern astronomy. Sir Robert Ball long ago suggested that they may have been fired from the extinct artillery of the moon, which seems hardly adequate. Some look to Jupiter for their origin. Other believe that they represent the first crystallisation into matter of those tinier particles of which the atoms of the elements are believed to be composed. In recent years their composition has been carefully investigated, and it is found that, besides twenty of our metals, they contain much hydrogen gas. The idea has therefore been suggested that they are fragments torn off the surface of our sun in "an earlier stage of its existence": a stage when it was a dead star with a solid crust. This speculation is, however, connected with the Planetesimal Theory, which will be noticed later.

We must not imagine space teeming with these blocks and particles of matter, as the light even of the nearer stars would in that case be very conspicuously affected. The gravitation of our earth causes some concentration of them in our neighbourhood. We are, however, acquainted with enormous swarms of them, travelling together through space, and these swarms bring us back to the comet. Several small comets which came under the notice of astronomers during the nineteenth century, and were known to have definite orbits, did not reappear at the calculated time. But there was very good reason to believe that certain swarms of meteors which appeared represented the remains of the lost comets. This strongly confirmed the belief, already held on theoretical grounds, that the nucleus, or denser and brighter part of the head of a comet, consists of a large swarm of meteors, sometimes hundreds or thousands of miles across.

The spectroscope cannot be said to have established this, though its results are in accordance with the theory, and no doubt is now entertained that it is the correct interpretation of the head of a comet. There are, however, still great difficulties and obscurities about comets. They partly reflect the light of the sun, but they also emit a light of their own, by which we recognise in them some of our familiar elements. This suggests that collisions of the component meteors are frequent enough to raise a large proportion of them to a white-heat. The swarm expands as it approaches the sun, but the speed rises higher and higher until the comet rushes past the great globe, or even passes through its outer atmosphere, at a rate, sometimes, of three or four hundred miles a second.

The tail offers further difficulties to the astronomers. The older idea, that it consisted of incandescent vapours which arose from the incandescent bodies in the "head," had, on reflection, to be modified. The comet of 1811 had a tail 100,000,000 miles long, and 15,000,000 miles in width, although it never came within the sphere of the Earth's orbit. The tail of the great comet of 1843 was estimated to be about 300,000,000 miles in length. As these enormous tracts of matter are in a state of the utmost conceivable rarity—one mathematician calculates that they are 45,000 billion times less dense than air—it is impossible to regard them as shining by white heat. That the matter of the tail is shot out from the head we have no doubt. Not only does the tail grow as the object approaches the sun, but the spectroscope now shows the stuff being actually driven along the tail. It leaves the head at about 5 miles a second, and soon increases up to about 50 or 60 miles a second. And since the tail is almost always directed away from the sun, it is plain that the driving force is in the sun. Many astronomers hold that the pressure of light itself suffices, but this can be exerted only on particles which are larger than the length of a light-wave (the 40,000th to the 80,000th of an inch), and electric or some unknown action is postulated.

In sum, the tail is generally regarded as a mixed mass of vapour and meteoric dust, driven outward by the terrific stream of energy from the sun. Its luminousness is not well understood, and is vaguely attributed to electrical action. The difference in form of the tails—which are sometimes straight and streaky, at others curved, and at others short and brush-like—is believed to be due to the proportion of the sun's repulsive action to the gravitational control of the comet. Some astronomers think that different chemical elements may be affected differently.

But I am not concerned with all the unsolved problems of the comet. The head of the comet is a large loose collection of meteors, large or small, surrounded by incandescent gas; and the only effect of our colliding with one would be to give us a shower of shooting stars. In fact, the chances of such a collision are very remote. The larger comets only approach the sun once in hundreds, if not thousands, of years, and the few that are known to cross the Earth's path round the sun have little chance of being there at the precise moment when we traverse that particular section of our orbit. It is said that if two of the tiny balloons, with which children play, were sent up in different parts of Russia, the chance of their coming into collision is a fair expression of the chances of our encountering the head of a comet.

Since the tail stretches millions of miles across the solar system we are more likely to pass through it. It is, in fact, claimed that we passed through the tails of the comets of 1819, 1861, and 1910. The earlier are now beyond the range of definite research, and astronomers are not agreed whether or no we passed through the tail of Halley's Comet in 1910. Professor Barnard maintained that the Earth did, about May 19th, 1910, pass through a faint duplicate or branch of the tail which was generally overlooked, and that certain unusual phenomena in the clouds at that time were due to the encounter. Sir Robert Ball used to say that he searched the records of the earlier encounters, and found only that a certain clergyman had to light a candle because the day was to some extent dimmed. These are the only claims of positive action of a comet upon the Earth, and the ancient fear may now be entirely discarded.

But while the fear of collision with a comet has thus been expelled from educated nations, collisions of a very much graver nature have been seriously discussed amongst men of science. It was not unnatural that, when it was discovered that the stars were vast globes moving through space at so many miles a second, the question of the possibility of collisions should be opened. The immense wilderness of empty space that surrounds our solar system at once promised us at least a very long immunity from the fear of such a catastrophe, but phenomena were observed in remote parts of the heavens, which many astronomers believed to be the actual outcome of collisions. Obscure stars were, as we shall see later, observed to blaze up with so sudden and vast a conflagration that the idea of a collision was strongly suggested. We shall see that other explanations of these phenomena are now more readily entertained, but there are astronomers who still believe that the very close approach, or partial ("grazing") collision, of two stars is probably the correct interpretation. Indeed, as I have already hinted in speaking of the origin of meteors, the Planetesimal Hypothesis, which has many supporters, supposes that our sun had such an experience, at the close of a former life, and was torn open, to begin its luminous career afresh, by the too close approach of a neighbour. There is an increasing disposition amongst astronomers to admit this possibility.

It is therefore interesting to discuss the contingency of collisions as it is viewed in modern astronomy. In considering this point we pass from our particular globe to the central orb of our system. We begin to use a cosmic scale. No collision is possible within the limits of our solar family. The various planets found their paths round the sun in the remote past. On theoretical grounds we suppose that there were originally a great many minor globes circling round the sun, at different speeds and at unsafe distances relative to each other. An anarchy of this description would be slowly reduced to order by, as in biology, a struggle for existence and survival of the fittest. The larger globes would absorb the smaller and settle down in permanent orbits, travelling at a speed adjusted to their mass and distance from the sun. We are apt to imagine this a wonderful arrangement until we reflect that, if they did not follow such paths, they would not be here at all. They would long ago have been destroyed. It is hardly remarkable that the survivors of a struggle are the best fitted to survive.

Thus harmony has been obtained within our solar system by the elimination of the discordant. Whether there is in space some medium that subtly resists the movements of the planets, and may ultimately disturb their progress and destroy them, may be briefly considered later. Those who are inclined to think so put the catastrophe long after what we are calling for the moment the end of the world : the cessation of life. We have, at present, to take our solar system as a unit, and ask if it is likely to experience a disastrous collision. We may, in fact, now confine our attention to the sun, for any grave disaster to the parent globe would immediately fall upon the whole planetary family.

Now it may be said at once that the possibility of our sun having a dangerous encounter with another sun within the period in which life may remain on this planet seems to be faint. It will be well to make this plain, however, as the explanation will serve as a basis for a wider consideration of such contingencies in a later chapter.

Years ago, in a seminary, I had a professor of philosophy whose knowledge of science would more properly have adorned an infant-school. A pupil one day asked him the distance of the moon, and he answered briskly (in the year 1885): "We do not know—for the simple reason that no one has been there." He might at least have known that surveyors are daily measuring the distance of objects without a measuring tape, and the same principle can be used in astronomy. If you can shift your point of observation, and if the object observed is then displaced against a more distant background, you have the material for a mathematical determination. I am, of course, simplifying the principle as far as possible. The essential part of it is the displacement of the distant object against a practically motionless background.

We have a very broad base for the observation of the stars. In six months' time the Earth will be 185,000,000 miles away from where it is when I write this. It will be at the other side of its path round the sun. Observed or photographed from two points so wide apart, the nearer stars show the required fraction of displacement, and the mathematician calculates the width of the angle of vision and the distance of the star. Thus the nearest star is known to be certainly between 24 and 26 billion miles away. We put it at 25 billion miles. Lately another star in the same constellation, the Centaur, is found to be about the same distance. The next nearest is 40 billion miles away.

Thus we have an enormous space, 80 billion miles in diameter, 240 billion miles in circumference, which contains only four stars. The chances of a collision between stars scattered over such a vast wilderness are seen at once to be infinitesimal. If we reduce the scale, and suppose each star to be a balloon one foot in diameter, we shall have four of these one-foot balloons driving across (not wandering erratically in) an area nearly fifty thousand miles across; not a superficial area, but a cube of space measuring so much in each direction. Collisions are almost unthinkable. If we study the directions of these four stars we come to the same conclusion. The nearest star is coming toward us at forty miles a second. At this rate it will take about 20,000 years to reach this part of the universe; but our sun is moving in a different direction, toward the Constellation Lyra, at 18 miles a second, and it will therefore be many billions of miles away when a Centauri arrives.

If we enlarge our field, and consider a much vaster group of stars, we find no greater cause for apprehension. The system of stars to which our sun belongs is, as I said, believed to have a large central cluster, round which, across some interval of thinner space, is the great ring (or spiral streams) of stars that form the Milky Way. It has lately been calculated—one must take the figure with reserve—that the central cluster is about 3000 billion miles across and 1500 billion miles in depth. Within this cluster the stars move at an average speed of about 20 miles a second, and are separated from each other by an average distance of (as far as we have determined) about fifty billion miles. In other words, as far as our knowledge goes, the average distance between the stars is about fifty million times the average diameter of each.

To state, however, that the average motion of the stars is rather more than 20 miles a second is misleading. A few of the stars travel at ten times this speed, and these would rush from end to end of our cluster in half a million years. The speed of the stars seems to increase as they grow older, as we shall see later. Moreover, some of these stars seem to qe of a monstrous type, and this increases their dangerousness. Arcturus, one of the fast travelling stars, must be at least 600 billion miles away. Its brightness at that distance—and the distance is probably greater—means that it emits hnndreds of times as much light as our sun; and since the spectroscope does not suggest that it has a much higher temperature, it is considered by many that Arcturus must have ten times the diameter, or 1000 times the volume, of our sun. Aldebaran is of the same order. Canopus is calculated (by Walkey) to give out at least 50,000 times as much light as our sun, and, since it is little different in type, it is believed to be an enormous star. Pickering calculated that Rigel is equal in light-power to 2,000,000 suns.

These larger figures must be taken with a certain reserve. They represent attempts to each beyond the range of our positive knowledge. Since no star presents a disk, even in photographs taken with our largest telescopes, its size cannot be directly ascertained. Indirectly, the size and weight of many stars have been found. When, as is common, two stars form a close and physically connected system, the diameter and mass of each can often be estimated. Our sun is not below the average, as far as these exact determinations go, but some suns are known to be many times as large. But we have further found that a star may be considerably more brilliant without being more massive, and we must be careful not to deduce the size of a star from the amount of light it pours out. Sirius, the brightest star, is nearly fifty times as luminous as the sun, yet only twice as massive. A star may be at a very much higher temperature than the sun, so that (on account of its expansion) it may have a very much larger and more intensely luminous surface, yet not a greater weight, than the sun.

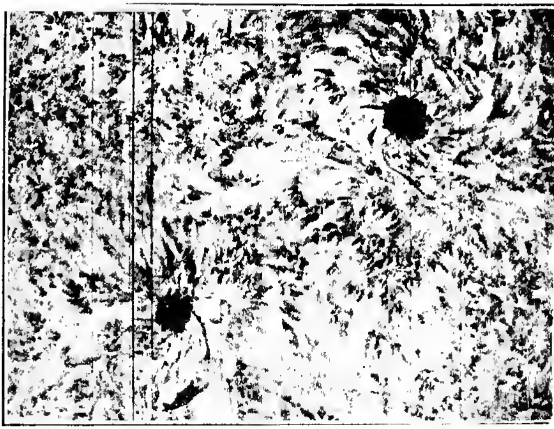
When, however, we have made all these allowances, the extraordinary brilliance of such very distant stars as Arcturus, Rigel, Aldebaran, and Canopus seems to imply that they are giant suns. Such suns would not need to approach very close to another sun in order to bring about its destruction. As a rule, massive as the stars are, they do not individually affect each other. The distance reduces their gravitation to a feeble influence. It is calculated that they must approach within a thousandth part of their average distance before they begin to disturb each other; and the approach need be less in the case of the larger stars.

Thus the chances of disaster are not confined to the contingency of a point-blank collision of two stars, which is regarded as very improbable. Not only are the stars scattered over enormous distances but their movements are presumably controlled by the whole stellar community, and may be more or less harmoniously adjusted. On this point, however, we are very imperfectly informed, and we cannot say whether or no stars may approach each other within dangerous limits. If they do, the tidal influence on each other of such vast bodies will be enough to tear open the crust that confines their molten interior, and this would mean the destruction of any planetary life in their vicinity. There are, as I said, certain outbursts observed in the heavens at times which some interpret in this way. A star, they say, has grazed or too closely approached, another star. Many astronomers now hold the theory that our planets are actually formed out of material flung from the sun, in great spiral tracks, owing to such an encounter ages ago. The whole question is in a very speculative condition, and we may be content with the reflection that if our sun has travelled through space for millions of years without meeting such a disaster, its good fortune will continue as long as man needs it.

The subject is, however, not complete without a glance at another possibility that has recently been suggested. Those stellar conflagrations ("new stars") to which I have just alluded, and will discuss more fully in a later chapter, are regarded by many astronomers as due, not to an encounter of star with star, but to the rush of a star into some resisting medium. May not a star, in its swift career, enter a nebula? And would it be burned up as a meteor is when it enters our atmosphere?

Of the possibility of our sun rushing into a nebula we can say even less than we said about star-encounters. We do not positively know the distance of any nebula, which means that they are very remote. Some of them, on the other hand, travel very rapidly, and many of them spread for billions of miles over space. What the likelihood or unlikelihood is of a star entering one of these tracts of the sky we cannot say, nor have we as yet realised to what extent their gauzy nets are drawn across the path of the stars. Our knowledge of them grows remarkably with the power or delicacy of our instruments. Of recent years it is generally accepted that there are "dark nebulae," as well as the luminous clouds that have been known for a century, and this extends the range of possibilities. Since we see such nebulae only when they dim or blot the light of the stars, we have no idea of their real extent.

The effect upon a star of entering one of these vast tracks of thin matter at twenty miles a second would depend upon the density of the nebulæ. Professor Arrhenius estimates that the nebulous stuff, as such, is too attenuated to raise a star to white heat, but he, of course, admits that there are varying degrees of density in the nebula, and that probably much solid matter has been caught in it. The nebulæ spread like great nets over space, and they must catch a good deal of the loose matter that floats about space. Astronomers generally think that to rush into one of these great aggregations of matter would be fatal to a star. The resistance of the medium, in such cases, converts the immense energy of the star's



SUN-SPOTS HAVING OPPOSITE POLARITY.

Photographed at the Mt. Wilson Solar Observatory with the Spectroheliograph (Hale).

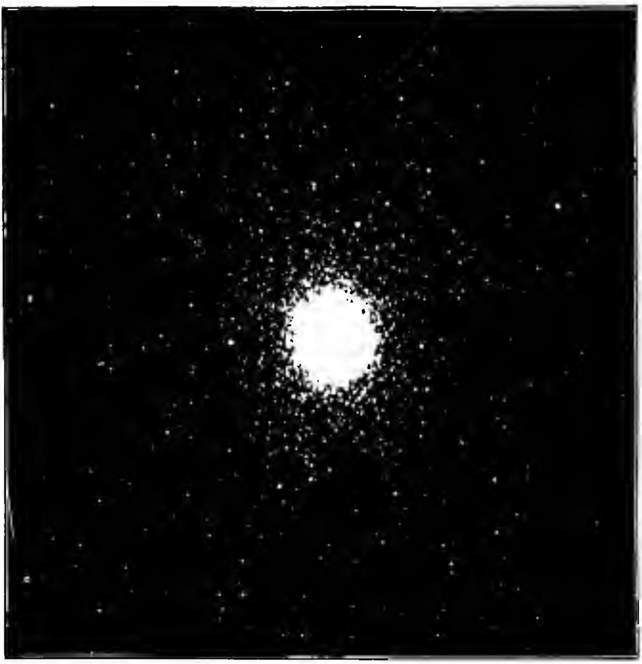
(*See p.* 106.)

SOLAR SPECTRUM (*see p.* 98).

Left: A BRIGHT NEBULA (in Cygnus). *Right:* A DARK PATCH, Probably due to a Dark Nebula.

Photo. by Barnard at the Yerkes Observatory.

[*Face p.* 86.



STAR-CLUSTER IN THE CENTAUR (*see p. 81*).

[*Face p.* 87.

motion into heat; and one need not reflect long to appreciate the energy that is employed in driving a trillion tons of matter through space at twenty miles a second. The star, if previously dead and bound by a rocky crust, will be raised to white heat once more, and may be again reduced to a gaseous mass, or a nebula. But, as I said, what the chances are of our star rushing into one of these tracts of matter and suffering disaster no man can say.

This speculation has led us out to the dim confines of our actual knowledge. But the suggestions I have considered are, it must be realised, taken from the living masters of astronomical science. It is a dull or timid type of mind that is interested only in such determined facts as the diameter of the sun or the distance of the nearest star. One follows with acute interest these trained and informed imaginations in their endeavours to extract large and luminous truths from the scattered data; and one is, of course, prepared to retire with them when the theory or conjecture is found to be inconsistent with new discoveries. Even in the last few pages, however, I have mainly relied on a groundwork of ascertained facts, and have only briefly followed some adventurous astronomer here and there in order that the reader may know what our experts think, as well as what they know, on the issue I am discussing.

CHAPTER V

THE DYING OF THE SUN

THE preceding chapters exhaust the first part of my inquiry. We find no malady of the Earth which threatens to put a premature end to the life on its surface, and we confine the possibilities, or certainly the probabilities, of accident within such narrow limits that we are not disturbed. We therefore turn with great interest to the second part of the inquiry. What will be the manner of the natural death of our world? And what, in the present condition of science, can we say about the question of time?

To the first question we can give a generally satisfactory answer. Life is remarkably adaptable. The story of biological evolution is a marvellous record of the successful adaptation of life to new conditions. Fishes have passed from the shallows of the ocean into abysses where they lightly sustain appalling pressures, and where the light must be provided by some illuminating machinery on the surface of their own bodies. Animals have passed from the water to the land, from the land to the air. Plants and animals have been fitted to sustain glacial climates after millions of years of drowsy warmth, and have met the conditions of existence in waterless deserts. Yet even the student of biology who surveys these remarkable adaptations to new conditions will say that the story of life on Earth will end when the radiation from the sun sinks below a certain measure. The light of the sun will assuredly not be indispensable to the men of millions of years hence, if it is indispensable to us, but its heat is essential. The great enemy that hovers about the Earth is the absolute cold of space; a cold estimated to be at least two hundred degrees lower than the most intense cold of the Arctic or Antarctic regions. The fiery stream of the sun, nursed and diffused by our atmosphere, keeps this enemy at bay. As the stream ebbs, the fatal cold will draw nearer, and it will ultimately prevail.

Even the most punctilious astronomer of our time will not affect to doubt that this will eventually happen. The dislike of speculation prompts some men of science at times to make curious statements, but since the eighteenth century at least no one seriously regards it as an open question whether or no the fires of the sun are eternal. Whether the sun has already passed its middle age and is declining: what the precise source of its prodigal expenditure of heat is: how long it may be conceived to last —these are controverted issues. But no one doubts that the fires of the sun will die and that then the story of planetary life will be over.

We have therefore now to summarise our present knowledge of the sun and to understand the reasons for this confident outlook. Here again we shall find plenty of obscure features and unsolved problems. As in other branches of knowledge, a more precise acquaintance has reopened questions which some had regarded as closed, and has taught us reserve. It will, however, not be necessary for me to say much on these disputed matters. What we know almost suffices for my purpose.

To begin with a brief expression, the sun is a great globe of metals, probably in a gaseous condition, measuring about 865,000 miles in diameter. It is a gigantic mass of the material with which we are familiar on Earth, except that we have not as yet recognised phosphorus, sulphur, fluorine, bromine, chlorine, and iodine amongst its elements, and there is in the outer fringe of its atmosphere a gas which is strange to us.

The foundamental difference between the sun and the earth is one of magnitude, because on this depends the high temperature which is the most prominent feature of the sun and the root of all its problems. That the Earth was once white- or red-hot at its surface no one doubts. The sun remains white-hot because it is 1,300,000 times the size, or 324,000 times the mass, of the Earth. Owing to its high temperature its matter is more expanded in spite of the immense pressure; and on account of the combination of the two the state of the the material in its interior cannot be imagined by us. It is metal so hot as to be gaseous, yet squeezed into the consistency of pitch or treacle, say some. What the temperature actually is we do not know. The attempts that have been made, along various lines, to determine the temperature of the shining surface which we see give the results generally varying between 5,000 and 8,000°. Of recent years there is a tendency to confine the variations between 6,000 and 7,000°. Many astronomers put it that the temperature of the surface is "about 7,000°," which is nearly double the temperature of the carbons in an electric arc. A more vivid idea will be possible to those who have felt the heat at the Equator, at a distance of 92,000,000 miles from its source.

What the heat of the interior is we cannot say. A distinguished physicist has calculated that it must reach a million degrees : some say many millions. Certainly it is appalling, and we must remember that, while the light comes from the surface, possibly from luminous clouds above the surface, the heat streams through the gaseous veil from below. This colossal heat implies conditions beyond our experience, and we must endeavour to obtain what knowledge we can of them.

Round the great globe of incandesent metal is a vast shell of gas, reaching out, on the average, half a million miles from the surface. The greater part of this, the broad halo or "corona" (crown) that flashes into sight, like a ghost in the dark, during an eclipse, is a layer of exceedingly attenuated gas, hundreds of thousands of miles deep. The outer fringe of it is mainly a gas which does not seem to exist, or has not yet been detected, on the earth. It is therefore called coronium. Nearer to the sun helium is the chief constituent, and nearer still hydrogen; though probably solid and liquid particles mingle with the gases. Recent examination with the spectroscope shows that matter is actually shooting out from the sun in this extended halo, and its appearance during an eclipse suggests this. At times (notably when the sun-spot period is at its height) it clings fairly equally to the disk. At other times it shoots out in long streamers, especially about the sun's equator, as if the breath of a giant, or some intense magnetic storm, were blowing it into shreds.

At the base of this crown the hydrogen and helium gases become a red-hot ocean, some four thousand miles deep, completely surrounding the sun. This again pales out of ordinary view in the diffused sunlight, and is best seen during an eclipse. The vapours of many metals mingle with the gases, and here the impression of "storm" which the corona gives us, is deepened. The red-hot gas is whipped into waves that would sometimes stretch from the earth to the moon. Long ago these red "flames" were seen licking the rim of the sun during an eclipse, and it was known that they were often of colossal size. A refinement of the spectroscope now enables the astronomer to see them at any time, and they give us a terrific impression of solar life. Masses of gas rise, in waves, mountains, jets, or tree-like growths, commonly to a height of 10,000 miles, and sometimes up to 300,000 miles. In May, 1916, one was seen to rise 500,000 miles. Astonished observers have at times seen them soar to a height of 250,000 miles in half an hour and then melt away. A speed of 300 miles a second is not uncommon, and one observer has seen the red-hot gas fly outward at the rate of 500 miles a second. We come nearer to the stupendous energy of the sun.

And just as the flames of the red-hot gas (or "chromosphere") shoot up into the corona, so great jets and fountains of the next layer, and clouds of incandescent calcium, rise into the gas. At times it looks as if a large area of the underlying ocean of metallic vapours were shot bodily into the higher regions. Another wonderful modern adaption of the spectroscope, invented and chiefly used at the Mount Wilson Observatory, enables astronomers to photograph these stormy regions in the light of a particular selected element, and shows us vast clouds of calcium and mighty whirlpools of hydrogen. But it will be better to ignore this stormy confusion of layers for the moment and examine the successive shells of vapour at the sun's surface.

Beneath the red-hot gases, passing into them as the evaporating or storm-swept ocean passes into the air, is an ocean of glowing metallic vapours. The upper part of this, about 300 miles deep, is called the "reversing layer," and is of very particular interest to astronomers and some interest to us. It absorbs some of the intense light from the layer below it. But here we reach a point where it becomes necessary to say a little about the instrument by which we read the lesson it conveys. I have already mentioned this instrument, the spectroscope, several times, and, although its principles are explained in almost every astronomical work that is intended for the general public, lecturing experience warns me that the explanation cannot be repeated too often or expressed too simply. The discoveries described in this book are mainly due to the spectroscope, and the reader will care to understand its action.

It is well known that light consists of a series of very rapid movements, generally called waves, in ether. These waves are started by the particles of luminous bodies, which travel violently to and fro, and they are propagated across space at 186,000 miles a second But the "waves"—it is convenient to conceive them as such—differ greatly in length, or in the distance from crest to crest. Generally speaking, they range between the 40,000th of an inch (in red colour) to the 80,000th of an inch (in deep violet colour.) The full rainbow band of colour is a blend of waves of all lengths. It is "white" or mixed light sorted out according to the lengths of the waves. This sorting takes place when a ray of white light passes through a dense medium: through, for instance, a moisture-laden atmosphere (which gives the rainbow) or a glass prism. The astronomer combines a prism, or a series of prisms, or a finely ruled grating, with a telescope, and this is the essential construction of the spectroscope.

But we should learn little from this rainbow band of light. We do learn something, it is true, In order to produce the "continuous spectrum," as the rainbow band is called, a white-hot substance must be sufficiently dense: it must be solid or liquid, or else a gas under great pressure. Consequently, when a luminous object fails to give this spectrum, as certain nebulae do, we know that it is a free gas. In such case, instead of a rainbow band of continuous light, we get only a few colours; and, as the light enters the spectroscope through a narrow slit, we get a few coloured vertical lines here and there instead of the continuous band of light. In the photographs of spectra the lines you see are, in their shape, images of the narrow slit at the mouth of the spectroscope.

One of the most fruitful discoveries of the nineteenth century was that each chemical element has its own set of lines in the spectrum. We raise each of the elements—iron, sodium, calcium, etc.—to incandescent vapour at the mouth of the spectroscope, and we find that the light of each is concentrated in a distant and specific set of lines. The atoms of different elements differ in structure, and start different waves in the ether. Hence the first great achievement of the spectroscope. Iron or hydrogen may be burning in a star 1000 billion miles away, yet we (in normal conditions) recognise it as readily as in the laboratory.

But since the sun and the stars, and the vast majority of incandescent bodies, are not free gases, the light of all their elements is blended in a continuous (rainbow) spectrum. Here the next great step was taken. It was found that this continuous band was crossed by thousands of dark lines, all of which fell into the position of the bright lines formed by the various elements in a free state. Experiment again solved the mystery. If you vapourise iron it will give its characteristic bright lines. If you then interpose similiar iron vapour between the first and the spectroscope, it will blot out the lines. It will absorb the waves which it would itself omit. It "reverses" the lines. Consequently, when we find the *dark* lines of iron or sodium in the sun's spectrum we know both that iron or sodium is incandescent in the sun, and that the vapour of iron or sodium lies between it and us, in this way we know what elements are in the sun, and we know that there is, outside the brilliant surface, an "absorbing layer" of those substances.

This simple account will suffice to make more intelligible the many references to the spectroscope and spectra—the spectrum is the photograph of the light of a body thus analysed—which fill these pages. Further extensions and refinements of the instrument cannot be described here. In sum, we turn it upon a body—a comet or a planet—and we know whether it shines by its own light or merely reflects the light of the sun. When a globe reflects sunlight, we can, within certain limits, tell whether it has an atmosphere and moisture, which would modify the lines. When a body shines by its own light, we can discover its chemical composition. From certain modifications of the lines we get glimpses of the physical condition of the star. Moreover, since the waves of light from a body which is rapidly approaching us are shortened, and the waves of light from a body which is rapidly receding from us are lengthened (just as the sea's waves are, in effect, shortened or lengthened according as your boat is heading against them or the reverse), the lines across the spectrum of that body are displaced. They are thrown, according to the direction of the movement, toward either the red or the violet end of the spectrum. Thus the instrument detects and measures movement; in the comet's tail, in the flames of the sun, in a nebula or in a star. Examined with the spectroscope, the "calm" heavens disclose movements of a portentous nature.

To return to the reversing layer. When we examine the spectrum of the sun, we find the band of continuous light crossed by thousands of fine dark lines. From this, it will now be understood, we know that the light-giving surface of the sun contains all our metals and gases (with the exceptions noted above) at a white heat, and the reversing layer is a mass of cooler vapours of the same elements. One is naturally inclined to picture an ocean of glowing metals with a dense steam of the same metals hanging over it, but probably the enormous temperature of the sun reduces everything to a gaseous condition; I mean gaseous in the technical sense, for the mixture may be under great pressure as viscous as treacle.

But it is important to notice that these vapours are not dark. The "dark" lines of the spectrum are dark only by comparison with the glow of the band of continuous light. The vapours of the reversing layer are as brilliant as the lime-light. During an eclipse, when the more vivid light is cut off, they give bright lines in the spectroscope.

The reversing layer is continued downward in a thicker layer of the same vapours, which is known as the "absorbing layer." This is of the same nature. It reduces or absorbs the light from below. Beneath it is the intense light-giving surface, or "photosphere," of the sun.

We say surface, but we have already seen that there is no definite surface of this extraordinary globe of metals and gases. We must not imagine the surface of a molten ocean, at times placid, and at times lashed up by terrific storms. The various layers are always torn and intermingled. The intensely luminous metals rise constantly in fountains that are hundreds or thousands of miles in height, and the vapours and gases above them are, as we saw, swept upward in stupendous rushes. Indeed, astonomers are as yet greatly divided and uncertain as to the nature of the vivid continuous light of the sun which comes from something that must be 5000 times brighter than molten steel. Many contend that only solid particles could give so intense a light, and enormous clouds or layers of incandescent carbon or calcium have been suggested. Others say that no metal can be otherwise than gaseous at the sun's surface-temperature. Electrical action on a gigantic scale has been suggested. The question is still open.

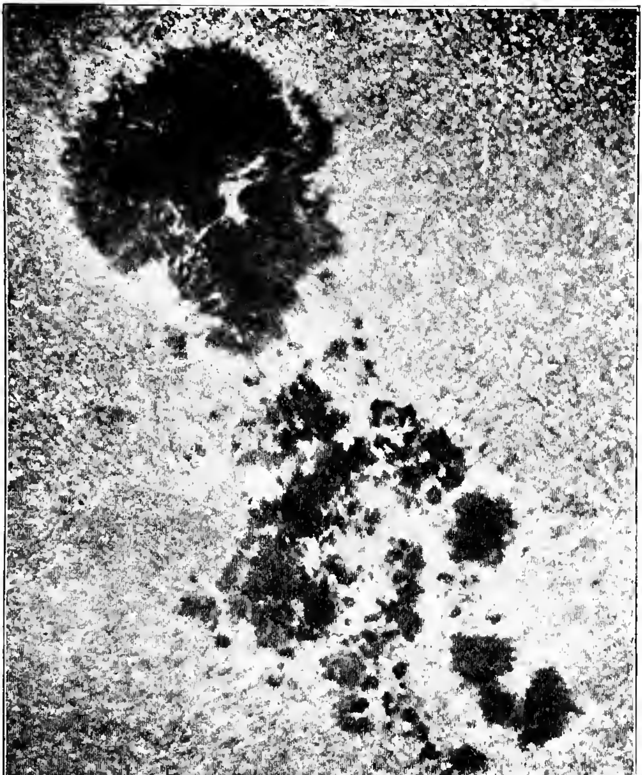
This, fortunately, does not disturb my single line of inquiry, which concerns the heat rather than the light of the sun. In this respect the situation is clearer. The sun is a white-hot metal globe, and it is spending its heat at a prodigious rate. Whatever the source of the heat is (a point we will consider presently), it is not inexhaustible. The majority of astronomers believe that the sun has already passed its prime, and is sinking; and an examination of some further features will support this.

The peculiar appearance of the sun's surface in a photograph is familiar. A network or veil of some dark material lies upon the luminous disk, and here and there, at odd times, are the dark patches which we call "sun-spots." The darkness is, as I said, relative. The heart of the blackest of the spots is really as intensely luminous as the white-hot lime in the oxy-hydrogen light. But the *relative* darkness is instructive. Beyond question these vapours are cooler than the metals below. It looks as if a veil of cool and obscuring vapours is gathering about the sun. This would be the beginning of the end.

Here, the student of astronomy would say, we really enter a region of acute controversy. Let us make plain what is really disputed and what is not.

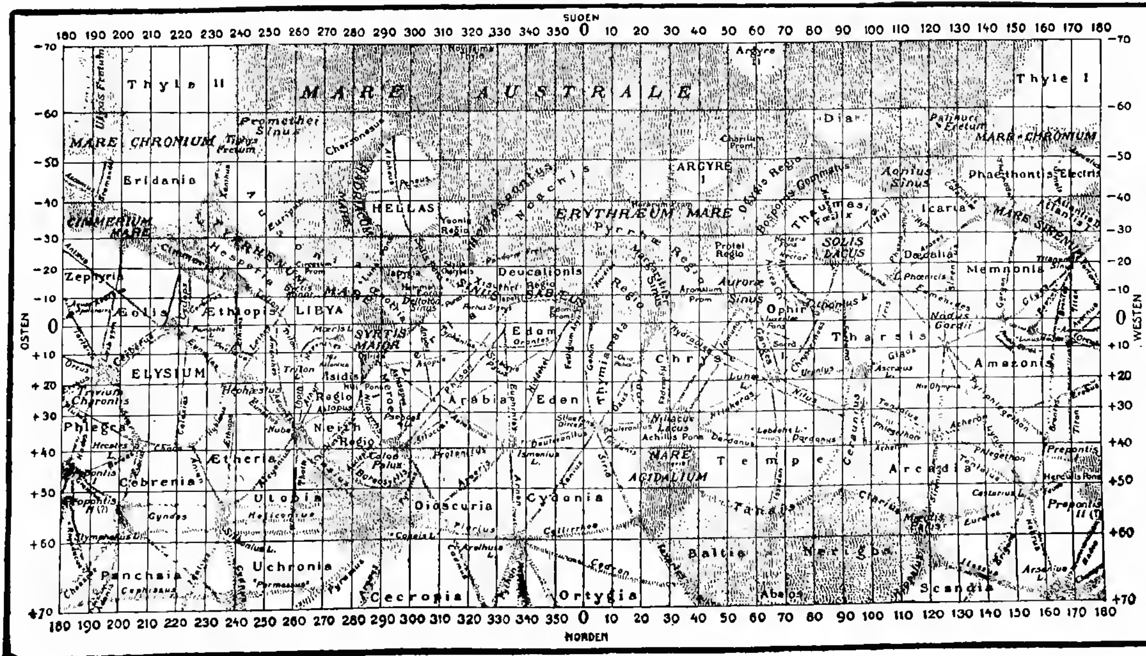
These features of the sun have been photographed and spectrographed for decades, and a good deal of settled information has accumulated. In earlier days the patches of light between the meshes of the spreading dark net were called "granules" or rice-grains." It is perhaps, a pity that these early astronomical labels are retained. The "granules" are the tops of great columns or mountains, hundred of miles in diameter, of the incandescent metal of the sun. This is now generally admitted, and it follows that the dark network itself is the cooler vapour from above pressing between the summits of the granules.

It has been suggested that the "spot" is an ocean, or vaster aggregation, of this cooler vapour, and, although the phenomenon is the subject of interminable controversy, all that we know seems consistent with this, and it is the only satisfactory theory of the sun's surface. The "spot" is, of course, a vast area, often 50,000 or 100,000 miles across. A single spot has measured 150,000 by 75,000 miles in extent, and the area of disturbance covered by a group of spots has measured 3000 million square miles. The spectroscope, showing the ordinary lines thickened, informs us that, as the relative darkness suggests, the material is here cooler and more absorbent. In other words, the spot plainly is a mass of cooler vapour. Miss Clerke, one of the least favourable witnesses, because she had a fixed idea that the sun was growing warmer instead of colder, puts it that the material at the centre of a spot gives out 50 per cent. less heat than the bright surface does. The spectroscope has, in fact, lately found hydrocarbons and other compounds in the spots. This is a sure indication of a



A GREAT SUN-SPOT.

[Face p. 102.



SUPPOSED MAP OF MARS (*see p.* 129).

cooler region, for such compounds do not otherwise exist in the sun.

Some astronomers declare the spectrum of a sun-spot puzzling and indecisive because it shows at times bright lines as well as the thickened dark lines. This is not surprising. Assuming that the spot is a mass of millions of cubic miles of cooler and therefore heavier vapour, we should expect its pressure to provoke a lively reaction of the photosphere, and this is precisely the complexion of the region about a spot. Vast and intense flames appear round its margins, and sometimes, like bridges of light, stretch inward across the dark region. The spectroscope shows that these are actual uprushes of heated material. When the spot-area is largest, these "faculae" (torches) soar highest, the flaming gas above is swept into immense waves, and auroral displays and magnetic disturbances of the Earth announce the outrush 92,000,000 miles away. There is some evidence that floods of electrified particles are actually shot across space to the Earth, throwing out of gear the electric network that civilised man has constructed. All these things do but confirm the view that the spot is a great ocean of cooler metal-vapour.

The most recent discovery in connection

with spots is that they have a vortical (or whirlpool) movement. The photographs of the hydrogen layer high above them show immense vortices, and the movements below seem to correspond. This also is consistent: is, indeed, what we should expect in the case of a down-rush of millions of tons of heavier vapour, surrounded by a corresponding uprush or "splash" of the fiery metal. There is a rent in the photosphere, as some describe the spot. There is a gigantic electric or magnetic disturbance, as others put it. There are cyclone and anticyclone. There is the influence of the rotation of the sun, the speed of which differs in different layers. These are all various aspects of a vast disturbance, the physical and electrical conditions of which our experience does not enable us to grasp; the central fact is the enormous accumulation of cooled vapour.

The most mysterious feature of the spots is that once in eleven and a quarter years they reach a maximum of growth and then slowly sink to a minimum. This is not strictly, but fairly, regular. Professor Turner has suggested that a swarm of meteors, revolving about the sun in this period, and actually grazing or tearing the surface, may be the cause; but the theory is not widely accepted. Others think that the rythm is in some way connected with the sun's rotation; and we may look to the same influence for an explanation of the singular fact that the spots never arise at the poles and the equator of the sun, but drift towards them. Some astronomers have suggested the analogy of our trade-winds, but they seem to forget that the direction of our trade-winds is determined by the greater coolness of our poles, and this is not the case on the sun.

These are outstanding problems. What is clear is that the metallic vapours and gases are rising constantly above the surface and, as they cool, veil the intense light. In the corona itself the spectroscope traces the rise and fall of matter. Such a circulation is inevitable. The thermal and electrical condition of the sun, the sustained blast outward of a terrific radiation, cause movements and features which it may take generations for us to grasp. But the general fact with which I am concerned is clear enough. Vast clouds of metallic vapour will rise in the sun's atmosphere and suffer a loss of temperature. There will be no rain of metal upon the sun, as there is a rain of the cooled moisture upon the Earth. The heat is too great. But by the same laws the vapor will descend, and in the spots we seem to have dense and enormous areas of these vapours; and the appalling outbursts round them suggest that they sink deep into the photosphere. In the course of millions of years these dark areas will extend. The proportion of cool absorbing vapour will increase. The dark veil will thicken. The sun's radiation will be checked, and it will eventually sink too low to support life millions of miles away.

The discovery in recent years of compound substances in the spots gives remarkable point to this view. Titanium oxide, magnesium hydride, and other compounds have been recognised. In the main body of the sun the high temperature keeps the atoms of the elements from entering into such compounds. The cooler region of the spot permits the combination, and we have here germs of the crust which will one day, as on the earth, confine the central fires. These compounds are, of course, temporary. The larger spots may last for months, but they do invariably disappear: heated and expanded by the fires below. But it is just to presume that, with the cooling of the sun, permanent spots will be formed, and in these the formation of compounds will proceed. These are the germs of the solid scum which will eventually form over the surface of the sun. But I defer to the next chapter a short consideration of this process. Here I have only to state the grounds on which astronomers conceive that the vaporous veil across the face of the sun will grow denser and will finally shroud its brilliance.

A few astronomers, like the late Miss Clerke, hold that it is an open question whether the sun is rising or falling in temperature. A star must reach its prime before it begins to slow down, and there will be some analogy between its condition before it reaches its prime and when it is falling from it. These astronomers do not doubt that the sun will ultimately be shrouded in the manner indicated. The issue they raise is whether the "yellow heat" of the sun is the stage before or after it reaches "white heat."

The chief reasons why the great majority of astronomers think that the sun is ageing cannot be given at this point. The stars, we shall see, fall into definite evolutionary categories, according to the state of their spectral lines, and our sun's spectrum puts it in the class of stars which have passed the prime of stellar life. Its density also suggests this, and it is strongly confirmed by the spectrum of the spots. By the lines of this spectrum the sun is related to a certain class of "variable stars," as I will consider presently, and these may be regarded as suns fighting for life, as it were, against a growing shell.

Yet, whether the sun is declining or no, it is at present quite impossible to assign a period during which it may continue to sustain life on the Earth. This is one of the points on which fresh knowledge has made the issue more uncertain than ever.

An inquiry into this point must, of course, first discover the source of the sun's heat. When the nature of heat was discovered, in the nineteenth century, this problem was hopefully attacked. It was found that the shrinking or contracting of the sun at a definite rate would suffice to explain its terrific radiation. Helmholtz calculated that if it contracted 157 feet a year, which it would take us thousands of years to perceive, this would suffice to provide its enormous heat. The mischief was that physicists went on to calculate, on this basis, how long it was since the sun became a sun (from a nebula) and how long the contraction would continue to provide the necessary radiation. Helmholtz said that the sun was not more than 17,000,000 years old. Lord Kelvin, after many vacillations, was disposed to grant it a past life of 25,000,000 years. In either case the future of the sun as a life-supporting orb was limited to a million years.

These estimates were warmly repudiated by biologists and geologists. Scarcely a single geologist would admit less than 50,000,000 years for the formation of the sedimentary rocks of the Earth alone, and the biologist supported the geologist. The physical calculation was amended and helped out in various ways. A constant inpour of meteors, some thought, might eke out the sun's energy. A period of ten to fifteen million years was allowed before the sun sank to a fatal debility.

Then, as I said, in discussing the age of the Earth, the whole issue was disturbed by new theories. Darwin's theory of the origin of the moon was favourable to an age of at least a thousand million years, and it was widely accepted. When radium was discovered, the longer period was still further favoured. It was claimed that the new discovery made "so much waste-paper" of Lord Kelvin's and Helmholtz's calculations. Not only were minerals in the Earth's crust said to have an age of hundreds of millions of years, but it was urged that there may be, and probably are, great masses of radio-active matter in the sun, and its heat may be predominantly due to these. As the life of these minerals runs to thousands of millions of years, an unlimited vista of future life was opened to the sun.

There we stand in modern astronomy, and reserve is the only reasonable attitude. Dr. Lindemann, for instance, holds that the whole life of a star is a matter of something between 20 and 50 million years; Professor Arrhenius says that it is a matter of thousands of millions of years. Since no school promises less than four million years for the continuance of planetary life, the average man may be content. But the reader should at least be warned that the new physical view, based on radio-active bodies, is not so secure as astronomical writers sometimes represent it. It will be enough to observe that, in the course of a debate on the subject at the Royal Astronomical Society a year or two ago, no less authoritative a physicist than Sir E. Rutherford scouted the whole claim that the discovery of radium has materially lengthened our estimate of the life of the sun. If the sun were made of uranium, he said, he did not believe that this would add five years to its life as a heat-giver; and he added that all the radio-active material in it, if there ever was any, may have been used up long ago.

The doctors differ. It is, as I said, not the least part of my design or desire to assign a date for the end of the world. My purpose is rather to present the discoveries and conjectures of scientific men which bear upon the subject. These discoveries give us at least a grand view of the universe in which we live The precise, or even vague, determination of a catastrophe that will overtake the men of millions of years hence is less important. To us the manner of the world's end is more interesting than the date.

CHAPTER VI

THE FATE OF THE PLANETS

If any point stands firmly in this shifting sand of speculation it is that the earth will remain habitable for several million years. Four million years is, I believe, the most niggardly estimate offered us of the future of the sun as an efficient heat-giver. What an astounding prospect this estimate, on which, as a minimum, all are agreed, opens out before us!

Man has been on the Earth for a few hundreds of thousands of years, but the enormously greater part of this time may be ignored, or may be accounted a semi-human period. With all recognition of the art of Magdalenian man, which might be put some 50,000 years ago, we may say that the human period proper began about ten thousand years ago. Then the lapses from civilisation must be taken into account. War and ambition have so spoiled the advance that it rather resembles a wide and irregular spiral than a march. Nine or ten centuries ago the state of Europe was appalling. We are only now entering upon the path of real human achievement. Laments of the "materialism" of our age are ridiculous. No age ever surpassed it in range and depth of social idealism. The scientific spirit and method are creeping from the laboratory into life. Mind is beginning to reign. And this creative mind, which is but entering upon its reign, is promised an æon of at least four million years for its work. Apart from the question of radio-active minerals, the majority of physicists and astronomers would say rather an æon of something more than ten million years! The most grandiose cosmic conception pales beside this prospect.

It is exalted, and becomes almost stupefying, if we pay attention to the modern rate of progress. There is nothing to suggest that this rate will relax. Civilisations are no longer encircled by waves of barbarism that may destroy them, and, if the lethargy of prosperity or sluggishness of administrative machinery destroys some, they can now only be replaced by a power that is more efficient as well as more vigorous. The imagination of the race is lit. Progress during so many thousands of years was snail-like because men were not conscious of high aims and great possibilities. We have now an acute consciousness that a continued progress will bring about a wonderful Earth, and we will not relax, though there may be periods of reaction. What the future Earth will be like the most vivid imagination cannot dimly conceive. A few centuries, at the rate we are going, will put speculative and applied science in a marvellous position, and no doubt something like the same period will be occupied in bringing perfect order and organisation into our chaotic social, industrial, and international life. Beyond those few centuries are millions of years of the progressive use of the developed mind of man. . . I repeat that this is the most impressive truth ever put before us.

One is tempted to imagine this race of supermen, of some millions of years hence, grimly confronting the issue of extinction. Probably long before that time science will have perfectly mastered the problem of the sun's heat, and will be able to state precisely at what period the radiation will sink to a level which would normally be fatal to the living inhabitants of the planets. Then will begin the greatest of cosmic events: a drama that has doubtless been played numbers of times already on the stage of the universe: the last stand of the wonderful microcosm against the brute force of the macrocosm. No doubt there are other spheres of the universe in which the drama has been carried much further. Stars like Rigel and Canopus are almost certainly much larger than our sun, and will therefore be longer-lived. It is a fair assumption, though by no means certain, that they have planets. On such globes, enjoying a longer life, living things may pass immensely beyond whatever their equivalent is for the human level of intelligence. The final struggle will only be the more titanic.

One conceives that our supermen will face the end philosophically. Death is losing its terrors. The race will genially say, as we individuals do to-day, that it has had a long run. But it will none-the-less make a grim fight. Life will be worth living, for everybody, long before that consummation is in sight. The hovering demon of cold and darkness will be combatted by scientific means of which we have not the germ of a conception. Flammarion has imagined the last men lived in glorified glass-houses, conserving the pale warmth of the dying sun. Mr. Wells put his men in the moon underground, with luminous streams. These are vague ideas of what men might do a hundred years hence, not four million, or fourteen million, years. It is absolutely useless to conjecture.

What I am writing may seem to some to smack of romance, yet I am confining myself to scientific platitudes, as far as principles are concerned, and only drawing the most obvious deductions from them. No one doubts that the fires of the sun will one day sink, and no one now doubts that, barring accident, which the long life of our planet does not favour, the catastrophe will not happen for some millions of years. No one doubts that it will creep on at a snail's pace, during millions of years, and I should be very much surprised if even the least imaginative man of science doubted that the conditions of the problem will be perfectly mastered long before that time. Assuming that the race will continue to progress at something like the rate it has done during the last five centuries, the data for the remainder of the vague picture I have suggested are complete. It will be a race of hyper-super-men that faces the catastrophe. The weakness of forecasting the social or industrial or political future is that your prophet naturally makes the man of the future adopt his own view of an ideal society or polity. But to forecast the progressive development of science and engineering, and culture generally, is quite safe. Hence we may get a dim appreciation of the equipment with which the last men will face this great problem, if we multiply the scientific progress of the last hundred years by fifty thousand or so.

Only one or two further suggestions may be made about that final struggle without departing from the matter-of-fact program of this book. It is clear that the dimming of the light of the sun will be a comparatively small inconvenience. Vegetation would cease. Men in the meantime may discover the artificial production of actinic rays on any scale they wish, but, as I said, the notion of men growing cabbages, or grass for cattle, in another million years, is ridiculous. Organic chemistry is one of the most progressive of our sciences.

Heat is the point of importance. Here I would only remind the reader of the enormous adaptability of living things to gradual changes of temperature. Before the last Ice-Age the elephant and rhinoceros wandered over England. This genial climate changed to arctic probably in something less than a hundred thousand years, yet branches of the elephant and rhinoceros worlds remained in Europe. Even those pachydermatous monsters developed fur-coats! Delicate flowers crept into the actual ice-fields. The *Soldanella*, which grows under frozen snow in Switzerland to-day, acquired a heat-producing apparatus in its own structure. The preceding, or Permain, Ice-Age had developed the warm-coated and warm-blooded mammals and birds out of the soft population of the Coal-Forests. So we must not imagine thin-blooded men like ourselves facing the cold. What nature will do for them, and what they will do for themselves with their wonderful science, we cannot dimly conjecture, but evolution will start again. As to other animals than man, the great majority of them will probably have been eliminated from the planet ages before: in the interests of health and cleanliness.

Beyond these vague and safe generalities I decline to discuss the great epic of man's final struggle for existence. And if we turn to consider the progress of the gradual cooling of the sun, we must, if we would keep to the same sober lines, be equally vague. We are not without indications. Our sun is not the only star in the universe and, while some of its fellows suggest to us its past, others suggest its future. We shall see this more fully in a later chapter. Here a very brief statement must suffice.

The stars have, as I said, been distributed into evolutionary classes. Strictly speaking, they are classified according to their type of spectrum, but few astronomers now doubt that this is a gradation according to age. Three of these classes come later than our sun. These are the deep-yellow, red, and deep-red stars. There is considerable ambiguity and controversy about the second of these classes (the M Type). It may comprise stars rising in temperature as well as sinking stars. But the N Type stars and many of the M Type are slowly expiring suns. Their spectrum shows the vapours gathering densely about them, and the elements entering into chemical combinations, which are not possible in the hotter stars.

The spectrum of a sun-spot, as I said, brings our sun into interesting relation to some of these stars. Especially interesting is one class of what are called the variable stars: suns which periodically show increase and decrease of light. In some of these cases a bright star is eclipsed periodically by a dimmer star, but there are others in which the phases are generally believed to be due to internal causes. This is not at all certain : I am using them for the moment only for illustration. It is believed that their inner energies periodically burst the shell of cool vapours which the spectroscope indicates about them. If our sun continues to have periods of maximum and minimum of sun-spots, when its vapours thicken, it will be a variable star. Already to a distant and sensitive instrument it would be a faint variable.

Thus the future of our sun seems to be that the comparatively dark vapours will thicken about it, and (as we see round the actual spots) there will be fiery rebellions of the imprisoned matter. With the progressive cooling the chemical compounds will become permanent. A sort of scum, constantly broken and melted, will form. From the Earth the yellow disk will be seen gradually to become red, then deep-red, lit by occasional bursts.

A later phase may be illustrated from the planet Jupiter. This great globe, intermediate between the sun and the Earth, is now generally admitted to be red-hot. The expansion of its matter is still very high. The cloud-envelope round it is so dense and impenetrable that the surface seems to be too hot to permit the settlement of water. A red light tinges the edges of the cloudbelts, and has for decades coloured a large and mysterious region of the planet. It is presumed that a crust has formed, but that it still dully glows with heat.

The geological record of the Earth carries on the story of evolution. At the base of the rocks are enormous masses of volcanic, eruptive stuff, illustrating the phase of thin crust and constant outbursts from below. The Planetesimal view of the Earth's origin recognises, like its rival, this early incandescence at least of the Earth's crust. In the course of tens of millions of years the crust has solidified and prevailed. Perhaps Mars shows the next phase: the Moon the next. The condition of all the globes of our system is in accord with the simple formula of cosmic life and death which I have given. However these globes originated—which is a matter of dispute—they were at an early stage incandescent, and the smaller (in normal conditions) cool down before the larger. The universe is a collection of metal globes cooling down.

Planetary life is, from this point of view, a chemical episode. At what point in the progressive cooling of the Sun the Earth will cease to be habitable it is quite useless to conjecture. I am putting conjectures before the reader only when they are solid guesses at the causes of a known phenomenon. But it must be borne in mind that the only alternative to the general line I am following is to suppose that the fires of the Sun are eternal. Even the most frivolous slighter of science does not believe that. It is a truism to say that the sun will be gradually extinguished, and at some point in the lowering of its temperature the coldness of space will invade the Earth. We assume that this will put an end to life.

What will happen afterwards is not of acute interest to us, and is a matter of vague analogy and conjecture. At some remote time, it is said, the air and water will leave our globe. The particles of a gas are in a state of violent agitation and mutual collision. At the outer fringe of our atmosphere their path, feebly controlled by gravitation, and less disturbed by collisions, leads off into space. In any case the water at least wlll freeze into a solid mass.

The further fate of the Earth is reached only by conjectures that have not a sufficiently positive ground to be considered here. Some believe that the planets will be gradually slowed in their paths round the sun. Our solar system is, apparently, not at all free from cosmic dust. It is now generally believed that even space beyond contains much besides ether. The light of the more distant stars is apparently intercepted to some extent. But what this cosmic dust amounts to, and whether it is enough eventually to disturb the planets, is extremely uncertain. It is the belief of many that in the course of prolonged time they will be affected by this resisting medium. Their orbital motions will be slowed, and, their speeds no longer sufficing to protect them against the Sun's gravitational pull, they will be sucked into the parent body. Others believe that the imprisoned elements may some day burst and make a swarm of meteors, or a cloud of cosmic dust, of our planet. Arrhenius believes that the unequal action of the sun's gravitation on the various parts of our globe would when its speed is lowered, crush it. Volcanic outpours would then make it feebly incandescent for a time, but it would break up and pour quietly upon the sun as a stream of meteoric dust.

These are very remote and much desputed conjectures. It will be more interesting to consider briefly whether the last stand of life against the invading cold is likely to be confined to the Earth, or to take place also on other planets.

The outermost planets of the system, Uranus and Neptune, cannot profitably be discussed.

At their vast distances they offer but small and obscure disks in the telescope. As they are very much larger than the Earth, though of a far lower density, it is suspected that they may still be in an early stage of planetary formation. Jupiter, we saw, is intermediate between the Sun and the Earth, and seems still to be red-hot. Uranus and Neptune seem to be intermediate between the Earth and Jupiter, and if life has not yet appeared, or has not far advanced, on those globe, it will have a short history. Uranus, at a distance of 1,755 million miles from the Sun, must receive 300 times less heat than we do. Neptune, 2,771 million miles from the centre, must receive 900 times less heat. If there is a still more distant planet, as many think probable, its share of the sun's heat will be negligible. It is useless to discuss the chances of there being life on these remote and obscure globes.

Saturn and Jupiter come next, and may, for the reason I have given, be taken together. Their immense size, yet low degree of condensation, suggested that they were in a very early stage of planetary formation. Jupiter has 300 times the mass (or weight) of the Earth, and is more than 1,200 times larger. Saturn is 719 times the volume of the Earth. With the advance of the telescope it was found that these globes are entirely and always surrounded by a dense mass of steam or cloud, and it was natural to infer that, while their temperature had sunk sufficiently to permit their oxygen and hydrogen to unite in the form of water, the heat of the crust was still too great to allow the water to settle on it. The suspicion was confirmed by the presence on Jupiter of a dark-red region called, as usual, a "spot" by the early astronomers, though it at one time measured 30,000 miles, in which we seemed to see some more vivid glare from below bursting diffusively through the dense clouds: as I have seen the glare of Vesuvius on a cloudy night during an eruption. These suggestions have been enforced by our increasing knowledge of the planets, and it is now generally recognised that their surfaces are red-hot. Possibly they are in the stage suggested by the lower part of the Earth's crust, which indicates a phase of constant and massive eruptions from below, which would in effect keep the surface at a red heat.

From our present point of view there will be a kind of race between the cooling of these large planets and the cooling of the Sun. Whether they will cool down early enough to permit the development of life on their surfaces before the sun sinks to a level which would make its distant radiation ineffective for them cannot be said. We do not know the length of the various phases of planetary development. Some day undoubtedly their surface-temperature will sink sufficiently to permit the waters to settle, and the boiling oceans will slowly cool. Possibly the slow process of the development of life will then begin. It would, in fact, not be unscientific to say that *probably* the story of life will then begin. The essential conditions —air, water, and the chemical compounds of the crust—are there, and we have no reason to suppose that any special circumstance favouring the development of life was present on the Earth and is not present on them. Organic chemists and biologists are now confident that life was a natural chemical growth in the primitive waters. But the story of life will assuredly not run far on these globes, if it ever begins. From the analogy of the Earth we should say that between ten and twenty million years would be required to reach the level of sea-weeds and very lowly shell-fish. Before that time, we saw, there is reason to expect a decrease of the Sun's radiation which would be fatal to life on those distant globes.

It is to Mars that we turn with the greatest interest in this respect. Before discussing it, however, let me call attention to two biological principles. The first is that life is, in our experience, found wherever the conditions of life are found. On our Earth this means, of course, that, in the stuggle for food, living things penetrate from the more thickly populated regions into every region where they can survive. I have pointed out in the preceding paragraph that this principle extends also to the first appearance of life. If, as every biologist now believes, the first appearance of life on a globe is as natural a phenomenon as the later multiplication of life, we shall expect life to arise wherever the conditions exist. That is the scientific basis of the common assumption of "life in other worlds."

The second principle is more important, because astronomers often in practice forget it. It is that life varies with the variation of its conditions. Of this also I have given illustrations, and a large volume might be filled with them. Yet the elasticity or adaptability of the life-substance is in practice constantly over-looked. Men take from some biological work the conditions (of temperature, moisture, pressure, &c.) within which life is found *on the*

Earth to-day, and they look for conditions within those limits on other globes.

This is entirely unscientific. Even on Earth we have occasionally to enlarge our limits. We now know for instance, that certain bacteria will live in boiling water and others will survive a temperature of—200° C. The main point is, however, that the conditions on Earth have varied enormously in the course of time, and life has become adapted to the changes. At one time there was no life on land, and we might imagine a fish-philosopher declaring that life out of the water was impossible. Now animals live in waterless deserts, and plants thrive in regions where water is abnormally scarce and fires are frequent. At one time there was no winter, no frost. When cold came the plants and animals were adapted to the change. This enormous adaptability of life must make us pause before we declare that the conditions of life are not found on any particular globe.

In the discussion of the question of life on Mars this principle is often overlooked. The conditions of the planet are certainly very different from those of the Earth, and the root of the difference is, as usual, the size. Mars has a diameter of 4,200 miles or very little more than half that of the Earth. We should therefore expect an approach toward the condition of the Moon: an advanced state of development, a large loss of air and water, and a proportionate coldness. These are the conditions which we seem to find, but on their precise degree astronomers are not agreed.

It is agreed that the atmosphere is thin—at least one fourth as dense as ours—though it is not suggested that there is not enough air to support life. The temperature is disputed. Professor Jacoby observes that with so thin and dry an atmosphere Mars must have an average temperature of—33 degrees F., or nearly seventy degrees of frost; and he is disposed to think that the white polar caps, which are plainly seen on Mars, may be a deposit of frozen carbon dioxide. Professor Poynting, Sir F. W. Dyson, and probably most astronomers, claim that the temperature all over the globe is well below freezing point. Others say that on five-sixths of the surface of Mars it is always above freezing point. The late Professor Lowell and others pointed out, however, that the reflection of light from the surface of Mars is low, and that the greater absorption of the Sun's rays may temper the climate. In any case, no one suggests that the temperature is too rigorous to permit life. The chief interest of the point is whether the temperature is too low for us to allow the existence of water-canals. That is disputed.

But the main point is whether Mars has, or has not, water. Professor Campbell in 1909 tested Mars with the spectroscope at the summit of Mount Whitney (15,000 feet,) and found no trace of vapour in its atmosphere. The lines of the solar spectrum are, of course, affected by moisture in the atmosphere—some men use pocket spectroscopes as barometers—and it was thought that at the top of Mount Whitney the vapour of the Earth would be substantially left behind and not disturb the experiment. No trace of vapour was found, and it was concluded by many astronomers that this was inconsistent with the idea of polar oceans and a large network of canals. It is disputed whether clouds are *ever* seen in the atmosphere of Mars, but none claim that they are more than very rare. Some hold that the atmosphere is too thin to sustain them. There are certainly no oceans on Mars. The large yellow regions of the centre, which are generally regarded as deserts, may be the sites of former oceans.

This desert region lies between vast bluegreen areas, and Professor Lowell, the great champion of life on Mars, and others regard these as areas of vegetation. At the poles themselves are undoubtedly white caps—they may be seen on any photograph—which diminish in size during the Martian summer. As is well known, Professor Lowell and some other astronomers hold that these are ice-caps; that the dark fringes which surround them as they melt are polar seas; and that the Martians convey the water over the planet by means of great canals or pipes. These polar caps measure 17½ million square miles, while those of the Earth measure 60 million square miles. There is a general reluctance on the part of astronomers to regard them as thick masses of ice and snow. They melt rapidly, and, as I said, there is at least little moisture in the planet's atmosphere. Probably the majority of astronomers regard them as coats of snow or hoar frost. They are very sensitive, and it is even claimed that they melt more rapidly when the sun spots are more active.

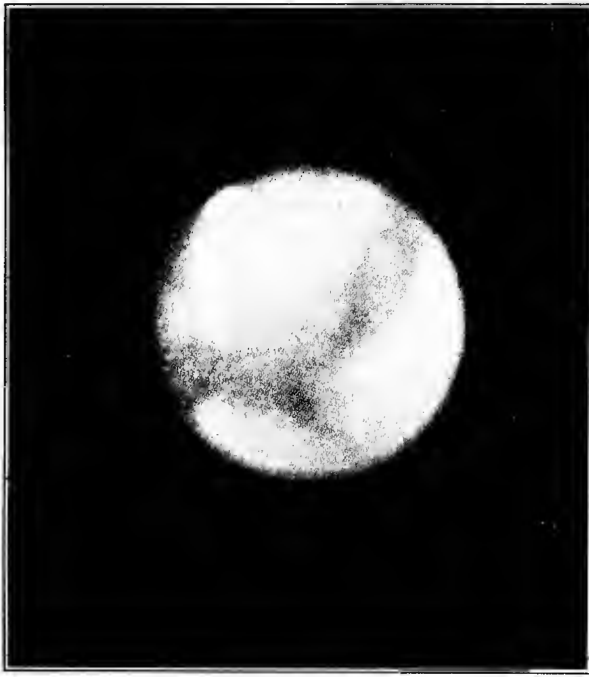
All these controversies, however, are influenced by the outstanding dispute about Mars: Are certain long straight lines seen on the planet's disk, and are they reasonably regarded as canals? It is not, of course, suggested that we see actual canals on a planet which is never less than 35,000,000 miles away from us. The theory is that the canals—some would prefer to say pipes, starting from pumping stations—run in pairs, and that we see the cultivated strips between or beside the canals. There is no rain on Mars, and it is felt than an intelligent race would invent some such system of irrigation.

The general reader wonders how, since we have photographs of Mars, there can be any dispute about the existence of such marks on its surface. He is, as a rule, not aware that the photographic plates used in the telescope are such tiny squares of glass that the figure of Mars on them, in Professor Lowell's photographs, is about the size of a pin's head. Even with the most powerful telescopes and the greatest feasible enlargement the disk of the planet remains a fraction of an inch in diameter. In some respects, however, the eye is superior to the photographic plate. It can seize and use a brief spell of excellent conditions while the long-exposure plate cannot. Hence many astronomers trust the prolonged observations of the late Professor Lowell, in the excellently placed Arizona observatory; while others, even of his American colleagues, declare that the hundreds of lines he has seen and sketched are due to "visual aberration" (as Professor Jacoby says.) The French astronomer Antoniadi has also closely studied Mars—though he has not made so prolonged a study, or in such good conditions, as Professor Lowell—and he declares that no straight lines can be seen.

Mars is at its nearest to the Earth once in fifteen years. The last approach was in 1907: the next will be in 1922. We may then expect a settlement of the question whether the lines exist or no. Already Professor Lowell has scored a measure of success. Photographs of Mars have been taken which show the lines, though some critics object that they are not straight. But if the full network of lines are shown, as seems to me probable, the controversy will but change its complexion. There is already a rival theory of the lines in the field. Professor Joly maintains that they are markings or furrows made by a satellite (or moon) that was drawn in, and scored the disk in its rapid sweep over the surface! Probably the question of Mars will cast the apple of discord into the academic camp for decades to come.

To the outsider it must seem strange that so little notice is taken—indeed, I am not sure that any has been taken—of another aspect of the matter. It is generally assumed that, if there are living things on Mars, they will be further advanced in intelligence than man is. The basis of this assumption is plausible. Mars, being smaller than the Earth, cooled more rapidly, and the story of life on its surface began earlier. But is it probable that beings far in advance of ourselves need vegetation? The amount of material which a living body actually needs daily is very small. The bulk of our food is sheer waste, and the greater part of our alimentary canal is burdened with a clumsy task. It is being reduced, just as those lamentable legacies of a pre-historic past, the teeth, are disappearing. Very strong indications point to an artificial and more economical production of food in the future. We may have either to reconsider the current estimates of the intelligence of the supposed Martians or the significance of the "vegetation beds."

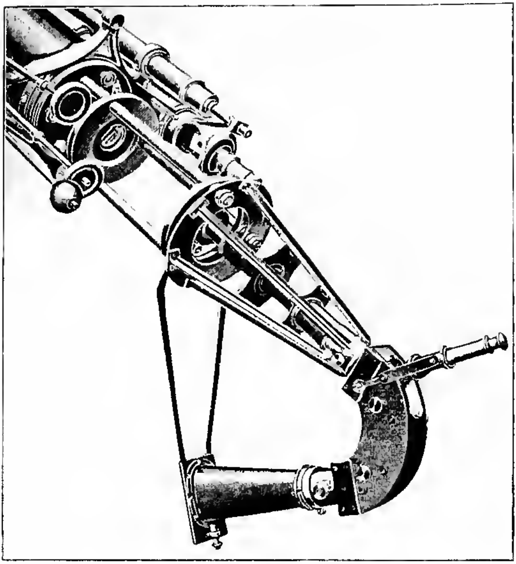
That there is life, and very advanced life, on Mars must seem entirely probable to any student of science who is not confined to one branch of knowledge. The conditions of Mars to-day are a degradation of earlier conditions. In those earlier conditions at least life could thrive, and it will have experienced an adaptation to changed conditions such as we see on the



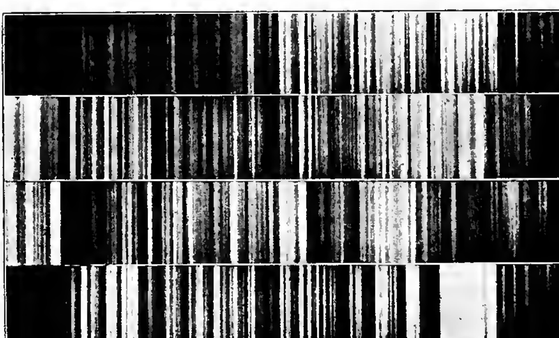
PHOTOGRAPH OF MARS

(The 60-in. reflector of the Mt. Wilson Observatory.)

[*Face p* 136.



SPECTROGRAPH AT THE OBSERVATORY, POTSDAM.
(*See p.* 146.)



SPECTRA OF VARIOUS FIXED STARS.
The second lowest is that of the Sun (*see p.* 146).

[*Face p.* 137.

Earth. What forms it may have assumed we have not the dimmest notion, but the evolution of animal life runs inevitably in the direction of increased intelligence. All the scientific probabilities are on the side of Professor Lowell.

Of late years the question of Venus threatens to rival in interest the problem of Mars. It closely approaches the Earth in size, and therefore offers a much nearer parallel. Unfortunately its disk is so bright that no markings definite enough to guide speculation have been observed Of late years, however, Professor Lowell and others have claimed that they observe such definite marks on the surface of Venus, and from these they deduced a remarkable feature. Since these marks constitute a permanent pattern, they infer that the planet always presents the same face to the sun. The pattern is claimed to be a series of broad spokes radiating from a centre, and if the planet rotated as the others do the pattern ought to change its position. It is suggested that the tidal influence of the Sun has slowed down the planet's rotation in the same manner as the Earth has—with the same result—reduced the period of rotation of the Moon.

This theory, and the statements on which it is based, are not generally accepted, though an increasing number of astronomers accept them. If the theory is correct, the conditions of Venus are singular, One half of it endures without respite the blazing heat of the Sun, which is less than 70,000,000 miles away: the other half is eternally dark and cold. It would seem to follow that any water on the side opposite to the Sun would long ago have been borne to the dark side and stored there as snow and ice. The evaporation would be considerable, and the upper currents from the hot to the cold region would bear it to the regions where it would be frozen. The remarkable brightness of the planet suggests to most observers a heavily-clouded atmosphere, and they find this inconsistent with Lowell's view. Professor Lowell thought the reflection of solar light more probably due to the immense amount of dust in the atmosphere of the torrid desert, and concluded that no life of a kind imaginable by us can exist on Venus. Others do not despair. Mr. Housden conceives vast glaciers pouring from the dark to the light hemisphere, and an irrigation-system as on Mars. Mr. Clayden contends that the rotation-period is very long, though less than the revolution-period, and so the snow and ice of a prolonged winter is gradually brought into the sun.

The conditions of Venus are clearly too little known to admit profitable discussion as yet. The innermost planet, Mercury, is said, like Venus, always to present the same face to the sun, and to have endured the same consequences At its distance from the sun (36,000,000 miles) this would be fatal, but Mercury is in any case so small a globe (3400 miles in diameter) that it is probably an airless desert like the moon. We can say only that on general principles, on the general bases of our present knowledge, we should expect to find some kind of life on Venus and an advanced life on Mars. Their populations, if they have any, will pass away with the population of the Earth, and some day a dull-red sun will faintly gild the planetary tombs that circle round it until they are gathered again into its womb.

CHAPTER VII

THE MESSAGE OF THE STARS

It will already be apparent that even if our sun or star were the only one within our knowledge the central theme of this book might be regarded as beyond reasonable doubt. There are a few punctilious astronomers who would not admit into academic publications any statement which has not been definitely "proved." This, fortunately, is not the general attitude of scientific men. Astronomical meetings and periodicals hardly ever announce a new discovery without eliciting a discussion of the probable meaning or causes of the phenemenon. Speculation guides research: often leads it astray, it is true, yet is in the main far more profitable than the uncalculating record of facts.

But it should not be forgotten that a large scientific statement may remain speculative, yet may have behind it an enormous mass of evidence. The formation of the atom from electrified particles, or electrons, is not proved. The evolution of life is not proved. The evolution of man is not proved. These and a score of other scientific theorems which are now beyond the region of doubt are not capable of proof. The evolution of our solar system is in the same position. It is an interpretation of the features of our system, but those features are so consistent and eloquent that there is no longer any room to doubt the correctness of the interpretation. If cosmic globes are masses of metal cooling down, the difference in size of the various members of our solar system will entail certain definite differences of temperature, density, atmosphere, surface, &c. These are, as we found, so exactly found, from the Moon to the Sun, that doubt is excluded. It is, curiously enough, people who have been accustomed to holding things on the feeblest evidence who profess doubt about the truth of such theories. In this case they have not the refuge of appealing to vicissitudes of scientific opinion. From Laplace onward there has been no change of opinion on this point. The solar system is running down: the Sun and the planets are gradually cooling.

This it is expedient to state clearly before we proceed. When, in earlier works I have made brief references to the eventual struggle of man against the invading cold of space, to the dull red rays of a dying sun falling upon the last of our race, even liberal men have spoken of "poetry" and "speculation." There is in this no poetry, and the speculation is of the feeblest order. It is a platitude that the fire of the sun will die down, and the "speculation" that it will pass to a dull red, and be unable to protect Earth from the cold of space, involves no more imagination than the belief that my white hot poker will turn red when it is removed from the fire, and will eventually be too cold to warm a mug of beer.

But our Sun is not the only star in the universe. It is one of hundreds of millions, at least, of like bodies. The stars, too, are globes of incandescent metal, swathed in envelopes of incandescent gas. We turn from the examination of our solar system to this vaster field, and we ask if our interpretation is proportionately strengthened.

Here we must proceed cautiously, and distinguish particular speculations that may be altered from large generalisations which are definitely established. The critics of science —*apparent rari nantes in gurgite vasto*—often miss their aim. They smile at vague suggestions of a thin red sun gilding the struggle of the last men—not that they have the slightest inclination to believe that the Sun is eternal—and they sonorously repeat really disputed statements. For instance, the birth of a star from a nebula is not at all so established and accepted as the theme of this book Not only have there been for years rival hypotheses, but of late years some have professed a doubt whether the general theory is right in any form. Speaking to the Astronomical section of the British Association in 1915 Professor Fowler said that the determination of the evolutionary sequence from a gaseous nebula to a red star was now "complete": ninty-nine per cent. of the spectra of the cosmic bodies, of which we have several hundred thousand, fall into line. But in the preceding year an equally distinguished British astronomer, Professor Eddington, had stated in an important work ("Stellar Movements and the Structure of the Universe") that we must regard with respect the view that the nebula is the *last*, not the *first*, stage of evolution; and he quoted in friendly terms the saying of Mr. Innes, that the fact that we have seen stars turn into nebulae ought to outweigh any amount of speculation about nebulae turning into stars. Since 1915 the opponents of the nebular theory in its strict form, have, perhaps, increased.

At the risk of making the reader feel that he is lost in a maze of controversy I will add that many astronomers would not admit, as we shall see later, that we have seen stars turn into nebulae. Indeed, it seems to me that Professor Eddington contradicts himself in regard to one of the chief grounds of his scepticism—the speed of planetary nebulae. These things we will consider later. They are quoted here only to show how involved the question of evolution is. I will endeavour to make the position plain to the reader; and, in order to keep a sober course of exposition, will give in this chapter the most solid part of our information about the stars and set forth the conflicting views of stellar evolution in the next chapter.

It is agreed that the stars are, like our own sun or star, globes of incandescent metal cooling, and the chief basis of this conviction—apart from common-sense perception that fires are never eternal—is that they fall into three great classes. Common experience would tell us that globes of glowing metal will pass through three stages: white (or bluish white) heat, yellow heat, and red heat. The stars fall into those classes. Colour is, however, only a general and superficial test. In the case of these immensely distant and variously-grouped bodies, the test has its limitations. If there is any, even the thinnest, matter in the intervening space, the farthest distant of the suns may have their light reddened (as that of the sun is in a fog or at sunset) by passing through a greater depth of this matter. Red light is less refrangible—less bent out of its path—by such a medium, and some stars may, on this account, seem red, when, on a nearer view, they might be yellow or white. There are other colours, which are not yet understood, in many stars.

We need a more delicate test, and this we have in the spectrescope. In this, as I said, the light of the star is admitted, after passing through the telescope, by a narrow slit (say, half an inch long and one thousanth of an inch wide) into a tube which conducts it through a series of prisms or a fine grating. It then passes, analysed into its various colours or waves, through a small telescope, and is registered on the photographic plate. The photograph shows a continuous band of light crossed by a number of dark lines, as we saw in the case of the Sun; and these lines indicate the elements, and partly the condition of the elements, in the stars, as well as the motions of those globes. The Harvard Observatory has especially undertaken this work, and has taken and classified the spectra of, to date, more than a quarter of a million stars. The scheme of classification there adopted is now generally received in the astronomical world. Professor Fowler says that we have "fully established" the fact of a decreasing temperature in the various classes of stars, from white to red, but there are, as we shall see, certain reserves to be made.

The inexpert may imagine that the interpretation of these lines is a matter of speculation. Substantially it is not. We can volatilise metals and so obtain photographs of their spectra at various temperatures. In some spectroscopes electrodes for thus heating metals or gases are fitted in front of the tube (or "collimator,") and on the same photographic plate, or by direct observation, we have the lines of the metal above or below the line of the same metal as it is in the distant star. We compare iron, for instance, under our noses with iron perhaps 5,000 billion miles away. Temperatures up to more than 4,000 degrees can be obtained in the modern "super-spark," and that is probably hotter than the temperature of red stars. The hotter stars, which are generally believed to have a surface-temperature of at least 10,000 degrees — some say as much as 30,000 degrees—go far beyond our power of comparison, but the behaviour of the lines follows a consistent path.

The Harvard classification begins with gaseous nebulae, which show bright lines on a dark ground (P Type), then gives stars which show bright lines on a dark ground (Q Type), and thirdly stars, which have bright lines on a faintly coloured back-ground and some dark lines (O Type). To these types, which are believed to illustrate the order of development, I will return in the next chapter. Let us confine ourselves here to less disputed matters.

After the O stars the Harvard scheme gives seven classes of stars headed B, A, F, G, K, M, and N. There are numerous sub-divisions of each, as the theory of evolution would expect, and one type shades into the other. But the general headings are useful as a temporary scheme of large classes. Father Cortie once genially remarked that the naming of the classes was "B A F ling," but it would be premature to alter it. The scheme is so serviceable, and seems to correspond so closely with reality, that the Harvard astronomers can, as a rule, classify a new spectrum almost at a glance. Only one star in 500 fails to fit the scheme. And this scheme affords the strongest confirmation of the conclusions we draw from an examination of the solar system.

Stars of the B Type are the hottest of the seven classes. The absorption lines of helium gas are the most prominent. Hydrogen also is prominent, and the lines of oxygen, nitrogen, carbon, silicon, and magnesium, which are absent from the earlier series, now appear. These stars are, as I said, assigned a temperature of 10,000 degrees at their luminous surface, and it is this intense heat which restricts the formation of metals. They are stars in the prime of life. As several stars in the comstellation Orion are of this type, the group is often called the Orion or helium group. To the eye they are the intensely brilliant blue stars. They number about 800, and some believe they form one cluster.

The lowest sub-divisions of the B group pass insensibly into the earlier of the A group. Here the helium lines lose their predominence, and the hydrogen lines gain. The metallic lines also increase. The most brilliant star of our sky, Sirius, is the leader of this group, and his name is often given to it. Vega and Castor also belong to it. In 1914 a star of this type was found to have a low luminosity, but the rule is that these stars have an intense blue-white brilliance. Only the increase of the absorbtion-lines of the metals shows that the temperature is falling: that denser masses of metallic vapours are gathering about the globe.

In the three following classes (F, G, and K) the lines of the metals predominate: in other words, the absorption-layer of metallic vapours increases, and a decreasing temperature is indicated. There is, of course, no sharp lines between the classes. The hydrogen lines steadily decrease, and the metallic lines steadily gain. Procyon is the leader of the first group: a group between the bluish-white and the yellow, in which the lines of calcium assume a marked predominance. Our sun, with Capella and Pollux, illustrates the next type. In this type the metallic lines overtake in strength, and gradually surpass, the lines of hydrogen.

The solar spectrum which I have reproduced on an earlier page is typical of the class, and the study of the Sun which we have made will suggest their characteristics. They are the yellow stars, and the increase of the dark lines suggests that they are more aged members of the stellar family than the preceding types. In the K class (exemplified by Arcturus and Aldebaran) the stars shading from yellow to red, the metallic lines increase, and the violet end of the spectrum, which is intense in the earlier types, grows fainter.

There follow two classes about which there is a good deal of dispute in astronomy to-day. These are the red stars. The natural order of evolution, on the line of a decrease of temperature, is from blue to white, then yellow, then to an increasingly deep red. But a moment's reflection will show that here there is room for dispute. Your poker is red-hot *before* it is white-hot, as well as when it is cooling. If a star is red, how can you say whether it is cooling or growing hotter? Obviously, the question is whether a star *does* pass through a red stellar stage before it reaches its prime, or is at its hottest when it passes from a nebula condition to that of a star. The Harvard classifiers, who are perhaps still generally followed, suppose the latter course. The mass of glowing gas, with bright-line spectrum, becomes an Orion star at full heat. But this is disputed. It involves a theory of the origin of stars, and, as I said, the field is occupied by rival theories, each of which has a very respectable following. I am not concerned with the origin of stars as such, and wish to make it clear that, contrary to a popular belief, there is much more agreement about the end of stars than about their beginning. But since the controversy here turns precisely on the red and later stars, something must be said about it. More will be said in the next chapter, when I arrange in some order the various views of the whole course of stellar evolution.

Let it be understood then that it is not disputed that the B stars are in the prime of life, and that they progressively cool, possibly with fluctuations, when they have passed that stage. But it is disputed whether the yellow and red stars are all to be placed *after* the white stars. Sir Norman Lockyer, for instance, who does not admit that stars are formed by the condensation of gaseous nebulæ, maintains that red and yellow lead up to, as well as follow, the white stars. He arranges their spectra in ascending and descending series. The M stars are ascending. The N stars he regards as the most advanced.

Then there are the Planetesimalists, who also reject the nebular hypothesis (in its strict form). The star, they say, is not formed from gas, but from a cloud of small particles of solid matter. We shall therefore, as they condense, see them rise from red to white heat, and then descend.

But the strongest opposition, the one which has, apparently, made the most impression, is that especially formulated by Professor Russell. He has generally convinced astronomers that stars of the M, or red type, are really of two very distinct classes. There are giant red stars and dwarf red stars. Some are great swollen globes of little density, others more compact, though of about the same mass: football and cricket-balls, someone has said. Antares, for instance, is one of the M. type. Sir F.W. Dyson points out that, although it is only twenty times the mass of the Sun (so it is calculated) and is red, yet it gives out at least 600 times as much light. If these figures are correct, it would be 10,000 times the size of the Sun, 1000 times less dense or compact, and only one sixth as luminous at its surface. This would be a typical "giant." Since it and its colleagues are so much less dense than the Sun and the blue stars, they cannot be regarded as older. They would in that case be more condensed.

Hence some astronomers hold that density is the real test of age. The older the star is, the more concentrated its material will have become, since, whatever supplementary heat may be derived from radio-active substances, the chief source is the shrinking of the mass. So Professor Russell and those who agree with him would divide the yellow and the red stars into two types. Some are approaching white heat: some have passed it. The evolutionary order really is, they say: M1, K1, G1, F1, A1, B, A2, F2, G2, K2, M2, N. Just as if you were to classify a large body of men according to their strength. The younger as well as the older would have to be classed as weaker.

It is plain that until the early stages of the evolution of a star are settled, we cannot point dogmatically to any red or yellow star and say that it is dying. But the reader must be on his guard against sceptical remarks that are sometimes made on this account. Whether the classes other than B are or are not to be divided, they represent stages of evolution and temperature. They tell the story of a star in so far as the theme of this book is concerned. The spectroscope is a kind of magical eye with which we look at the universe and discover that its hundreds of millions of stars are of different ages. A drama of the most portentous dimensions is unfolded before us, beside which the hundred million (or, it may be, thousand million) years of the life of our sun seem small.

Take Canopus. We do not know its size or its distance, but we know, since it offers no "parallax," that it is more than 1000 billion miles away. It is therefore many thousands of times more brilliant than the sun : most astronomers calculate that it must give out at least 10,000 times as much light as our Sun, and some say 50,000 times. Yet it is not in the prime of life : its spectrum is between F and G, or less suggestive of heat than that of Sirius. Now Sirius we know to be twice the mass of the Sun, and 48 times as luminous. It is a fair assumption that a star which has a lower type of spectrum than Sirius, yet is equal in light-power to 10,000 suns, must be enormously larger than the Sun. The life of such a star, whether it has passed or is approaching its prime, suggests a period of time which begins long before and will long outlive the story of the Sun.

Take Antares, the red star. If the Russell theory is correct, and it is a young sun, yet has at least twenty times the mass of our Sun, it will take ages to reach its brilliant prime and an equally vast period to cool. It opens an appalling vista of the future. If, on the other hand, it is a dying sun, with the vapours gathering about it, its condition points to an era of the past which dwarfs the long history of our own central luminary.

We have, therefore, in spite of all obscurities and disputes, obtained a wonderful view of the universe. It has, like a city of men, its generations. Its citizens are of all ages. It does not matter even if our Sun is claimed to be on the up-grade instead of the down-grade. This would merely draw out that future of millions of years for mankind at which those who are unfamiliar with astronomical matters so instinctively, yet so foolishly, smile. There is no middle view, the great majority of the stars are not in the prime of life. They are living illustrations of the truth which we deduced from a study of the Moon and the Sun and the planets. The universe is a collection of globes of gas or metal, or both, cooling down. If they have first to climb from red to white heat, so much the longer the process. The stages of later development remain uncontroverted.

It may be added that another surprising feature of the stars is at present being studied, and it may before long help to settle the disputes about classification. Evidence has for some time accumulated that the speed of stars increases as they grow older: or, to avoid controversy, as they follow the scale of the classification. At present this baffles astronomers of all schools. The planetary nebulæ, which the Harvard scheme puts in an early phase of development, ought, according to this law, to move very slowly. But they move even more rapidly than the yellow or red stars, to say nothing of the blue. Of the thousand or so stars whose speed has been determined the helium stars move at about 8 miles a second, the hydrogen (A) stars at 14 miles a second, the yellow stars at 18 miles a second, and the red at 21 miles a second. But the average speed of 42 planetary nebulæ which have been examined proved to be nearly thirty miles a second, radially. We shall see that other nebulæ, even gaseous, have been found to be in fairly rapid motion—spiral nebulæ in *very* rapid motion—and this has greatly intensified the controversy about the early stages of stellar development.

But at the other end of the scale this supposed law of the increase of speed with age has equally disturbed the new views. The red stars move more rapidly than the white and the yellow, and in this respect there is no distinction of giant and dwarf. The M stars, as a class, travel swiftly, and this seems to encourage the Harvard scheme. The point is enforced when we discover that red stars which form close doubles with other stars are relatively far from their companions; and it is believed that this separation of companion-stars increases with age, so that a large separation ought to mean a great age. This feature will be discussed later.

I am frankly stating the great obscurities and difficulties of the whole question. The immense accumulation of data in recent years has disturbed the simplicity of the older theories. The stellar universe is more varied and complex than was imagined. Every theory of the order of development has its difficulties. This is the sober argument of those who would have us refrain from speculation until the observation of facts has proceeded very much further. That seems to be an extreme conclusion, for even an abortive speculation has its use, as well as its interest. It is a mould in which one attempts to fit the facts, without injuring them. If they do not fit, let it be discarded and another tried.

But the reader must steadily hold in view that the general truth of evolution grows stronger through all these vicissitudes of particular applications of it. If it prove true that double stars recede farther and farther from each other as they advance in age we shall find, in the very varied orbits of double stars, a new clue to, or check on, the order of development. As far as our present knowledge goes, the spectrum of these stars also advances along the scale, in proportion to their divergence from each other. That is another promising line of research. If, again, it proves true that the individual velocity of cosmic masses increases with their progress in development, we shall have a fresh check upon the evolutionary classification. On this point, however, great caution is required. The suggestion has been made that in a nebulous stage the mass is less influenced by the gravitational control of the universe, which increases as the mass becomes denser. That does not, however, seem to accord with the facts, and the law of motion may prove complex. It is at present very little understood.

Thus the new and disturbing discoveries promise in the end a more satisfactory settlement of the order of evolution. When the three or four lines of inquiry are brought into agreement, it will be difficult to resist the order they indicate. At present we must be content to know that the existence of a great variety and continuous graduation of stages of temperature has been established. These cosmic masses are cooling down, and are destined to extinction, even if some must rise before they begin to decline. The universe fully confirms the lesson we learned from our Sun. That is all that concerns us here.

I may therefore close with a description of the last two classes of the Harvard scheme. In the M stars the blue and violet end of the spectrum continues to fade, and the dark lines grow broader and more numerous. Such are Antares, Betelgueuse, and Mira Ceti. A large number of the stars of the class are variable, or show periodical and considerable variations in the light they emit. The meaning of this will be considered in the next chapter. The outstanding characteristic is the number and great breadth of the dark lines. It is recognised that some of the broader, or fluted, lines indicate the presence in the star of titanium oxide. The correspondence of this with the spectrum of a sun-spot, which is an area of denser and cooler vapour, is apparent. These stars are wrapped in dense, comparatively cool vapours which permit the formation of compounds.

In the last, or N class, the degeneration continues. The violet end of the spectrum is very faint. The whole band of colour is covered with dark lines, some of which are very thick. Experimental research into these lines shows that they come from compound substances such as combinations of carbon and the gases. This indicates a further degree of cooling, and it is agreed to place these small deep-red stars (such as 19 Piscium) in the last phase of visibility. It may be that in their vicinity the struggle for life has entered upon, or even already passed, its final stage.

A subsidiary class, R, was created a few years ago to accommodate a small number of stars whose spectra show the heavy dark lines of the N type strangely associated with a good development of the violet end. These are not yet understood, and we must expect that in a population of hundreds of millions there will be divergences from type which will long puzzle us ; just as there are abnormal specimens of any biological species.

For my purpose it suffices to disentangle from the knot of speculation and controversy the general truth I have indicated. When we place together typical spectra of the various classes we have the confirmation which I proposed to seek. Omitting the earlier classes, we have, from the B or helium type onward, a plain indication of increasingly thick absorbing-layer and cooler su face, But we must remember that these are merely points selected out of a continuous series. The hundreds of thousands of spectra exhibit so sensible a gradation from class to class that there are already 40 subdivisions, and the number grows. It is a remarkable achievement for a science (spectroscopy) which is not a hundred years old.

In our study of the solar system we found a number of bodies which corresponded entirely to the theory that they were different stages in a process of cooling. The correspondence is so close, and the facts fail so completely to suggest any other theory, that it is beyond the region of serious doubt. Examining the Sun closely we found it possible to imagine various stages of the process other than that we actually find in the Sun; stages earlier than the present condition of the Sun, and others later, yet not so advanced as the condition of Jupiter. In the broad heavens we now find these stages exemplified in myriads of suns. We have stars so hot that the absorbing-layer consists only of a few metallic vapours mingled with masses of the lighter gases. As we go down the scale, the metals, the elements which are dissociated at the higher temperature, successively appear, and the absorbing-layer of vapours deepens. In the end gases and metals unite, which implies a still lower temperature. The phases of the development of a star are no longer a mere creation of the scientific imagination.

CHAPTER VIII

THE LIFE-STORY OF A STAR

One may imagine a very punctilious or reluctant person insisting upon that effect of our knowledge which I have candidly described. You have, he may say, thousands of suns at various degrees of temperature, but you cannot prove that any are actually dying. If some of the red stars are rising, why not all of them? Why not assume that all the red, yellow, and white are in a stage before the blue stars? Or, again, is it not possible that all began their luminous career together, and the larger take longer to cool?

The first difficulty is, as I said, outside the range of exact disproof on account of our uncertainty about the early course of a star. It is therefore advisable to devote a chapter to a simple account of the various views of astronomers on this subject. But the difficulty itself ceases to be serious when we confront the situation intelligently. Astronomers, whatever their views of the origin of the stars, assume that at least a proportion of the cooler suns are sinking. Consideration of their density and motion is, as I said, already a partial check on the spectroscopic test. The density of double stars can often be positively ascertained and compared with that of our sun. Our sun is relatively dense, and so we have strong reason to say that it is past its prime. But the general answer to the difficulty is that in an enormous population of various ages it is obviously absurd to suppose that all are less than middle age. If all the stars were blue or white or yellow, we might imagine that there had been a definite beginning of the system at some time or other. This is not what we find. We judge the stars by analogy. What we see is one generation, of all ages, from the embryo to shrivelling decay.

The second difficulty also vanishes upon examination. The condition or spectrum of the stars is not related to their mass. They are not so many globes of metal, raised to a white heat *at one time*, the smaller cooling down first. The stars differ less in mass than we used to think. It would not be safe, Professor Eddington says, to place our Sun below the average. Although our Sun is not of an intensely luminous type, if we compare it with 19 of the nearest stars it is brighter than 14 of them. On the other hand, suns that we have reason to regard as immensely larger have much the same type of spectrum Science does not point to a definite beginning· It suggests a flow, a rise and fall, as in a generation of living things.

To understand this completely we must glance at the whole story of a star. though it is not strictly to my purpose. If therefore it is found to be clouded with controversy and unsolved problems, the reader must remember that my main point is independent of any theory of the origin of a star. But these theories have crossed our line of inquiry so often that a brief account of them will probably be welcomed.

There are three fundamental theories of the origin of a star, and two at least of these have a very large and respectable following among modern astronomers. The inexpert reader is apt to be bewildered by the conflicting currents of astronomical literature on the subject, and the sceptic is very prompt to press his claim that the so-called "solid" teaching of science is but a stream of ever-changing speculations, similar to, but less long-lived than, the succession of creeds and philosophies. It is not superfluous to reflect that these speculations do not constitute the "teaching" of science. They are interesting attempts to put a broad and luminous interpretation on those facts which do constitute the solid contribution of science to contemporary culture. Scientific men differ amongst themselves about them, and never represent them as other than theories which at the time seem to accord with and illumine the facts.

But the best answer to this sort of complaint about the changes and contradictions of scientific opinion is to trace patiently the permanent growth of knowledge amidst these partial hypotheses. Now there has been, in regard to the origin of stars, such a steady growth of knowledge. There is a central shaft or trunk amidst all these perplexing branches: a theory of the origin of worlds on which all astronomers are agreed. Stars are formed by the aggregation of vast loose masses of matter into globes: this aggregation is due to the force of gravitation, and it is the main cause of the heat of the stars; and when this condensation reaches a certain degree, the heat and light decrease and the star dies. There has been no vacillation on this teaching during a century; and the first part of it at least goes back much more than a century.

The conflict of opinion begins when you ask what is the nature of the diffused material which is condensed into stars. More than a hundred years ago (in 1796) Laplace suggested that this material was gaseous. Sir W. Herschell had drawn attention to the fact that there were in the heavens, besides the brilliant minute points of light, certain dull-white patches, of appreciable extent, which came to be known as nebulae ("little clouds.") One of these, in the constellation Andromeda, which is well over head in the northern winter, can easily be seen with the naked eye, and it will give the reader some idea of the origin of the name. Herschel at first fancied that these were separate universes at an immense distance but he later concluded that some at least were enormous masses of luminous gas, and the spectroscope, when it was invented, confirmed this. Laplace's theory accordingly took deep root in astronomy. There were nebulae, or masses of diffused gas: there were partly formed stars, with great gaseous envelopes: and there were sharply defined globes with more moderate atmospheres. The theory seemed to be but a description of stages of world-making which we actually see.

But Laplace supposed that in condensing the nebula threw off circular rings at its successive fringes, each of which condensed into a planet, and this part of his theory came to be questioned. Most mathematicians declared that the theory did not survive close dynamical consideration, and with the advance of our instruments, we discovered that the bulk of the nebulae, which seemed to be in process of condensation, were, not ring-shaped, but spiral. In fact, the universe was much more complex than early observers thought. Stars were double, triple, and multiple. Some formed great families or clusters. Our solar system, a single star, was a misleading model. So the famous "nebular hypothesis" began to receive very critical treatment on this side.

Most astronomers, looking to the gaseous nebulae, still held that these diffused masses of gas are the starting-point. Sir Norman Lockyer, however, put forward what is called the "meteoritic hypothesis": the theory that the diffused material to be gathered together into stars was not gas, but a vast swarm, or number of swarms, of meteors. He found many adherents, but the "planetesimal hypothesis," of more recent origin, has a larger following. This supposes that the material that condenses into globes—it is always a question of condensing a very diffused material into globes—consisted of a vast mass of tiny particles ("planetesimals") which had been shot out of pre-existing suns. Thus our Sun is believed to have had an earlier life and died. Then, it is suggested, another sun approached within danger-limits, and, by tidal action, tore open the crust on opposite sides of our extinct sun. The imprisoned matter shot out at a terrific rate, forming long streamers, which were coiled spirally round the Sun by the influence of the other star. The matter of these streamers condensed into our planets. Thus we apparently get an explanation of the spiral form of the nebulae, as well as a theory of condensation, which is, it is claimed, free from dynamical difficulties.*

It will be seen when we consider these rival theories in the general outline which is all that the inexpert care to master, there is much more

* Professor Bickerton (*The Romance of the Heavens*, 1901) had for years contended that a "partial impact" or "grazing collision" was the starting-point. He supposes that part of each of the grazing stars is vaporised and fused into one mass.

common ground than is often represented. Even if we add what may be called a fourth theory, there is still a continuity. Radio-activity has, as we saw, inspired a theory that globes may burst when the pressure of the hardening crust reaches a certain pitch. It is therefore suggested that the beginning of a star may be the bursting of a dead star, which, like the approach of another star, would scatter its contents over space. Here, still, the formation of a star is a gathering together, with increasing temperature, of an extremely diffused mass of matter.

We may go a step further in the way of finding common ground if we consider more closely what a "nebula" is. We shall see then that it is not surprising that the nebular theory has changed its form, since the nebula has, on closer acquaintance, ceased to be a simple thing. To say, as is sometimes said, that the nebular theory is discarded, is ridiculous. Nebulæ and nebulosity (great stretches of cloudy stuff) are increasingly discovered with every extension of our instruments of research, and their connection with the birth of stars is regarded by the great majority of astronomers as beyond doubt. But the nebula need no longer be claimed to be a mere cloud of gas.

Many now doubt if a mere cloud of gas *would* condense by its own gravitation.

Something like 10,000 nebulae have been registered individually in astronomical catalogues, but this is a small fraction of the known number. Keeler, an assiduous student of them, estimated that about 120,000 of them are shown on our plates of the heavens. More recent students have found that this is far too low an estimate. The number known may be nearer to half a million. What is more important is that they fall into quite different categories. It is usually said that there are gaseous, or irregular nebulæ: spiral nebulæ, which are not gaseous: and planetary nebulæ, which show a dense white disk (suggesting that of a large planet) in the centre.

Herschel, as I said, wavered between the opinion that the nebulae were separate universes, and the view that they were masses of gas, about to become stars. Now we have seen in an earlier chapter that the spectrum of a gas (unless it is at a great pressure) consists of thin bright coloured lines on a dark ground, while a solid or liquid (or gas under pressure) gives a continuous light band, perhaps crossed by dark lines. When this test was applied to the nebulæ, they fell into two classes. Some were definitely known to be great expanses of luminous gas, since their spectra showed bright lines only; others gave the opposite type of spectrum. Further, with the improvement of photography, a large number of the nebulae were seen to have a spiral form. It was these which gave a continuous spectrum. Let us first consider the gaseous nebulæ, of which about 150 are definitely recognised.

The great nebula in Orion is the chief member of the group, and the abundant photographs have made its appearance familiar. That it is a vast expanse of luminous and extremely attenuated gas the spectroscope has put beyond doubt. Its spectrum consists only of the bright lines of the lighter gases, helium, and hydrogen, and a third gas, known only in nebulae and nebulous stars, which has been called "nebulium": it is considered to be one of the lightest of the elements.

What the size of this great cloud may be we do not know. If one remembers, in examining the photograph, that every minute star-point represents something like a million miles, one has an incipient idea of the colossal magnitude of the mass. It lies beyond the range of measurement of distance, or is probably more

Photo by] [*The Yerkes Observatory*

THE GREAT NEBULA IN ORION.

[*Face p.* 172.

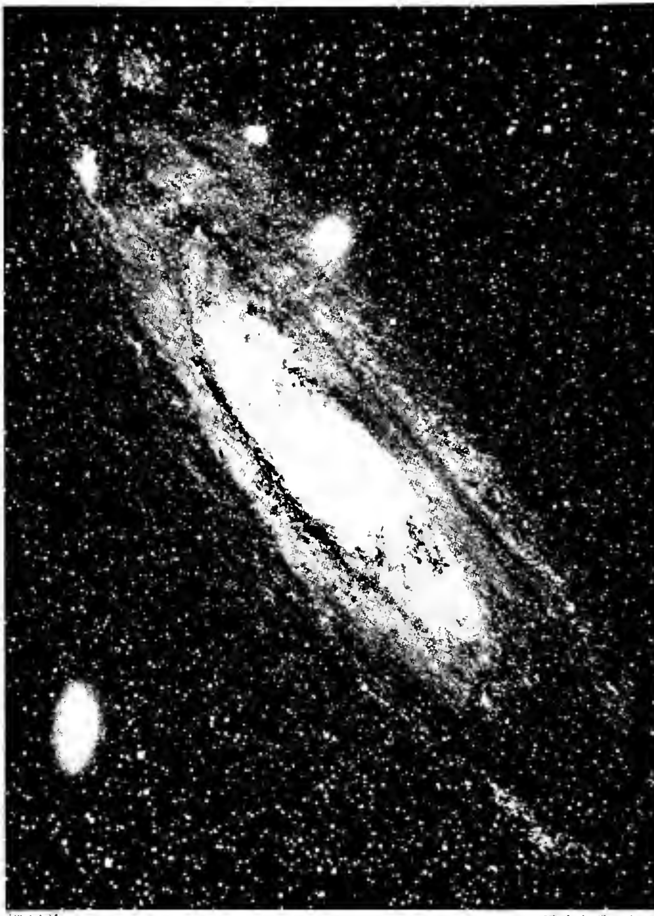


Photo by] [The Yerkes Observatory.

THE NEBULA IN ANDROMEDA (see p. 177).

[Face p. 173

than 1,000 billion miles away. If we were to suppose it just beyond the range of measure ment, its diameter would be at least 150,000, 000,000,000 miles, and finer instruments trace enormous streamers of it winding over the whole constellation. But we have no reason to suppose that it *does* lie just beyond the range of measurement. We may say, at the most, that there is good reason to regard it as within the limits of our stellar system. It is a stretch of luminous gas that would certainly extend from here to the nearest star, and may be as large as the whole space covered by the inner family of stars to which we belong.*

Here then we have, not a cloud of gas that might slowly, with vast outpour of heat, contract into such a solar system as ours, but the material to make a large number of worlds. The stars in the dark space on the photograph, which looks as if giant shears had cut an enormous piece out of the filmy stuff, cannot be proved to be actually within the space. They might be merely in our line of sight to it. But spectroscopists declare that they find an

* Pickering recently estimated its distance as 400 billion miles, which would give the brightest part of it alone a diameter of 35 billion miles ("Harvard Circular" No. 205, 1918), but this is uncertain.

affinity between the spectra of some of these stars and that of the nebula, and they conclude that there is a physical relation. They are also similar in their movements. Hence the strength of the conviction that this enormous expanse of gas is the stuff that worlds are made of, and is being slowly used to construct worlds: possibly when some large body enters and affords a nucleus of condensation.

The most recent examination of the nebula seems to confirm this. The source of its light we do not yet know. If it is merely a great stretch of infinitely attenuated gas, it is difficult to see how it could have a high temperature, and so the first impression, that it was a mass of glowing gas, a "fire-mist," was generally abandoned. A temperature of—300° was suggested. Electric or some unknown action was supposed to render the frigid gas luminous. There is, however, a tendency to revert to the first view, and some have assigned the nebula a temperature of 15,000° (*Astrophysical Journal*, October, 1914). Dr. Campbell, the director of the Lick Observatory, says in one of the most recent discussions of stellar evolution (*Popular Science Monthly*, October, 1915) that to assign the light of the nebula to heat is "the simplest hypothesis now available." We have, however, discovered that the nebula is not the quiescent mass it was supposed to be. Some rotational movement, as well as irregular movements of various parts of it, have been detected. We are tempted to see in these the early stages of condensation. It can be shown theoretically according to many that condensation would lead to a rotational movement—hence the ultimate whirl on an axis of all cosmic globes—and collisions at the outer parts might assist such movements. When we connect these movements with the nebula's structure, as recently detected in the spectroscope, the evolutionary view is confirmed. The centre of the nebula (and the gaseous nebulae generally) gives lines which are unrecognisable, but are suspected to be due to helium under special conditions. Round this there is a great sphere giving the lines of helium: beyond this a larger sphere giving lines of hydrogen; and outside this again is a region having an unknown radiation which seems peculiar to nebulæ. This is fair evidence that concentration is proceeding. Some however, think an invading body is needed as a nucleus.

The Ring-Nebula in Lyra and other gaseous nebulæ were found by Mr. Wright to have essentially the same structure. But we need not suppose that these vast luminous clouds consists only of gas; indeed, some astronomers find it impossible to believe that such expanses of extremely attentuated gas could hold together without a mixture of solid particles. If space contains any large proportion of "cosmic dust," travelling at a high speed, much of it would be apt to be caught in these gaseous nets. There are positive indications that nebulæ must contain such matter. There is a nebulous appendage to the star R Coronae Australis the light of which increases or diminishes with the light of the varying star, and it would seem that the light of the star is reflected from the surface of the nebulæ. Mr. Slipher has found that the nebulosity round Merope, one of the chief stars of the Pleiades, has a spectrum which is a fainter copy of that of Merope itself. He suggests that the nebulosity is, or contains, a mass of scattered dust which reflects the light of the star.

This much may be said in the way of conciliating the various views as to the nature of the stuff of which worlds are made, but we have to proceed very cautiously in this direction. Let me give two illustrations. Suggestions of cosmic dust in space have grown of recent years, and this dust ought to have a scattering or screening effect on the light of the more distant stars. Careful research found that there was no appreciable interference with their light except at enormous distances. Mr. King, of McGill University, then surprised astronomers by showing (*Nature*, August 26th, 1915) that even this moderate assumption of interference with the light of the stars would, when closely investigated, lead to the couclusion that our system contains 300,000 times as much matter in the form of loose gas and dust than in its hundreds of millions of incandescent suns. The second warning may be taken from the (non-gaseous) nebula in Andromeda. Its distance must be at least 1,500 billion miles. If we put it at this distance its diameter must be at least 50 billion miles, and Professor Jacoby has calculated that if the nebula (taken at this minimum size) were 300,000,000 times less dense than our Sun it would nevertheless, in view of its enormous size, even at that great distance attract the Earth as strongly as the Sun does. This nebula, however, is, as I said, regarded by many as a distinct stellar system.

These considerarions greatly encourage the older view that these masses of cosmic stuff are in the main vast expanses of gas in an infinitely attenuated form, as their spectra suggest. And the further our research into the universe goes, the more we find of this nebulous stuff. In such great clusters as the Pleiades we find it winding in every direction and mantling the stars. It lies along enormous stretches of the Milky Way. In places it is dark—a dark shadow upon the star-field—sometimes faintly lit at the margins. It may consist of the gases and electrons shot out of the myriads of flaming suns: it may be an original growth from ether: it may have both, or many, sources. It may be the thin ghost of worlds that have burst, or destroyed each other. But that it represents the beginning of new worlds we have the strongest ground to hold. It is also significant that the blue stars and the gaseous nebulae are mainly found in the region of the Milky Way: the red and yellow stars are not. The nebular hypothesis is very far from dead, though it is not now held in the Laplacean form.

The next step in tracing the origin of a star is not clear. We have two further types of nebulae, the spiral and the planetary; and the first idea was, naturally, to regard these as further stages in the condensation of the gaseous stuff. Here, however, there is much difficulty and controversy.

The spiral nebulae are remarkable and mysterious structures. I have in an earlier chapter given a photograph of one which lies, like a great catherine-wheel, square to our line of sight, so that the typical structure of a spiral is clear. Two vast luminous arms start from opposite parts of a central mass and coil spirally round it. This structure is, as I said, regarded as peculiarly agreeing with the Planetesimal Hypothesis, or the more general idea that two stars may at times approach each other too closely, and by their mutual tidal action destroy each other. It is plausibly shown that such an encounter would, or might, draw out the flaming entrails of the star in these spiral wreaths.

But the size of these stupendous structures must not be forgotten. Take the great spiral nebula in Andromeda. This object is turned more or less edgeways to the Earth, but the dark rifts and luminous streams and general contour convince us that it is a spiral. Its size is, as I have explained above, appalling. If we assign it the minimum distance of 1500 billion miles, it must measure at least 50 billion miles from end to end. It may be enormously more distant and larger. Moreover, whatever its real structure is, it is in a more advanced stage than the gaseous nebulae. It gives a continuous spectrum crossed by dark lines. This means that if it is gas, it is gas at a great pressure and with cooler vapours surrounding the incandescent matter. That this could be the outcome of the encounter of two suns is unthinkable. Even two stars like Canopus would not produce anything approaching so vast an object. And, imperfect as our research into the spiral nebulae is as yet, we know that a colossal size is common among them.

This difficulty pinches also the nebular hypothesis. Such objects as this have no relation to the relatively small nebula which is believed to have been condensed into the globes of our solar system. There may, of course, be multitudes of small spiral nebulae in the heavens, but clearly we must hesitate to put these vast structures as the next phase in the development of a nebula into a star. They may be conceived as forming immense clusters of stars. In that case, however, we no longer have the model of a spiral nebula for the formation of an individual star. It is the mighty mass as a whole that is spiral.

Hence it is that, as I said in an earlier chapter, astronomers are more and more disposed to regard these objects as not true nebulæ (diffused clouds of matter) at all. Mr. Slipher has conjectured that the Andromeda nebula may be an enormous mass of cosmic dust (a dark nebula) lit by a large central sun, which shines brokenly through the mist. This again is irreconcilable with its stupendous size; nor does the structure of the spiral nebulae which we see facing us at all encourage this view. They have knots and patches of brilliant light along the arms; there are immense dark lanes between the arms and the centre; and the size of the centre is often very small in comparison with the whole.

Many therefore now regard the spiral nebulae as "island universes," or other stellar systems than ours. Not only their size and unknown distance, but other features seem to suggest this. Andromeda has not merely a continuous spectrum, but it is a spectrum of the K, or solar, type. This is, as far as our examination has gone, common among spiral nebulae. Further, while the gaseous nebulae nearly always lie on or near the plane of the Milky Way, the spiral nebulae are all nearer to its poles: which confirms the idea of disconnectedness. In fine, they travel at enormous speed. Andromeda is moving away from us at about 250 miles a second: a nebula in Virgo at about 800 miles a second. As we saw, it is believed that speed increases with age. These speeds therefore not only do not favour the idea of an early stage of evolution, but some of them are beyond anything we know within our stellar system. So it is thought that they may be separate universes. vast systems of stars like ours, separated from ours by great abysses of space. Some suggest that they may be collections of relatively small stars whose light blends together at that distance.

This is a fascinating speculation. The mind delights in grandiose spectacles of immensity, and the idea that this stellar system of ours, this collection of perhaps a thousand million worlds, is but one of many such systems which we faintly discern across black abysses of space, is certainly one of the most grandiose ever presented to us in astronomy. But it is, if I may say so, a little too grandiose for us to accept it on the present imperfect evidence. It is confidently said by astronomers that the greater part of the known nebulae, which may number hundreds of thousands—we have not counted more than those on a few plates—are spiral. Naturally, there is no inherent reason why there should not be half a million stellar systems, or millions of them, each measuring hundreds of billions of miles in extent. But most of us hesitate, and perhaps it is as well to wait until our knowledge increases. Wonderful as our discoveries have been in fifty years, we are but putting together the rudiments of a cosmic philosophy. The universe is like a great photographic plate which science is slowly developing. Only the "high lights" stand out as yet.

There are other difficulties, and many astronomers prefer to adhere for the present to the older view. The structure, when we examine it in the finest photographs, strongly suggests condensing nebulosity, not masses of stars. Many of the stars on the edge of the Andromeda nebulae seem to follow its outline and belong to it, as if parts of it had already crystallised into stars. As to the spectrum, Sir W. Huggins found some bright lines, such as we find in the spectra of early stars. The immense distance—a recent estimate is that the average distance of the spirals is 50,000 billion miles away, but such estimates are very speculative—the vast size and the rapid motion are certainly difficulties, but they cannot as yet be said to prevent us from regarding the spirals as immense masses of glowing gaseous stuff condensing into stars, with cooling metallic vapour encircling the centres of condensation. Of late years it has been noticed that "new stars" often appear in spiral nebulæ. But this may mean either nebulosity or a close collection of stars.

The third class of nebulae, the planetary nebulae, may be said to offer only one serious difficulty. When we examine the photographs of a few we feel strongly that they represent the last phase of a nebula and the first phase of a star. They show great variations of form, but there is a common characteristic: a broad white central disk (like that of a large planet) surrounded by a more or less spherical nebula. The spectroscope finds in them the nebular structure of concentric shells of helium, hydrogen, and nebulium: in some the dark lines of helium and hydrogen (nebulium never shows dark lines) have been found. On the other hand, while the broad nebulous halo connects them with nebulae, the central disk or nucleus is identical with the earliest type of star, the "Wolf-Rayet star," which also has bright lines. Thus both the telescopic appearance and the spectrum encourage us to believe that here is a phase between the gaseous nebula and the early star.

The difficulty is that they travel at a great speed, and, as we saw, the conviction is growing that speed increases only with age. Of 42 planetary nebulae which were tested the average speed was about 30 miles a second, which far surpasses the average speed even of the red stars. From this some conclude that they cannot be a phase between an almost motionless gaseous mass and a star, but must be the debris of a destroyed world: a star which had run its course and attained a great speed. Professor See suggests that two such bodies might collide and form a spiral nebula, which could then condense into a star.

The difficulty must have weight, and must teach us reserve. But the laws of the motion of cosmic bodies are as yet not known in even an elementary fashion, and it seems strange that this obscurity should be allowed to overrule the very strong evidence in favour of the view that they are nebulae passing into the condition of stars. If we keep a mind open to the possibilities of large varieties in the formation of cosmic bodies we are less troubled by the conflict of these antagonistic speculations. Nebulae may, as I said, have various origins. They may be aggregations of the gaseous and electronic matter which is shot out of the stars into space, or they may be actual crystallisations of new matter out of ether. In these cases one would expect them to begin their careers as quiescent expanses of gas, which would begin to collect solid floating matter.* But others may be the wreck of shattered suns which had run their course, and these would presumably have a high speed. Collisions of such nebulae would rob them of their speed, and increase their mass, temperature and condensation. In some conditions the nebulous stuff might condense into meteors, instead of large globes. In other cases it might form spirals. Some recent experiments by Mr. Becker tend to show that long nebulous streamers ("bacula") may be expected to take this form. It is for the future to say if a large diversity may not be at the root of all these difficulties.

When we attempt to take the next step in the evolution of a star we again enter a field of controversy. The classification by spectra places two categories of stars (Q and O) before the blue or helium stars. These, known (after their discoverers) as the Wolf-Rayet stars, give bright lines and a faint continuous spectrum.

*I have expressed this idea in an earlier work. A recent article by W. D. MacMillan (of Chicago University) in the Astrophysical Journal (July, 1918) very ably develops the same idea, and shows how conflicting opinions may be reconciled on that supposition.

Again there is, of course, a great variety and a steady gradation. In the later sub-divisions the hydrogen lines, which are characteristic of the whole, become dark in some instances. As a class they have the same spectrum as the nuclei of the planetary nebulae. We might put it that, while the latter are nebulae with stellar cores, these are stars with nebular envelopes. In other words, they are stars with immense luminous atmospheres of hydrogen and helium. They have a very high temperature.

From this point onward the stars, judged by their spectra, pass through the series I described in the last chapter. The O stars are hydrogen stars : that is to say, they have, enveloping them, such masses of glowing hydrogen gas that it dominates their spectra. The B stars are helium stars : in their spectrum helium, the second lightest element, prevails, and in successive subdivisions oxygen and nitrogen and some of the lighter metals appear. In later classes the heavier metals, and at length compounds of gases and metals, appear. The whole scheme is beautifully suggestive of evolution and decreasing temperature. The condensation of the gases of the nebula into a star would produce a terrific heat, so that they would glow intensely through their whole atmospheres and give bright-line spectra. The atmosphere slowly cools and the metals, which may have actually been formed in the interior, slowly emerge. The earlier stages would probably be rapid, as the loose texture would allow a greater radiation of heat.

The various difficulties and controversies which beset this very attractive arrangement of the contents of our universe in evolutionary order I have already explained. The most serious difficulty is the large size and luminosity and small density of some of the red stars. It is not impossible that a way of harmonising these features with the above scheme will be found. These red stars are very distant—on the average 6000 billion miles away—and very large, and it remains to be seen how far the interference with their light in space affects their spectra, and how their great mass may influence their development. We must remember, however, that the blue stars also are very distant—most of the nearer stars are of the solar type—and that some large and remote suns, like Canopus, are not red.

In short, astronomers are patiently tracing the lines of the evolution of the stars, and are not yet agreed upon a scheme. Astronomy is a rich field for speculation, and possibly some of the new ideas will disappear, and the temporary difficulties be adjusted. That the stars are evolving no one with even an elementary knowledge can doubt.* If to-day we had no traces of earlier civilisations and of prehistoric man we should nevertheless, from the immense cultural varieties of the race, be not only confident of human evolution, but able to reconstruct its lines to a great extent. That is the position in astronomy. We are confronted with objects in every stage of evolution. It will not be surprising if one generation does not suffice for the perfect arrangement of these stages. As far as the special theme of this book is concerned we have already a satisfactory agreement. The cosmic process consists in the concentration of immense diffused masses of stuff into globes: the terrific heat caused by this concentration makes the globes incandescent: the heat slowly sinks, when a certain stage of contraction is reached, and the stars slowly die. On that there is no contro-

*Dr. Campbell says (*Popular Science Monthly*, Nov., 1915) that the "essentially unanimous view" of astronomers favours the line of evolution I have chiefly followed. This is an overstatement, but it certainly shows that astronomers are not all "at sixes and sevens."

versy. I have described the existing controversies in order to make this point clearer.*

*Further recent articles by astronomers on evolution are ; one by Dr. Jeffreys in *Nature* vol. 101, pp. 447-9 (tracing the origin of our solar system to the catastrophic approach of two stars 3,000,000,000 years ago) and one by Prof. Perrine (a paper read to the National Academy of Sciences at Washington in March 1918) suggesting that, while all stars are slowing down, some may be in parts of space where they sweep up much cosmic matter and have their life renewed and prolonged.

CHAPTER IX

VARIABLE STARS

It is often said that, besides the evidence of the general course of stellar development which I have just summarised, we have certain special indications of the later stages. In estimating what will be the probable line of our Sun's advance toward extinction we assumed a phase in which the vapours, and especially the compouuds which are beginning to form temporarily in the spot-regions, will grow much denser and obscure the disk. This seems to be the condition of the M and N stars, and, apart from the large red stars of little density, it is generally agreed that they are sinking.

Both intrinsic probability and the analogy of cooling metals suggest that there will then be a prolonged struggle between the forming scum or crust and the fiery mass it is imprisoning. The skin, which we naturally assume to pass in time from gaseous to liquid, and liquid to solid, will prove, as it grows, too small for the globe. The pressure on its relatively thin texture will be enormous. It will crack and be repeatedly submerged. We should expect constant eruptions of the fires from below. The Earth obviously passed through such a phase. There are literally miles of volcanic rock at the base of our crust, and even now matter at a very high temperature and terrific pressure lies below the crust and occasionally bursts through. In so vastly larger a body as a star this phase of conflict ought to be titanic.

To-day, we saw, flames of a white-hot metallic vapour are flung as much as 200,000 miles above the normal surface On a dying, dull-red sun such spurts of fiery metal or gas would be conspicuous at a very great distance. Do we find this phase illustrated in any of our stars?

It is said that we do, and even that we can trace the story further than this among the stars. When a sun sinks below the condition of, say, 19 Piscium (number 19 in the constellation of the Fishes) its dull glow falls below the range of visibility. It will still radiate heat and some day we may have instruments which will detect such radiations, and classify stars which give no coloured spectrum. The ethereal waves or pulsations which are registered in the spectrum are only a small section of a great and continuous range. They are the waves between the 40,000th and the 80,000th of an inch in length. At each end are other waves which need other instruments to register them.

In the meantime, however, a dark star, or a star too dim to be perceived even with the telescope, may reveal itself in several ways. It may conceivably pass between us and a bright star, close to the latter, and shut off its light for a time. It may collide with or approach another star, or rush into a mass of cosmic dust. In any of these cases it will be apt, since a star which has run its course is presumed to have a very high speed, to be raised to incandescence once more and thus to betray its earlier invisibility. It is said that we do witness these things, and the consideration of our subject would obviously be incomplete unless we carefully studied these interesting claims. In this chapter therefore I discuss the claim that we see stars in the stage of conflict between the confining crust and the heated interior, and that dead stars sometimes cross the light of living stars. In the next chapter we will discuss the alleged resurrection of dead worlds.

It is expedient to grasp more clearly certain features of the stars which have as yet been mentioned only incidentally. The first is that they are very commonly associated in pairs. The stars which are thus physically connected are not separable by the naked eye, and very many of them cannot be separated even by the most powerful telescope. The spectroscope, however, often puts it beyond dispute that what seems to be, even in the great Yerkes telescope, a single pin-point of light is really the mingled beams of two stars which may be separated from each other by millions of miles of space. I have explained that the lines in the spectrum of a star are displaced if it is moving rapidly toward us or from us. In the case of these "binary" stars, as they are called, in order to distinguish them from double stars which merely lie close together in the line of sight, the lines in the spectrum are double, and one set of lines may indicate approach while the other set shows recession: if the stars are well placed for observation by us, and are close enough to influence each other.

We know in such cases that there are two stars which are circling round a common centre. As they are usually bodies of approximately equal size, one does not occupy the centre and control the other, as our Sun controls the planets. They are rather like two trains on a circular railway (though it is not quite circular), at opposite points of its diameter, running round a common centre of gravity. Their distances from each other and periods of revolution differ enormously. One couple, δ Cephei, complete their revolution in four and a half hours. A number of pairs make their revolution in a few days. Sirius, the brightest star, consists of two stars, one of which is more than twice the weight of our Sun, and the other is about the same mass as the Sun ; and they take about 50 years to make their circle. This is so wide a couple, and so near to us, that the fainter star can be seen in large telescopes. The nearest or second nearest star to us, a Centauri, consists of two, each about the mass of the Sun, which are 2,000 million miles apart and require 80 years to make a revolution. The star Castor of the Twins, is a couple of couples, and it is estimated that they take about 900 years to traverse the larger orbit.

In the present state of our knowledge it seems that at least 8 stars out of 20 are binaries or multiples (triple, quadruple, &c.) though it is only in relatively few cases that orbital motion is detected and measured. This feature of the stars is proving very important in connection with the inquiry which I am recording. It is generally supposed that a double star is the outcome of a single comparatively small nebula, though some hold that one star has captured another. Astronomers are not agreed as to the cause of the rotation of the nebulae and stars. Some hold—Sir Robert Ball has developed the point at length —that the condensation of a nebula will of itself cause the nebula to rotate, because of the different speed of particles near to and far away from the centre. It is then suggested that when the nebulous or viscous mass rotates at a high speed, it will draw out in an elongated form and may break into two halves. The Moon is generally believed to have been born of the Earth in this manner. Other astronomers are not convinced by this reasoning. They assume that the matter of the nebula gathered about two nuclei, or thicker centres of condensation ; and they look to external bodies to give a rotating movement to the forming globes.

But on the next step astronomers are fairly agreed. Two large viscous masses circling round each other will have an immense tidal influence over each other and—to put it shortly—this will tend to drive them further and further apart: as the Moon is supposed to have been removed from the parent Earth. If this is so, the distance apart and the lengths of the periods of revolution of these binary stars will prove important clues to the age of the couples, and it is interesting to see how a classification on this ground compares with a classification by spectra.

In an article on stellar evolution (in the *Popular Science Monthly*, November, 1915) Dr. Campbell give remarkable figures to show that this line of research strongly confirms the Harvard scheme which I have followed. When the couples are very close together, as I said, the most powerful telescopes cannot separate them. At the other end of the scale, when they have drifted very far apart, they will not appear to us as having any connection. The partnership will have been dissolved. Some very curious relationships of stars which are now very widely separated in the heavens are now being detected. Sirius, for instance, is believed to belong to one small family with five of the stars of the Great Bear.

Now when we ask how the telescopic doubles (the pairs which can be separated by the telescope) are distributed over the classes which we have formed on spectroscopic grounds, the answer is instructive. Of 164 of them which have thus been classified none were earlier than the B, or helium, type: 4 only were of the B type: 131 belonged to the classes A to F: 28 fell in the G and K classes: and one only was allotted to the M and N types, (the red stars.) In other words, 159 out of the 164 couples belonged to the types A to K—the middle-aged stars of the Harvard scheme. This is a very impressive corroboration of the line of development we have followed. The only reasonable interpretation of the figures is that in the B and earlier stars the pairs are *too close* for the telescope to separate them, and in the red stars they have drifted *too far apart* for us to connect them. And the spectroscope confirms this. Double stars which are so close that we know them to be pairs only by the duplication of their lines in the spectrum—they are called "spectroscopic doubles" or binaries—are most common in class B, and they decrease in proportion as we descend to class M. The δ Cephei stars which, as I said, circle round each other in $4\frac{1}{2}$ hours—they must brush each other's atmospheres—are early types of B stars.

This is a very interesting development, as far as it goes, but we must not forget that the numerical basis is small, and that the whole question of the movements of the stars is very obscure. Besides this orbital motion of the components of binary stars, there is the common motion of the pair through space. This is ascribed to the control of the entire stellar system, and is believed to increase with age. There have, however, been suggestions of late that other circumstances may complicate it. Recent observation tends to show that the speed of the stars increases as their brightness decreases: that, in other words, the fainter are, on the average (except in class A,) the fastest. Some have therefore suggested—though this is warmly contested—that the size of a star may have to be taken into account. If it has a low density and large volume, it may suffer more from even a very attentuated resisting medium. It is noticed also that the highest speeds are on the edge of the Milky Way. Is there in that region more gravitational pull, which has to be overcome by greater speed? Is there a slightly greater resistance in other regions? Or, as Professor Eddington suggests, are the stars born in the region of the Milky Way, and do the young stars, of low speed, cling to it?

And the whole question is further complicated by the discovery that, above all the particular motions of the stars, we discern two great streams or drifts in opposite directions. Since a third, smaller class of (in this respect) almost stationary stars has been detected, there has been an ingenious suggestion that the stars of our system may all be revolving about a common centre. The first stream would be the stars moving out from the centre: the second stream the stars returning to it: the third class the stars at the turn of their orbit. The centre is placed by some in the part of the heavens occupied by the constellations Orion, Gemini, and Monoceros: by others in the Centaur. Our sun is said to be moving away from it, and to be already 600 billion miles away from it. This, however, does not seem to throw any light on the fact that one stream seems to be older than the other: one is richer in blue and yellow stars, the other in yellow and red.

These perplexing problems must make us hesitate to draw conclusions from speed. The system, as such, is very imperfectly understood. If, however, the examination of the binaries is extended, and continues to show the same proportion in the various spectral classes, we shall have evidence of great value, apart from the larger motions of the stars. Other features of the binaries are being studied in the same hope, and an account of our actual knowledge will show at once how we are advancing, and how cautious and critical the advance must be. In the first class which I take a more accurate research has already corrected an earlier and very popular supposition.

The dead and invisible sun ought, apparently, to be for ever a subject of mere conjecture and speculation, since it sends no light to us, yet it is not many years since Sir Robert Ball used to fascinate audiences with direct proof of the existence of these invisible stars. It was understood that they occasionally crossed the light of the shining stars, and that this revealed their existence as surely as the unlit ship does when it blots from your sight the light of a more distant vessel. We has realised that these are not dead, but relatively faint stars, and the entire phenomenon of "eclipse" is much better understood.

The classical specimen of this group of "eclipsing variables" is Algol. The name ("The Spirit"—compare "ghoul") was given to the star by the Arabian observers because it behaved in a singular and perplexing manner. Every third night its light slowly decreases, remains at a lower level for eighteen minutes, and then slowly returns to its normal level. There was in early astronomy no clue whatever to the natural interpretation of such an event, but the modern science soon discovered the cause. Algol is a binary, and the pair of stars are so placed relatively to the Earth that when one of them is farthest away from us the other is exactly between it and us. One of the two is, moreover, much fainter than the other, and

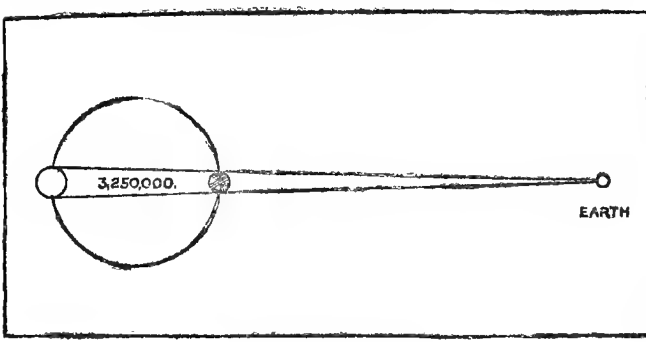


Diagram of Algol

when this comes between us and the brighter star the latter is temporarily eclipsed.

For a long time it was customary to speak of the "dark" companion of Algol, and, since 123 stars of the kind were known, it was felt that we had here a glimpse of a fairly large population of dead worlds. Cases in which the companion star passes exactly before the other, in our line of sight, and is near enough to it to obscure its disk, must be rare. We had a right to take the 123 eclipsing variables as a very small proportion of a very large class. But the searching scrutiny and more perfect equipment of our time have put an end to this romance. In not one of the 123 cases is the eclipsing companion found to be an extinct star.

Revolving pairs of stars offer remarkable opportunities to the mathematician, and he tells us details about these distant worlds that seem to the inexpert almost incredible. It was long ago established that Algol consists of two stars which are separated by a distance of 3,250,000 miles; that one of these stars measures 1,061,000 miles in diameter and the other 830,000 miles: yet that the two together weigh only two-thirds as much as our Sun. The smaller star is nearly as large as our Sun, yet has only two-ninths of its mass. Since our Sun is so expanded, or has so little density, that we must regard it as gaseous, it was suspected that a star only one tenth as dense as the sun would hardly prove to be a dead world. The last stage of evolution means great density and hard surface. Algol's companion was gaseous, and an improvement in the method of testing the light of faint stars has completed the disillusion. Dr. Stebbins invented a "selenium-cell," which has its electrical qualities altered when light falls on it, and it proved to be more sensitive than the photographic plate. With this he was able to establish that the "dark" companion of Algol is in reality 16 times as bright as the Sun: the larger star is 240 times as bright as the Sun. They are both young gaseous stars, in an early phase of development.

All the variables of this kind that have been examined have proved to belong to the earlier classes of stars. Most of them are either helium or hydrogen stars: a few are of the next (F) class: none are known to be later. There is really more contrast of brightness between Sirius and its companion than between any Algol variable and its eclipsing companion. While Sirius is 25,000 times as luminous as the Sun, its companion is only 48 times as luminous. Algol's companion does not entirely cover its disk during an eclipse, but even if it did there would not be a total cessation of light, as it is smaller. We realise, in fact, that all double stars would be variable, or suffer partial eclipses, if the orbit were, like that of Algol, turned edgeways to us. Except during the actual eclipse, we should have the light of both stars; and this would necessarily diminish when one star disappeared behind the other.

The real significance of the Algol or eclipsing binaries is therefore quite different from what had been thought. They do not reveal dead stars, but they confirm our view of the earlier stages of stellar evolution. In them a very close proximity of the two stars is united with a B or A type of spectrum. The brighter pair of the four which compose the star Castor are separated only by 854,000 miles, and both have very low density. They tend to enforce the belief that the order of development is from blue to yellow, and on to the red stars.

Another class of the variables, which takes its name from β Lyrae, has the same significance, and indeed does not differ much in character. These are stars whose light varies considerably in periods of a few days. All have an early type of spectrum and little density. They are generally believed to be very close binary stars, so placed that the light of one is periodically cut off by the other, as I explained. It is calculated that the two gaseous masses which compose β Lyrae are so close as almost to form an oval of light: showing us at times the long diameter of the oval and at other times the short. They strongly suggest a stage after the division of the nebula into two.

A third class are known as the Cepheids (from the typical star δ Cephei), and here we may eventually find interesting confirmation of our theory of the Sun's development. At present the class are exposed to conflicting interpretations. They are stars which, in very lengthy periods of time, greatly increase their luminosity and then fall back to their normal level. The immense distance from each other of two stars which take one or several years to complete a revolution forbids us to think of eclipse: as other features also forbid. It was then thought the two stars might be travelling in or through a resisting medium, or nebula, which might clear their atmosphere as they advanced toward us and cause them (or the larger component) to show a bright disk. But these stars are very numerous, and the theory of a resisting medium has never been quite satisfactory.

It is now the increasing belief of astronomers that these stars are not double, and the new theory is very interesting and pertinent to my inquiry. The periodical brightening is probably, it is said, due to changes of light in a single star. The periodical outbursts which these changes indicate may be due to some internal cause, or they may be provoked by a periodical encounter with a nebula, swarm of meteors, another star, or a large planetary body. There are obvious difficulties in supposing that a star which does not revolve in an orbit shall meet a resisting medium or a disturbing neighbour with fair regularity. We know, it is true, no reason why there should be this periodic pulsation of light on internal grounds, but the supposition seems to offer less positive difficulties.

The theory is interesting because these stars are generally of the same type as our Sun. Not only therefore is the failure to identify them as binaries very significant, but the new hypothesis superficially accords with the future of the Sun which we have anticipated. Our Sun is at present a faintly variable star, on account of its eleven-year sun-spot period. If this period shortens, and at the same time the pressure of the denser vapors enormously increases, the Sun will sink in its normal luminosity, but it may be expected at the culmination of its period to spurt out even greater flames and jets than we now witness. As it is, we saw, the spot-regions, especially at maximum, are surrounded by appalling uprushes, and the radiation is so intense as to cause, or provoke, magnetic storms on the distant Earth. It has lately been contended that the Cepheids are particularly bright stars. One is therefore tempted to see in these Cepheid variables a chapter of stellar evolution later than that we find in the sun to-day.

The theory must, however, be held with reserve. The outbursts of light on these distant stars must in themselves be prodigious. All that the eye perceives is that a faint point of light in the heavens rises slowly by that tiny measure of brightness which astronomers call a "magnitude." But the spectroscope, recently used in investigating them, reports that during the increase of light the spectrum of the star changes from F to A, and this means, as an astronomer would suspect, a terrific change of temperature. One student has calculated that the temperature rises 3,000 at the star's surface. Another estimates that the atmosphere of the star rises to a height of 75,000 miles under the influence of the seething outburst. In another case (R R Lyrae) it has recently been noticed that the lines of the star's spectrum are displaced in such fashion that we ought to infer that the star nearly doubles its speed toward the Earth: from thirty to fifty-seven miles a second.

One must hesitate to put any interpretation on phenomena which so mightily transcend our experience. These stars are generally of the solar class, or a little hotter, and there is nothing in our Sun's behaviour which gives us the least clue to the spectacle of such globes rising in a few days—as some of the Cepheids do—to the appalling temperature of the helium stars, and then sinking in a few days to the solar level. Every theory seems inadequate. One feels that another secret of the heavens here awaits revelation.

In the last class of the variable stars we have somewhat less obscure traces of the later stages of stellar evolution. These are red stars: they have very lengthy periods—rarely less than a year—for their change of light: and they are, apparently, not binaries. Mira Ceti (the "wonderful star" in the constellation Cetus) gives its name to the class. It has a period of, with considerable irregularities, about 331 days from maximum to maximum, and since it steadily recedes from us at a rate of 39 miles a second it is regarded as not binary. Most of the stars of the class are faint, and therefore not good subjects for spectroscopic examination in this respect. All that we know of them suggests that they are dying suns.

At maximum their light increases hundreds-fold, and the spectroscope shows that great flames of hydrogen characterise the outburst. Ordinarily they show the type of spectrum which is regarded as an indication of senility. They have abundant and thick dark lines, the violet end of the spectrum is very faint, and there are the well-known broad bands or flutings which indicate titanium oxide. They are relatively cool stars, wrapped in dense masses of absorbent vapour. But with the periodic increase of their light the bright lines of hydrogen flash upon the spectrum : in one case, at least, the line of helium has been found. From what we have seen in earlier chapters the reader will understand that this appearance of a few bright lines in the dark spectrum is easily interpreted by the astronomer. No matter how faint the increase of light may seem in the telescope, no matter how distant the star may be, the spectroscope tells a plain story. The dense and relatively dark vapors of these distant worlds are periodically rent by a fiery outburst, and the ordinarily invisible masses of hydrogen are rendered incandescent.

It has been suggested that these stars may revolve in an orbit which at one point encounters a dense swarm of meteors or other resisting matter: or that a swarm of meteors revolves round the star and approaches closely enough to disturb it. We saw that a similar theory has been put forward to account for the periodic changes of the Sun. This theory is beset with difficulties, and it is more commonly believed that these pulses of light are due to internal causes. The most plausible supposition is that we witness a phase of the struggle of imprisoned gases against a growing skin. The vaporous or liquid rudiment of a crust is forming, and, since this increases the pressure on the condensed gaseous masses, there is a periodic release or re-adjustment by the escape of an immense amount of the compressed gas.

Some have gone so far as to suggest that on these stars there may actually be living things. It is supposed that they live on the cool crust, and that, while this is sufficiently warmed by the heat from below, light may be supplied by the glow, reflected from the clouds, above the eruptive apertures. Of planetary life, if they have planets, there can scarcely be question, since the Sun itself has sunk so low. This seems to be an overestimate of the age of such bodies. They are stars of the M and N classes, in the last stages of visibility, but they *are* visible, even apart from the periodic conflagrations. And when we consider the vast distance of the stars, and the very thick shell of gases which surrounds them, we must feel that a red glow at a distance of hundreds of billions of miles must mean something more even than the red-hot surface of Jupiter. Their temperature is put at something like 3000 degrees, and the spectrum itself suggests that only a very refractory metal like titanium withstands it. Of life there can be no question, and it seems to be premature to speak of a "crust." The most reasonable view is that the denser patches ("spots") which we know on our Sun are here spread over the entire surface, and the gases and metals below are making their last flickers or protests of vitality. Probably they will sink below the range of visibility long before any crust is formed on them.

Thus the variable stars do seem to carry us a stage further in reading the story of the end of a world. We must, however, as I said, bear in mind the obscurities which still cling to the class, and we must hold any theory with reserve. There is very strong evidence that both the Cepheid and the Mira variables are not binaries, and that their variations are not due to eclipse. Further, the suggestion that these long pulsations of light are due to internal causes is less exposed to difficulties than the supposition that they are due to interference from without; and of internal causes the one that spontaneously and most strongly suggests itself is the struggle, which we should theoretically expect, of forming shell and imprisoned contents. We must, however, recognise that the periodicity is not traceable to any law that we at present know. That is an obscurity rather than a difficulty. It does not conflict with the interpretation we put on the phenomenon, though we do not yet know why it should be a feature of the phenomenon.

The greater difficulty arises when we try, as we are tempted to do, to arrange these various changes in a series, illustrating the advance of a star toward extinction. Our Sun may be in a slight degree a variable star, but its relatively small fluctuations have no analogy with the vast periodic rises of the temperature of Cepheid variables, which are of the same, or an earlier, spectral class. Moreover, while the Sun's period is eleven years, the period of the Cepheids is a matter of days, and then in the Mira variables we rise again to a year or several years. We must frankly admit that this is at present very mysterious. The periods of the variable stars are marked by irregularities, often large irregularities, but they are fairly definite in every case, and none of the guesses at the meaning are quite plausible. Perhaps here again we do ill to look for uniformity: to look for a continuous series where there may be, as in biology, divergent lines of evolution. However that may be, we have found in the variable stars very strong confirmation of the general view of development which the Sun and the planets suggested to us, and we now turn to a consideration of the actual end of worlds—and their resurrection.

CHAPTER X

THE RESURRECTION OF WORLDS

LITTLE more than half a centnry ago it was customary to smile when scientific men spoke of millions of years. The practice was certainly an improvement upon an earlier and less genial attitude, but it was unreasonable. It is, however, still not uncommon. More than once, after giving a lecture on evolution in biology, which covers only a few million years, I have heard intelligent-looking members of the audience repeat to each other, with disdainful smiles, "Millions of years!" Yet there is no doubt whatever that the facts within our knowledge to-day compel us to contemplate these appalling vistas of time. Even the narrower view of the Earth's story, which is now regarded as undermined, would not allow less than twenty million years. To-day no geologist would allow less than that period, and few would be content with it, merely for the formation of the

Earth's crust. And why one should be prepared to allow twenty million years yet reluctant to admit a hundred is not very intelligible.

But the contents of the universe which we have now somewhat superficially examined suggest a far longer period of time: an immense frame in which the story of our Sun occupies a relatively small place. Sirius, which is known to be two and a half times as massive as the Sun, and is in a much earlier stage of development, opens out to the imagination long eras after our Sun is extinguished. Canopus, tens of thousands of times more luminous, yet later in development than Sirius, suggests a still vaster period. The dark red stars, with slowing pulse indicated on their spectra, inspire us with a vision of ages long before our Sun was born. In short, remaining within the range of known facts, the universe impresses us with a suggestion of incalculable abysses of time both before and after our story is run.

Our final stage must be to attempt still further to enlarge this conception, or to inquire if there are, as is commonly said, serious grounds for doing so. Very few astronomers, for instance, do not now observe confidently that there are multitudes of dead stars in addition to the shining myriads which we study. One distinguished astronomer used to say that the proportion of dead stars to living is probably much the same as the proportion of cold to red-hot horse-shoes. On that view the dead worlds would enormously outnumber the living. What is the basis of this belief?

There is no doubt that for a long time the chief and most positive ground was the periodical eclipse of the Algol type of stars. In these cases, it was thought, the dead worlds flitted across the light of the living. That is, as we have seen, untrue, and the astronomer falls back upon a calculation made long ago by Newcomb and Kelvin. They endeavoured especially from the speed of the faster stars, to estimate the gravitational energy of our stellar system, and they then asked if the stars we perceive were plausibly sufficient to explain this energy. They concluded that the stars we see must be only about one fifth of the total number of globes in our system. The dead or invisible stars must be much more numerous than the visible.

This calculation, however, fails to impress many astronomers, and it is still less likely to impress those who cannot follow it. Mathematical reasoning is a wonderful implement of modern research, but the starting point of the reasoning must be beyond suspicion. In this case the data were very imperfect. The number of the stars in our universe is estimated so differently, and the mass of the great majority of them is so entirely unknown, that the conclusion may be far astray. A glance at photographs of parts of the Milky Way will explain this. There is no possibility of counting the crowded points of light which blend in these star-clouds. Some astronomers still vaguely state that the stars of our system number a few hundred millions: some say that they cannot be less than two thousand millions. And from the average weight of a few hundred stars we cannot venture to give the average weight of a thousand millions.

It will be remembered, too, that in Lord Kelvin's time too little attention was paid to the existence or quantity of loose matter in space, apart from the stars. It was thought that if a star shines brightly across a thousand, or even ten thousand million miles of space, the space must be practically void of matter. To-day it is generally admitted that there is matter of some kind in space. In fact, I quoted in an earlier chapter the conclusion of a mathematician that even the slight interference with the light of the stars which was generally admitted implied, seeing the appalling dimensions of space, a quantity of stuff 300,000 times as great as the matter actually moulded into globes. Again we have to set aside an interesting but unsafe line of inquiry.

The general and the firmest ground of our belief in the existence of dead stars is, as I said, analogy. The period of visibility of a star is analogous to the life of an organism. It is at first compacted in the womb of a nebula, or whatever the cosmic material is conceived to be. It has its youth, its prime, and its slowing age. And wherever we see a generation o living things, of all ages, we recognise it as one link in a lengthy chain of generations. We are encouraged in applying this to the stars because we see the material waiting to be made into worlds, a new generation of worlds. Nebulous matter has turned out to be extraordinarily abundant, and we know that matter is constantly escaping from the globes into space, and presumably accumulating somewhere. A thousand million stars belching atoms and electrons into space for hundreds of millions of years suggest a large amount of cosmic dust somewhere. Then when we find the living stars moving onward to extinction we feel that there is a chapter beyond. Where there are many dying, there are still more dead. Red stars are, for some reason, very distant, and no doubt this prevents us from observing the later phases of development more closely and abundantly. But we see enough. We should be as naive as young children if we, seeing so many growing old and approaching death, nevertheless doubted if any had ever died before.

But we must not press too far the analogy with living things. The 1,500 million living men are a mere fraction of the whole of humanity, living and dead. For hundreds of thousands of years the material of the dead has accumulated. If we applied the same reasoning to the stars we should have to suppose that the living suns bear a minute proportion to the dead. It might, in fact, be suggested that unless the universe had a definite beginning, at a point of time measurable from now, this would be the case. If time has run indefinitely before the episode of our solar system began at all, the fields of space ought to be choked with the bodies of the dead.

The answer is that here the analogy with living things breaks down altogether. Stars do not die and remain petrified corpses of worlds. For them there is a resurrection. It is at least claimed that we do witness phenomena which must be regarded as the revivification of dead worlds, and this claim must be the next point of our inquiry. If it is established, it not only gives us the desired proof of the existence of dead worlds, but it adds extraordinary interest to the whole story.

The claim refers, as will be understood, to the "new stars"—usually, for some unintelligible reason, named, in Latin, *novae*—which are announced from time to time. "Temporary stars" is the more cautious name now given to them, but the majority of astronomers still regard them as dead, or very dim, worlds which have recommenced the course of stellar life. There are, however, very many who reject the idea that these literally represent the evaporation of a solid globe into a nebula, which may in its turn condense into a solid globe. As usual, I propose to recount what is made of them in the astronomical world to-day. Even if we have to discard an interesting theory, or at least to hold it with greater reserve, we extend our knowledge of the universe and get a firmer grasp of the subject we are mainly considering.

New stars have been observed occasionally in the heavens for more than two thousand years. Probably if we had the Egyptian and Babylonian records the known list would be greatly extended. It would still, however, be very imperfect. These earlier observers were restricted to the few thousand stars which the naked eye surveys, and the appearance of more distant or smaller suns would not be perceived. Since the invention of the telescope and improvement of astronomy the number of new stars has grown, and it grows with every decade. Ten were seen between 1572 and 1886: more than a score since the latter date. Now that the stars are, down to a low magnitude, permanently registered on photographic plates and charts, discovery becomes more certain and more frequent. Moreover, a new star is now attacked by a great complexity of apparatus and a variety of specialists, and its features are very closely studied.

To the eye a new star is a matter of feeble interest. At some point in the sky where no conspicuous star had been seen before a point of light appears, and in the course of a few days, as a rule, attains the brightness of our naked-eye stars. One or two of these objects have rivalled the brilliance of Sirius. But when we recollect the distance of the stars we dimly appreciate that the brightening of this point of light means an appalling conflagration in some part of the universe. In some cases these new stars increased their light thousands-fold in a few days, from the time when they first became visible.

In the modern period these strange appearances were at once assailed by hundreds of spectroscopes, telescopes, and telescopic cameras, and many surprising features of the remote catastrophe were detected. In the month of February, 1892, a new star was discovered in the constellation Auriga. By that time the constellation was well charted on photographic plates, and there was no need to rely on the recollection of astronomers that no star had hitherto been visible at that spot The plates showed that up to the preceding November there had not been even a star of the fainter type. Succeeding plates, however, showed, although it had not been noticed at the time, the star creeping from magnitude to magnitude during the winter months. "Creeping" is a fair description of the advance of the point of light on the photographic plate, but this rise from magnitude to magnitude, even in the course of three months, really indicates a prodigious rise of brilliance in the star itself. Before the end of December the formerly invisible star had reached the fourth magnitude. It then sank a little for a time, and rose at the beginning of February to the third magnitude. After that date it sank slowly, with many fluctuations, until at the close of the year it had returned to the limits of invisibility.

The spectroscope, directed to it at the time of its maximum brilliance, revealed a singular fact. The lines of the spectrum were double. There was a set of dark and a set of bright lines, and the displacement was such that the two bodies which gave the lines seemed to be moving apart at a rate of 820 miles a second! It had already been suggested by Bickerton that these "new stars" represented the outcome of the collision of two dark worlds, and the discovery of the two sets of lines confirmed the suggestion. It was still further strengthened by the discovery that, as the star faded, a nebula was seen to grow round it. It seemed as if a globe had been shattered and reduced in part to luminous vapour, scattered over an enormous field of space, by some such colossal rise of temperature as the shock of a collision would bring about.

Many astronomers thought the collision of stars improbable. Even if we suppose that there are numbers of invisible globes, besides the hundreds of millions of living stars, the distance between them is still so vast that, counting the logical chances, we must regard a collision as a very rare and unlikely event. It is as if one imagined two one-foot balloons travelling swiftly across an area very much larger than the Earth. When, therefore, new stars began to multiply, the theory of collision was weakened. Even the modified suggestion that the two stars may have approached within some million miles of each other and destroyed each other's crust by gravitational pull, did not find general favour. A new star appeared in 1893: another in 1895: a third in 1901.

In 1901 the apparatus of the astronomer had again improved, and the new star, which appeared in the constellation Perseus, was subjected to an intense scrutiny. It was the most brilliant *nova* of modern times, rising in the course of a few hours from the 13th magnitude to the position of one of the most conspicuous stars in the heavens. It is calculated that this means that the light of the star increased 60,000-fold in that time. Though the rise was so rapid, the star followed essentially the same course as its predecessor, and this was now watched with acute interest.

At first it gave a continuous spectrum, and this, as the star brightened, was found to be crossed by dark lines. At the maximum of its brilliance bright lines crossed the spectrum, in addition to the dark, and the relative displacement of the two sets of lines indicated a movement from each other at the rate of 700 miles a second. The lines of iron had the form which they take only in the hottest stars, and the bright lines of incandescent hydrogen were very conspicuous. Masses of hydrogen seemed to be rushing out at a rate of nearly a thousand miles a second. In time the continuous spectrum faded altogether, and only bright lines were given. The atmosphere of the star was now brilliant enough to eclipse the glowing metal body. Then, in the course of a year, the star sank to the tenth magnitude, and a nebula gradually appeared, growing outward on every side. The spectrum of the object became the characteristic spectrum of a nebula. It seemed as if a star had been converted into a nebula: that is to say, that a metal globe weighing trillions of tons had been vapourised by heat and scattered over hundreds of millions of miles of space.

Even the photographs taken in our largest telescopes do not convey the faintest impression of these cosmic conflagrations unless we keep steadily in mind their immense distance. The new star in Perseus was so far from us that the actual catastrophe must have occurred in the days of Napoleon, and it had taken a century for light, which crosses space at a rate of 186,000 miles a second, to bring the message to us. The star gave so slight a parallax that its distance has been variously estimated at from 600 billion to 1600 billion miles away. Even if we accept the lesser figure, it will be realised that the cloud or nebula in the photograph is in reality of a stupendous size. Its growth was prodigiously rapid. The new star was seen on February 22nd. A month later a ring of nebulous stuff was perceived at a vast distance from it, and in a few weeks the cloud-like matter could be traced tens of thousands of millions of miles on every side of the waning star.

Another new star appeared in 1903: another in 1912: another in 1918. The course is essentially the same in all cases. The star is raised to an extraordinary brilliance in a very short time, and it then returns, in a few weeks or months, down to or below the limits of visibility. As it fades, nebulosity appears round it, and the spectrum becomes that of a nebula. But the further stages of the phenomenon have now been observed, and these also are remarkable. The last four *novæ* have been kept under observation, and it has been found that in a few years they lose the spectrum of a nebula and show the spectrum of a Wolf-Rayet star: the kind of star which, as we saw, comes between the last phase of a nebula and the earliest (helium) stars in the Harvard scheme. The nebular lines disappear, the continuous spectrum of the star reappears, and it is crossed by bright lines.

The comparative rapidity of these changes, and the multiplication of *novæ* have made the majority of astronomers reluctant to accept the older view. Collisions or close approaches of stars ought, as we saw, to be infrequent, yet new stars are not infrequent. It is felt, too, that if in these cases two stars grazed each other, or rushed past each other, the spectroscope ought to perceive for a long time two sets of lines. Both bodies would be rendered luminous, if they were not luminous before, and there would be a combined spectrum of two bodies receding from each other. This we do not find. For a time, as I said, we find two sets of lines, and these show a very rapid divergence of two bodies, but it is generally felt that these lines mean only that great masses of hydrogen are being shot out from the star in which the catastrophe occurs. When this crisis is over, we have the spectrum of a single star, crossed by the bright lines of the nebulous matter. The rapidity of the changes also dissuades us from thinking of a collision or encounter of stars. We can hardly imagine a dead world turned into a nebula, and this into an early type of star within the space of three or four years.

Other explanations are suggested. Professor See thinks that in these cases a large planet, not another star, has collided with the *nova*, and, after being reduced by the heat to a luminous vapour, has been absorbed by the star. This interpretation certainly meets better the difficulty which arises from the speed of the changes, though it raises others which need not be discussed here. One might however, recall that many astronomers believe that in time our planets will be sucked into the Sun, long after the latter's extinction. The thought of Jupiter crashing into the sun may suggest a conflagration of the type supposed; but we must remember that other astronomers who have worked out this final phase believe that the planets would first be ground to powder and would pour quietly upon the Sun as a stream of cosmic dust.

A large number of modern astronomers (Professor Pickering, Professor Fowler, etc.) think that in these catastrophes we witness the explosion or bursting of a dead star: an occurrence which the discovery of radio-active metals had led many to expect. Professor Bickerton, who, with some others regards the catastrophe as generally due to the grazing collision of two stars, believes that the *nova* of 1912 was a case of explosion. Sir Norman Lockyer believes that the conflagration is due to the mutual encounter of two great swarms of meteors, the friction of the encounter raising them to white heat and ultimately reducing them, or part of them, to vapour. The Planetesimalists and some others still see in the phenomena the outcome of the close approach of two stars, tearing open each other's crust by tidal action, and scattering a cloud of particles ("planetesimals") over space in the form of spiral coils round the rent body.

But the view that is now generally favoured is that a dark or dim star has entered a nebula, or some dense tract of material lying across its path in space. The extraordinary abundance of this material, as revealed in modern photographs, seems to make it not unlikely that a star may at times enter a tract of it. Luminous clouds of matter stretch, in some parts of the universe, billions or trillions of miles across space, and we have now very positive reason to know that the luminous nebulosity is not the whole. It had long been noticed that there were dark patches or lanes in the faint white stream of the Milky Way. Some of these plainly represent regions of comparatively empty space amidst the thick-strewn fields of stars, but others are confidently believed to be due to the obscuring of the stars by masses of invisible nebulosity. Professor Barnard (see a remarkable article by him in the *Astrophysical Journal*, January, 1916) has especially studied these objects, and he concludes that in most cases these dark rifts and patches are dark or dim nebulae lying between us and the more distant stars. Some nebulae are variable, and sink at times to a low degree of luminousity. In some dark regions of space long-exposure photographs have discovered a feeble luminosity. In other parts of the universe the dark patches thin out at the edges and become faintly transparent. In a word, the more penetrating study of the universe which our improved instruments permit is disclosing vaster and vaster stretches of both luminous and non-luminous nebular matter.

It is quite clear that while a collision of star with star is unlikely, the chances of a star entering one of these nebulous regions are great. It is certainly not impossible for stars to collide or approach so near as to disrupt each other, and this may be the cause of some of the *novae*. But the chances of becoming incandescent by entering a nebula are immensely greater, since the nebulae often stretch billions of miles. And in point of fact, as Dr. Campbell shows, 24 of the 29 *novae* occurred in the region of the Milky Way, which is the richest in nebular stuff, and three of the remaining five appeared in nebulae or nebulous regions. This lends considerable weight to the theory that a dead or dim star has entered a nebula and been raised to incandescence.

Some astronomers doubt if the friction of a rush through a nebula would suffice to make a star white-hot. The truth is that we are very imperfectly acquainted with the density of nebulae. On the whole these vast clouds of matter must be inconceivably thin, but there seem to be degrees of thinness, or denser and lighter parts, as gravitation would lead us to expect. A compromise is in this respect proposed, and it seems to accord with the most puzzling feature of the new stars: the great rapidity of their changes. It is suggested that they are not themselves vapourised or turned into nebulae. They remain compact globes, and are merely raised to incandescence at the surface by the bombardment of the particles of the nebulous mass through which they rush. They then, many astronomers suggest, light up the nebula itself, and the nebula continues to reflect their light as long as the surface of the invading star retains its glow, or until it has traversed the nebula. I have earlier given other instances in which it is claimed that nebulous matter surrounding certain stars is really reflecting the light of the star.

This theory seems to agree both with the rapid ebb of the light of the new star and the comparatively rapid disappearance of the nebula. It has, however, difficulties of its own. It remains difficult to understand how a body whose temperature has risen thousands of degrees in a few days or weeks can sink again in a few weeks, and why there should be such fluctuations in the sinking of its temperature. A greater difficulty, to my mind, is that the nebula grows as the star sinks in brilliance, and is largest when the star has sunk to its former low level of light. To suppose that the light of the nebula is but the reflected light of the star suggests, in one respect, a remarkable spectacle. Since light travels at 186,000 miles a second, the small cloud which appears about the star at the end of six months must represent a stretch of space measured by a six months' journey of light: it must be about three billion miles in extent. But in this case we should expect the parts of the nebula which are nearer to the star to fade as the star fades: we should expect to see the luminosity sweep outward rather as a broad ring than as a fairly uniform haze.

When we further recollect that the spectroscope indicates the outrush from the star of great masses of incandescent gas we feel that it still seems more probable that a star has been, at least partially, reconverted into a nebula; and the gradual, though comparatively rapid rise of temperature of the *nova* (so clearly traced in the *nova* of 1892) suggests that the cause was a rush into a dense part of space, not an encounter with another star. Whatever difficulty arises from the speedy changes of the spectrum of the *nova*, the fact remains that for one or several years the object presents the spectrum of a nebula. The continuous spectrum is lost in a blaze of gas—of the customary hydrogen, helium, and nebulium—and, even when it reappears, it is crossed by the lines of incandescent gas. This must be a central fact in the discussion of new stars. The characteristic thing is not so much the raising of the temperature of the surface of the star as the sudden appearance round it of this tremendous atmosphere of white-hot gas. The most reasonable interpretation is that the star has received such an enormous increase of temperature that its gaseous shell has been greatly expanded and raised to incandescence; and this implies that the star was previously in an advanced and comparatively cold condition. The conflagration—I do not, of course, use the word in the chemical sense—is, in fact, so great that there seems to be an actual reduction of the contents of the star, in part at least, to the state of the simpler gases, and these are shot out over space at a rate of hundreds of miles a second. The new star of 1918 followed the same course as its predecessors. If, as it seems necessary to suppose, in view of the spectrum and other features, the light of the nebula is not the reflected light of the star but emitted by the nebulous stuff itself, we have a luminous mass of stuff certainly hundreds, perhaps thousands, of millions of miles in extent expanding round the temporarily brightened star. This represents a mass of matter immensely larger than the atmosphere of the star.

There is, therefore, very good reason still to retain the view that a star has been, at least partially, reduced to a nebula. This seems to be the best clue to follow where every theory has its difficulties. Yet we must steadily confront these difficulties, and must hold any theory on sufferance, awaiting further knowledge of these singular occurrences. The rapid disappearance of the new nebula, while the nebulae with which we have long been familiar remain for decades practically unchanged, is not easily understood. It is widely believed that in these phenomena we have, not the main lines of stellar evolution, but an accessory or subsidiary line. The cataclysm, leading to an immense rise of temperature, puts an aged Sun back to the fiery youth of a Wolf-Rayet Star, and from this stage it will, presumably, pass to the condition of a blue (or helium) star, and traverse once more the slow course of stellar life. It is one form of resurrection.

But the main line of evolution may be the condensation of patches of the great gaseous nebulae into stars. We might approach the question in a very different and interesting way by asking how frequent the birth of a star ought to be to keep the stellar population at its present level. The data are uncertain, but the result of calculation based on widely accepted figures is curious. If we take the life of a star to be a thousand million years, and the population of our stellar system to be a thousand millions, it will obviously need, on the average, the appearance of a new star every year to maintain the population of our universe. Others say that a new star must be born every two years. Now at the present rate of our progress in discovering "new stars" we may reasonably expect in time to detect one every few years, at least. The overwhelming majority of the stars, we must remember, have not been charted, and very distant *novae*, especially in thickly populated regions, might not be noticed.

This calculation is, however, very precarious. The number of the stars of our system is unknown: the length of life of a star is still less known, and it must vary considerably: and, for all we know, the number of our stars may at present be either increasing or decreasing.

Let us be content with the positive addition to our inquiry which these new stars furnish. We now know that dim suns may be raised again to an early stage of stellar development. We know also something of the mechanism of the universe by which this resurrection may be brought about. Old and dying stars must, on the law of motion which we saw, move at a very great speed, and have a far greater chance of meeting the kind of catastrophe which amounts to a re-birth. Whatever the particular nature of the catastrophe—and it need not be the same in all cases—we know that beyond the law of death which we have traced there lies a hope of resurrection. But here we pass to the last and highest stage of the wonderful cosmic philosophy which astronomy affords, and we must consider it in a more systematic and comprehensive manner.

CHAPTER XI

THE DEATH OF THE UNIVERSE

THE reader will I trust, have kept steadily in mind the dual purpose with which I entered upon the writing of this short work. The primary purpose is expressed in its title. It is a study of the universe from a particular and narrow point of view: an inquiry into the present state of our knowledge regarding the end of the world. But such an inquiry cannot be pursued without many glances at other branches or aspects of astronomical science, and I have taken the opportunity to summarise our knowledge on many other and related themes, and explain the incidence of new discoveries and views upon the older and more familiar theories of the making and unmaking of worlds.

I have very frankly created an impression of uncertainty and indecision in many matters. As I said at the outset, the last decade has witnessed very considerable progress in astronomy, and many of the new features which have been discovered in the heavens are held to be inconsistent with the older views. In a few cases older views which had become very popular have had to be definitely abandoned. In many others they are still held by distinguished astronomers against what we may call new schools. In still further cases older views are still stoutly held by the great majority of astronomers against a few recent theorists. Counting heads is an unprofitable business in science, but I have tried to convey to the reader in each case whether the difference of opinion which I describe is of the first, second, or third of these categories. There is in some quarters of the scientific world a fashion of decrying as "out of date" every position which even a few recent speculators have assailed. It is as well to remember that in every generation new views are put forward, often with great pertinacity and dogmatism, which are not destined to survive. Many of the new views of particular phenomena which I have introduced are doubtless of this character. I have stated all in order that those who are interested in astronomy, though not even amateur astronomers, may have some appreciation of the position.

But before entering upon the final stage of the inquiry it is advisable to take stock of the situation. Quite apart from conflicting views, we have surveyed a mass of established facts in regard to the universe which give astronomy a proud place among the sciences. Indeed, when we consider the appalling distance of the great majority of the bodies which the astronomer studies—when we reflect that immense and complicated fiery globes, millions of miles in circumference, are in the most powerful telescopes mere needle-points of light, or are but registered as faint specks on photographic plates that have been exposed in those telescopes for eight or ten hours—we feel that astronomy remains the most wonderful and most fascinating of the sciences. About even those very distant globes a rich harvest of facts has been gathered, and the instruments by which this is done are amongst the most remarkable achievements of the modern mind.

Then, in regard to the controversies which have, like thickets, beset the reader in his course through this book, one must not lose the sense of proportion. Many of these relate to particular phenomena in regard to which we can patiently await further refinements of our knowledge. Such are the questions of the nature of the round formations on the Moon, the nature of the light of a comet (part of which is not yet understood), the precise source of the Sun's brilliant light and the precise nature of its "spots," and the existence or nature of lines on the face of Mars. These, the reader may have forgotten, are the only serious controversies in the first six chapters of this book. They are subsidiary points, and, quite apart from them, we found a mass of settled information which gave a definite answer to the question with which we opened the inquiry. Every feature of the members of our solar system tells the same story. These globes are masses of metal cooling down. The Sun lingers behind the others on account of its size, but it will cool, and then life will cease within the limits of our system. We may even say with confidence that this is not at all likely to happen within many millions of years; probably not for something more than ten million years.

It is when we turn to consider those more distant globes, the nearest* of which is so far away that two suns, each comparable to ours and 2000 million miles apart, shrink into a

*I refer to Alpha Centauri, though some now claim that another star in the Centaur is a little nearer.

single pin-point of light, that controversy naturally thickens. Yet here still we must keep a sense of proportion. We have already a vast and settled body of information about the stars and the power and refinement of our research may be judged by the astronomer's ability to take a pair of stars so far away that no telescope has ever separated them, and tell us their mass, their diameter, their light-intensity, and their distance from each other.

Further, the chief controversies which have in this section beset our path are more strictly concerned with the earlier than with the later stages of stellar development. The starting-point of the star is disputed, and this may be largely because we look for a single starting-point where there may be several. On the later stages, which more properly concern us, there is more agreement. Chiefly it is disputed whether the stars begin as blue stars and follow a steady line of degeneration, or whether part of the yellow and red stars may not be advancing in temperature toward the blue stage before they enter upon the descending curve. I have stated all opinions, but I prefer to keep for the present to the view that the nebulous star becomes a star in the prime of life, and that the yellow and red stars are ageing. That is still the prevailing opinion. But we ought to hold no opinion dogmatically until the three suggested tests of age (spectrum, density, and movement) have been much more widely applied, and are brought into something like harmony. Here also it is possible that there is more than one line of development. In fine, the subject is complicated by the new view, founded on radio-activity, that the star may grow more diffused, or burst, as time goes on, and run its course independently of nebulae. This view is as yet the most purely speculative of all, and it does not seem to be favoured by the condition of the globes of our solar system, which we know well; and I accordingly leave it aside.

There is, then, a general and solidly-grounded belief that the stars are, like our Sun, globes of metal cooling down; and the question next arises whether the entire system to which our Sun belongs may be eventually extinguished. We saw that many believe that there are other universes—other stellar systems—than ours. It is far from certain that the spiral nebulae to which they refer are stellar systems. I have preferred to regard them, as many distinguished astronomers still do, as masses of gaseous matter at enormous pressure, or in an advanced stage of condensation, preparing to break or crystallise into immense clusters of stars. There may be other stellar systems like ours, but it is at present useless to speculate on the matter. Does the man of science foresee or forecast an end of the stellar system to which we belong? That would be, in a sense, an end of the universe.

Many physicists and astronomers have predicted such an end. The theory is not, of course, that when all the luminous stars in our system have run the course in which we find them to-day an eternal darkness will brood over our part of space. We have seen that our stellar population is not in the nature of a series of clocks which were wound up at a certain date and will run down at a certain date. We have rather the impression that we momentarily look round upon a particular generation of stars: we instinctively think of generations that have gone before and other generations to come. No one supposes that the stars will cease to exist when their glow is extinguished. If there were no mechanism in the universe for bringing them back to the starting-point of stellar career we should at the most expect that our system will in a few hundred million years exist only as a collection of dead, dark worlds. But we have seen that there is such a mechanism. Whether the revival of incandescence be due to internal or external causes, it is a frequent fact, and the imagination is therefore fired with a vision of a universe whose life flows on like that of a biological species, save that a generation may mean hundreds of millions of years instead of a few decades.

But while this suggests to many astronomers that our universe may be an instance of perpetual motion, stars rising to incandescence and sinking indefinitely, certain distinguished physicists profess to be able to put a term to this vista of eternity. A star may be restored to life, to a vivid glow of light and heat, because its energy has not perished but assumed another form. The energy needed to bear through space a body weighing trillions of tons at one hundred, or even two hundred, miles a second, is stupendous. This energy may be converted into heat. If the star is slowed by friction or collision the energy of motion must be converted into heat. Energy is never destroyed. If two rapidly travelling stars approach each other, the energy of gravitation comes into play, and it may release the appalling energies imprisoned beneath the crust of a dead world. But at every fresh incarnation, so to speak, the star loses a very great proportion of its energy. It pours its heat and light and electricity prodigally for millions of years into space. Now heat, these physicists say, is only partially reconvertible into other forms of energy, so that the universe is a mechanism for converting other forms of energy into heat, without an adequate compensating arrangement. In time, therefore, all energy will be converted into heat, diffused throughout a stagnant universe. There will be a state of what they call "entropy": a state as fatal to the stars as would be the freezing of a generation of living things.

It is, fortunately, not necessary to enter at length into the consideration of this point. Physicists themselves are not merely not agreed upon it, but the majority are opposed to the theory of entropy. Its chief flaw can be realised without any high technical equipment. When it is said that the other forms of energy are convertible into heat, yet heat is only partially reconvertible, it should be added that this is our experience on the surface of our globe. That nature has no different laboratories than those found on one small dying globe in the vast universe is a quite unjustified assumption:

that there is no compensating arrangement *anywhere* in the universe because we find none in our restricted terrestrial experience is a claim that we cannot allow.

The theory, in other words, implies a knowledge of the mechanism of the universe which we certainly do not possess. Wherever our inquiry has turned upon our broad knowledge of the mechanism of the universe we have found it very imperfect. We do not know what operations are conducted in the fiery bowels of a star, the dim recesses of a nebula*, or the still more obscure depths of that ocean of ether which fills the universe. Only of recent years we have discovered the most amazing complexity and energy in those tiny, invisible particles of matter which were, a few decades ago regarded as indivisible and unanalysable "atoms." These limitations of our knowledge must, as Sir Oliver Lodge says, forbid us to entertain the theory of the death of the universe by "entropy." Hence I need not consider the efforts of Professor

*In the remarkable article by W. D. MacMillan (*Astrophys. Journal*, July, 1918) to which I have previously referred there is a striking development of the idea that radiant energy is absorbed by the ether and locked up in new atoms.

Arrhenius and other physicists directly to prove its unsoundness.

Is the universe, then, eternal? The word has no legitimate place in a scientific treatise. We can neither prove nor disprove the eternity or infinity of matter. Attempts have been made by mathematicians and metaphysicians to prove that a material universe cannot be either infinite or eternal, but these attempts are futile. The question whether the sum of material things is infinite and eternal transcends, not only all experience and all that we can positively deduce from experience, but the highest reach of philosophical reasoning. The most that we can say is that both scientists and philosophers now assume the eternity of the material universe because, as Sir Oliver Lodge puts it, they find it quite impossible to conceive the opposite: to conceive things suddenly beginning to exist or suddenly passing out of existence. A star may cease to exist as a globe and be converted into a thin cloud of gas or dust, but that is not one whit nearer to annihilation. On the other hand, if we could positively prove that the life of such a star as Canopus covered a period of five thousand million years, and that the stars had already passed millions of times from death to life, from darkness to light, we should not be one whit nearer eternity. Just as if we could definitely prove that our stellar system measured a hundred thousand billion miles, and every spiral nebula meant a similar system, we should be no nearer infinity. There is at present no trace of a ground on which we could conceivably prove that the material universe is infinite and eternal, and therefore the words are better avoided.

Yet with this reserve we may, in virtue of the discoveries of the last fifty years, build up an impressive picture of the universe, and with this I would close my inquiry. The picture is in parts only suggestive and sketchy. Certain lines are clear, and, we are confident, will never need to be re-drawn. Other lines are like the dotted lines with which a geographer suggests, on definite grounds, the contours of unexplored regions. Some details make an even greater demand on the constructive imagination. Yet I do not lose sight anywhere of established facts, and in the main I use these or very plain deductions from them.

Let us first repeat what the universe is. We find ourselves more or less near the middle of a great assemblage of stars numbering hundreds of millions: probably, it is said, between one and two thousand millions. They are widely believed to be grouped in the shape of one of those spiral nebulae we have seen: at least the greater part of them are distributed in a circular or spiral coil (or coils—the Milky Way) round the vast inner cluster to which our Sun belongs. These stars are billions of miles away from each other, and all traverse the vast area in which exist at a speed varying from 5 to 250 miles a second. In the intervening space are enormous stretches of matter scattered with infinite thinness over space: besides moving particles or groups of particles (meteors, comets, etc.) which may be caught hourly in the nebular nets or drawn into the globes.

Let us leave open the question whether this is one of many similar material universes, and let us probe to its foundations. The foundation of this fabric of material things is, as far as our knowledge goes, ether. We must not be tempted to think that, because radium was discovered only a few years ago, we here rely on a theory of the origin of matter which is quite new and may not prove permanent. It was known for many decades that some substance besides matter filled the universe from end to end, passing through material bodies as water passes through a sponge, linking the most remote star with the Earth: and it was suspected at least three or four decades ago that this would prove to be the substance of which the atoms of matter were ultimately formed. The discovery of the composition of the atom, to which the discovery of radium led, has but given a very positive basis to a theory which many eminent physicists had long regarded with confidence.

What the precise nature of this ether is we cannot say. There are those who quibble as to whether or no it ought to be called material, but such a controversy is obviously futile. It is not "matter" in the accepted sense of the word, though it has inertia and extension, which are defined as the fundamental qualities of matter. Its nature, however, so far transcends our experience that we cannot picture it. It is neither solid, liquid, nor gaseous. Some think that it has a granular texture: others that it is perfectly continuous. On these points we can do nothing but speculate. It is clear only that it must have tremendous energy, and many find it convenient to imagine it as an infinitely attenuated and jelly-like substance which responds so sensitively to the motions of the particles of matter which dance to and fro in it that they start in it "waves" (of light, heat, electricity) which travel at speeds reaching nearly 200,000 miles a second.

This is the basic substance of the material universe. One need not now describe at any length how we have come definitely to connect it with the composition of the atoms of matter. Briefly we have found that the atoms of some of the heavier metals spontaneously and continuously break up. The atoms of thorium and uranium are such metals. An atom of uranium loses particles gradually and becomes, first ionium, then radium. The radium atom continues to shoot out tiny particles (at ten thousand miles a second) from its system, and passes through a further and increasingly rapid series of transformations; and it is believed to end its dissolute career as lead. These changes are effected by the discharge from the atom of two different kinds of particles, known as the alpha and the beta particles: the former are confidently identified as charged helium atoms, and the latter as the ultimate etherial or electrical units, "electrons."

As is known, a monumental mass of laboratory work, conducted with instruments hardly less ingenious than those of the astronomer, are the ground on which these conclusions are firmly based; and the reader will now understand some of the references to radio-activity which have occurred throughout this book. In all 34 of our chemical elements have been discovered to be radio-active. Uranium, the most notable, is believed to take no less than 5,000 million years to pass through half its series of transformations, but on this side the physicist speaks with less confidence, and, as we saw, the estimate of the age of our rocks based on the radio-active metals they contain varies very considerably. On the other hand, there is no doubt whatever that the explosion of these atoms, the emission of particles at thousands of miles a second, implies a terrific energy within the atomic systems. It is calculated that one pound of radium-emanation would at first emit heat at a rate of 23,000 horse-power. Hence the conclusion that the imprisoning of masses of these radio-active metals within cooled globes may lead to portentous explosions, and that, on the other hand, their presence in the stars may be an important source of the total heat-production. On this point also, we saw, physicists are not agreed. I have previously quoted some observations of Sir Ernest Rutherford which must make us regard these claims with reserve.

But the point which more closely concerns us is not disputed. Our physicists are convinced that the atoms of matter are built up from the smaller and more fundamental units which are commonly known as "electrons." The man of science speaks of these as "units of electricity," positive and negative, but it is believed that they are in some sense units of ether (vortices, knots, centres of strain, or thicker aggregations of granules—on this we can but speculate). The hydrogen-atom, the lightest of all, seems to be (in the simplest state) a combination of one positive and one negative unit. The helium atom contains, apparently, four positive and two negative electrons. The number rises until we have in the heavier metals hundreds of these minute particles circulating, with colossal energy, at relatively vast distances from each other, within a space so small that trillions of these atomic systems would fit inside the head of a pin.

Now here we glimpse a physical truth which at once raises fresh aspects of inqury we have pursued. When were the material atoms which make up our worlds formed out of ether? Were they—as some believe to be the case in regard to the origin of living things—formed once for all at a remote date, to follow their evolutions henceforth independently of ether? Or are our material worlds constantly rising from a depth below the nebula—from ether—and returning to it? Here we are attempting to reach the largest generalisation ever suggested to the mind of man and we shall not be surprised to learn that the evidence is at present quite inadequate. It will however, be of great interest to seek what clues we may find to the solution of this great problem, and attempt to gather the vast and varied contents of our universe into something more nearly like unity.

The gaseous nebula seems to me to be the proper starting point for such an inquiry. It seems quite impossible to regard these stupendous stretches of gas as the outcome of either encounters or explosions of stars. They contain (as also do the large spiral nebulae) the material of myriads of worlds, and they contain only—as far as their light instructs us—the three lightest elements: helium, hydrogen, and nebulium. The structure of nebulium is not known, since it has not yet been found in our atmosphere, but it is believed to be one of the lightest elements. Now in order to conceive these gaseous nebulae as the result of cataclysms like those which give us new stars it would be necessary to suppose that an immense cluster of worlds met such a catastrophe, and that the catastrophe was so complete as to reduce all their metals to the condition of the simplest gases. There is nothing in all our experience to justify so romantic a supposition. It is more plausible to regard these nebulae as parts of space in which matter is being actually formed from electrons. The fact that only the lightest and simplest elements are present, and that (as we saw) the heaviest of the three occupies the central region, strongly confirms this supposition.

We have then two alternative ways of conceiving this formation of matter from ether, and our knowledge does not permit us to choose definitely. Perhaps, indeed, both are true. On the one hand, we may suppose that in such regions there is an aboriginal development of matter out of the ether of space. How this may be done, or what may be possible in conditions so remote from our experience, we do not know. It is a pure speculation. On the other hand, these may be centres for the accumulation and re-formation into atoms of the floods of electrons poured into space by the stars. We have, as I stated in an earlier chapter, positive ground to say that our Sun discharges such streams of electrons into space.

The blue stars must be even more prodigal. It is not a very fanciful supposition that these discharged units meet and cohere in the intervening space, and there enter into the formation of the simpler elements.

Two things may then be supposed to happen. On the one hand, other matter which traverses space would be apt to be arrested in these comparatively denser regions. Probably it is not electrons only that are shot out beyond the gravitational control of the stars; and there are the particles of gas which depart from the surfaces (the atmospheres and oceans) of the various globes. The originally gaseous nebula may be enriched by a very considerable mass of matter. In any case gravitation would come into play, and it would be intensified by this ingathering of extraneous matter. Gravitation still defies the scrutiny of modern physics, but it is believed to be a function of ether. Possibly the formation of the denser centres which we call electrons causes in some way the strain or stress which we call gravitation. Whatever its nature is, it would come into play in the nebula. If the nebula were entirely formed from the ether, we might imagine it so uniformly spread that gravity would find no centres for condensation. The other contributions which I have suggested would entirely destroy this uniformity, and the matter would gather round nuclei of condensation. The first stage of star-making would commence.

Let us assume that the Wolf-Rayet stars (which are few) do not represent a normal phase of this development, but are, as is generally believed, the issue of new stars or catastrophes. We may also leave aside the comparatively small number of planetary nebulae until the question of speed is in a more satisfactory condition, But the spiral nebulae we may still, with reserve, regard as the next phase. Most of those we know are so vast that there is in them the material for at least thousands of worlds. That offers no difficulty, for we know numbers of clusters containing thousands of stars which seem (from their common type and motion) to have originated from one parent nebula. Indeed these clusters and the large spiral nebulae conspire to encourage us in this view of the stages of development. But the origin of worlds is not my proper subject, and I will not linger over it.

From a nebulous star, a partially condensed body, we take it that a blue star, with the helium gas still predominating in its spectrum, would be produced. The nebulium, the outer fringe of gas of the original nebula (as we saw), has now so far cooled that its lines gradually disappear. But the main body of the star is so hot that the atmosphere is still brilliantly incandescent, and the second layer, helium, floods the spectrum. The temperature is, we saw, considered to be at least 10,000° C. Whether metals can exist at all at such a temperature we cannot say. It is probable, as Sir Ernest Rutherford says, that the metals are actually produced in this fierce alchemy as the furnaces cool. If we could discharge electrons, at a terrific speed, into the proper position in the structure of the atoms, we could bring about the long dreamed-of transformation of matter. In the portentous conditions (of heat, electricity, and pressure) of the blue stars this may be possible. Many astronomers believe it to be the case. If we accept their belief, we have the lighter gases produced in the nebula, and the heavier gases and metals in the star.

Then, when condensation has reached a certain pitch, and no longer produces greater heat than the gaseous body can radiate, degeneration begins. I have described its course and the outstanding difficulties of arranging our stars in a definite series. Apart from a few astronomers who attach what seems to be an excessive importance to radio-activity, it is agreed that, whether or no we can point to particular stars as ageing, the stars pass through yellow and red phases and then to invisibility.

From this stage, we saw, they may be brought to the early phases of stellar life by some kind of catastrophe which raises their temperature by thousands of degrees. And even if the number of new stars does not prove adequate to maintain the stellar population, we have the alternative view that matter is forming afresh in the mighty gaseous nebulae and leading to the formation of absolutely new stars. Much controversy has been expended on the question whether the *novae* are or are not sufficient to keep up the population of our system. It is of little use to discuss the question until we have some idea of the length of life of a star, the number of our stars, and the real proportion of *novae*. On all these points our knowledge is very imperfect. In a recent discussion between well-known astronomers one held that the life of a star did not occupy more than 40 or 50 million years, and therefore from 5 to 10 new stars would be required every year to maintain a population of 1000 million stars: others retorted that the life of a star must be at least 1000 million years, and that therefore one new birth every year would would suffice: while others believe that the total number of the stars is nearer 2000 million than 1000 million. We have, obviously, not the data to settle this question.

But the formation of great tracts of matter in the nebula, whether directly from ether or by the concentration of discharged particles, seems to be beyond question, and this may prove to be the normal origin of stars. We should then have two lines of restoration: by collisions, encounters, or explosions which bring back a sinking sun to incandescence and by the concentration of the streams of discharged electrons or formation of new units from ether. Here, as I said, we are at the dim confines of our actual knowledge, and I am but vaguely suggesting the possibilities it holds out. We have not the slightest ground to forecast an end of the stellar system to which we belong. We revert to the analogy of living things. Worlds may die, but the race goes on. Inhabited globes may perish with their living populations, but in a universe so remarkably varied, yet one in material and in its physical laws, the conditions of life must be found repeatedly. Wherever the diffused nebular matter settles into a globe, the gases will necessarily lie outside of and envelop the metals. If the globe is large enough to retain these gases, oceans and atmospheres will be an inevitable side-issue of development; and the material of living plasm is found everywhere.

Thus the study of the broad universe at once confirms and corrects the conclusion we draw from the study of our solar system. The law of the individual globe is death. For aught we at present know a stellar system may die, but none of the facts within our knowledge suggests such a thing. We may at least confidently say that, while the universe offers us the dramatic spectacle of worlds wearing out their prodigious lives and dying—of living things slowly climbing to a mental height from which they can survey the wonderful system in which they live, then passing into the dark—it seems itself to have the promise of indefinite duration. There is neither optimism or pessimism in science, and with its triumph both optimism and pessimism will perish. The wise man appraises realities, and extracts from them all that they can contribute to the aims of the individual and the race. But for those who yet persist in regarding such facts emotionally it can be no small matter that, although our race has in its higher members already attained a splendid sense of creative power and the wonderful knowledge I have summarised, it most probably has still many millions of years, before the Sun goes down, to realise its dreams and purposes.

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