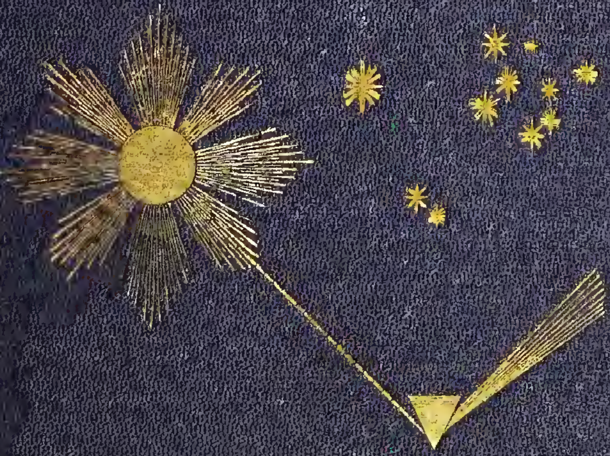
RADIANT SUNS



A SEQUEL TO "SUN, MOON & STARS"

BY A. GIBERNE

A Ray of Sunlight passed through slit and prism and thrown upon a semi-transparent screen.

RADIANT SUNS

A SEQUEL TO 'SUN, MOON AND STARS'

BY

AGNES GIBERNE

AUTHOR OF 'SUN, MOON AND STARS,' 'THE WORLD'S FOUNDATIONS'
ETC., ETC.

With a Preface by MRS HUGGINS
and many Illustrations

'In Thy light shall we see light.'—Ps. xxxvi. 9.

LONDON
SEELEY AND CO. LIMITED
ESSEX STREET, STRAND
1895
5

PREFACE

The ever-widening interest in science, which distinguishes our time, produces naturally a large growth of popular scientific literature. Such literature, when of a high order, cannot fail to do educational work, as well as to interest its readers; it may even fulfil a noble mission in bringing home to the masses of men not simply new scientific facts, but the truth, so constantly overlooked, that the investigator, absorbed in pursuits far removed from those of ordinary life, is also a toiling worker, and a worker of the highest order.

Astronomy, the most ancient of the sciences, appeals to the imagination no less than to the intellect. Early men, no doubt, felt this; and intelligent children, who in many ways stand in something of the position of early men, usually feel it too. It is a great pleasure to me to have the opportunity of saying that I think the following work will delight intelligent young readers, as well as older ones, and at the same time give real teaching.

Miss Giberne is already well known as a successful popular writer on scientific subjects. The present work is designed as a sequel to her *Sun, Moon and Stars*,—an admirable astronomical book for beginners,—and treats in a similarly clear and happy manner of the more modern sides and facts of Astronomy. Indeed, the children and general readers of to-day, who long to know something of the hosts of heaven, owe much to Miss Giberne; for her *Starry Skies* is so written as to satisfy as well as to stimulate their first curiosity; and, later, they will find her *Sun, Moon and Stars* and the present work also fascinating and full of information. It may well be that some Newton or Herschel of the future may in old age point to these books, and say, 'These first awoke my longing to be an astronomer!'

It seems to me that it is not simply in describing well the facts of Astronomy that this little book and its predecessor are valuable. Imagination, which plays so large a part in science, is appealed to constantly and wisely by the Author, and in a way that cannot fail to give mental training to her readers. Indeed, there are few pages in the present work in which, beyond the scientific information directly given, there is not also indirectly enforced some lesson of high practical value. Among others, that the ultimate goal of all true science is TRUTH, and that It must be faithfully and fearlessly pursued, without haste and without rest; also, that suspended judgment, so often necessary, is indeed the only true scientific attitude of the mind towards those questions about which our information is very incomplete, and that such a state of mind is quite consistent with a cheerful faith that looks forward to future possibilities of the increase of our knowledge. Not of little importance is the further lesson conveyed, that it is alone, by delicate discrimination, extreme and even wearisome accuracy, and untiring patience, that in most cases any increase of our knowledge of Nature can be won. And, finally, it may be seen that all the sciences are closely correlated, and that all sincere followers after Truth form essentially a Brotherhood.

This is great teaching. And while it is so given as to be attractive to youth,—and what is taught to the youth of a nation mainly makes a nation,—older readers will, I think, find pleasure and profit in the perusal of this volume, as they did in the one which preceded it.

In matters of opinion I am, of course, not responsible for the Author's views; but I have no hesitation in bearing witness to the general excellence of her work, and in wishing it success.

MARGARET L. HUGGINS.

UPPER TULSE HILL, S.W.,
June 1894.

AUTHOR'S PREFACE

In this sequel to my former work on the same subject, which has received so wide and kind a welcome, I have endeavoured to avoid, as far as possible, treading in the same grooves. *Radiant Suns* is entirely supplementary to *Sun, Moon and Stars*, entering more closely into subjects which could there be merely glanced at, and explaining difficulties which could not there be entered upon, besides giving a large amount of completely fresh information.

The book falls into three divisions. First, a sketch of the History of Astronomy leads upward from earliest ages to the wonderful later developments of the science, which are chiefly ranked under the head of Spectrum Analysis. Secondly, Spectrum Analysis itself —what it means, and what it teaches— is carefully gone into. Thirdly, the Stellar Universe, as now known, is considered; and some great theories, which may in the future gradually take their place as proved truths are also presented to the reader.

In the historical portion my aim has been to give short outlines of the lives of only the greater men of the past,—stars, for the most part, of the first magnitude. If a few of the second magnitude have crept in, this has been for the sake of necessary reference to their particular labours.

Spectrum Analysis is no easy subject to popularise. I can but plead to have done my best. At least some general idea of its meaning and of its scope may, I trust, be gathered by the untrained reader from the following pages.

The kind words of Mrs Huggins really leave little more for me to say, beyond an expression of my very warm gratitude to her, for the trouble which she has so unsparingly bestowed in looking through the sheets of this volume, suggesting improvements, and giving to my readers, as well as to myself, the benefit of her long experience in the practical working of Spectroscopic Astronomy.

AGNES GIBERNE.

WORTON HOUSE, EASTBOURNE,
July 1894.

CONTENTS

PART I

ASTRONOMY OLD AND NEW

PART II

THE SPECTROSCOPE AND ITS TEACHING

PART III

THE STELLAR UNIVERSE

LIST OF ILLUSTRATIONS

PART I

ASTRONOMY OLD AND NEW

RADIANT SUNS

CHAPTER I

THE DAWN OF ASTRONOMY

THE beginnings of Astronomy lie in the distance of earliest historical ages. It is no easy matter to say when first, in all probability, this science grew into existence.

There are other ancient branches of learning; but few, if any, so ancient as the study of the Stars. Geology beside Astronomy is as a babe in the cradle beside an old and grey-headed man; and of nine-tenths at least of the 'ologies the same may be said.

Indeed, in point of age, no other science can take precedence of Astronomy. No doubt, men thought of themselves, and of the world on which they lived, before they thought of the stars; but they did not think of themselves or of the earth scientifically.

The first faint approach to anything of the scientific mode of thought was, there can be little question, in respect of the stars.

Some might debate this point, so far as to put Astrology before Astronomy in age. But if Astrology could in any true sense be termed 'a science,' it was in that sense actually one with Astronomy.

The Astrology of earliest ages was the then science of the stars, and out of Astrology grew Astronomy. Astrology now, if the thing really exists, is a matter for weak brains and untaught intellects. Astrology *then* was the struggle of ardent and foremost minds to read the mysteries of the skies.

Astronomy as an infant science was alive before the British nation was heard of; before Saxons or Franks had sprung into being; before the Roman Empire extended its iron rule; before the Grecian Empire began to flourish; before the Persian Empire gained power; before the yet earlier Assyrian Empire held sway.

Among the ancient Chaldeans were devoted stargazers—much more devoted than the ordinary run of educated Anglo-Saxons in this nineteenth century. They earnestly sought, in the dim light of those ages, to decipher the meaning of heaven's countless lamps. We have better instruments, and more practised modes of reasoning; also, we have the collected piles of knowledge, built up by our forefathers through tens of centuries.

Yet our search is in essence the same as was theirs,

—to know the very TRUTH about the stars. Not merely to start some attractive theory, and then to prove that our theory must be right, because we have been so clever as to start it; but to discover that which IS in those regions of Space. No lower aim than this is worthy to be called scientific.

Mistakes, of course, are made; how should it be otherwise? A man finding his way at night, for the first time, through a wild and unknown country, will almost certainly take some wrong turns before he discovers the right road.

In Astronomy, as in all other natural sciences, blunders are a positive necessity, if advance is to be made. We have to grope our way to knowledge through observation and conjecture; in simpler terms, through gazing and guessing. Observation of facts leads to conjecture as to the possible causes for those facts; and each conjecture is proved by later observation to be either right or wrong. If proved to be right, it takes its place among accepted truths; if proved to be wrong, it is flung aside. Some pet delusions die hard, because of people's love for them.

'This is the way we go in science as in everything else,' wrote the Astronomer Royal, Airy. 'We have to make out that something is true; then we find out, under certain circumstances, that it is not quite true; and then we have to consider and find out how the departure can be explained.'

Such 'making out' and 'finding out' must sometimes mean, and does often mean, the giving up of an old conjecture or theory, and the putting of a new one in its place,—which new one has again, sometimes, to abdicate in favour of yet another.

The greatest men have occasionally made the greatest mistakes; and quite naturally so, because they deal with the greatest subjects. Ordinary men, of smaller minds, make blunders perpetually; but they do it in connection with such unimportant matters, that no one pays any particular heed. When a man of gigantic intellect makes a gigantic mistake, all the world hears of it.

There are men whose intellects, beside the intellects of common men, are as the Matterhorn beside a mole-hill; yet the Matterhorn is not heaven. It is only an earthly mountain; great in comparison with a mole-hill, small in comparison with the heights and depths of the Universe.

It is no disparagement to such a man, to allow that he makes mistakes. If he be morally great, as well as intellectually great, he will, when he discovers his error, frankly avow the fact, giving up readily his best-beloved theory, in the presence of truth.

Schoolgirls in their teens, and schoolboys in knickerbockers, are always in the right; while men and women of particularly limited brain power never by any chance make a mistake; but minds of larger grasp are very apt to confess themselves wiser to-day than they were yesterday.

Astronomy, as an infant science, mixed up with Astrology, existed in the days when the Pyramids were juvenile, and when the Assyrian bulls were modern. How much farther back who shall say?

The ancient Chaldean star-gazers had rivals among the early Egyptians; and the Chinese profess to have kept actual record of eclipses during between three and four thousand years. The earlier records are not trustworthy; but of thirty-six eclipses reckoned by the Chinese sage, Confucius, no less than thirty-one have been proved true by modern astronomers.

We cannot name with certainty those people, whose shepherds first gazed with intelligent eyes upon the midnight sky, and noted the steady sweep of stars across the firmament.

Intelligent eyes, that is to say, so far as man then knew how to use his eyes intelligently,—so far as man had begun to note anything in Nature, to watch, to compare, and to conjecture causes.

In those times, and indeed for long afterwards, men thought much more about the 'influences' of stars upon their own lives, and about supposed prophecies of the future to be read in the sky, than about the actual physical condition of the stars themselves, or the causes and meanings of the various phenomena observed in the heavens.

The desire to know, for the pure delight of knowing, had perhaps hardly begun to dawn upon the mind of man. What people did want to know was what might be going to happen to themselves; whether *they* would be happy or unhappy; and the stars were chiefly of interest as appearing to tell beforehand of troubles or joys to come.

It is difficult, most difficult, for us now, in the clear daylight of the nineteenth century, surrounded by its flood-tide of knowledge, to picture the actual condition of things in those long-past ages; the complete absence of information with respect to Earth and Sky.

In heathen lands,—or in the neglected heathen districts of some parts of our own country,—or in the mind of a little child,—we find indeed something of the same ignorance. But *then* it was the foremost of mankind, the most thoughtful, the most cultivated, the most lofty in intellect, who knew of such things absolutely nothing!

They did not know, because they could not know. They had barely begun to learn. Not only were telescopes then undreamt of; but no Science as such existed. Men saw, like little children, almost without seeing, without noting, without observing, without separating one thing from another, without classifying.

There was then no science of clouds and air, no science of Nature's laws, no science to tell men, in the words of a modern poet, that 'things are not' always 'what they seem.' Earth to man, in those days, was boundless, and the sky was a revolving crystal sphere. No Universe, as we understand the term, lay beyond.

The wisest of men in those times knew less of the outspread heavens than many a small child now knows in the National schools of England. Earth and sky were one vast bewildering puzzle. They had to discover everything for themselves,—how the sun rose each morning and set each evening; how the seasons changed in steady sequence through the year; how the moon and stars journeyed in the night; how the ocean-tides went and came; how numberless everyday phenomena took place.

Centuries of time, and generations of lives, were spent in the simple finding out of these most elementary facts. Countless mistakes were made, and countless false conjectures were started. And each fresh discovery that was made, and each fresh truth that was established, opened the door to further mysteries lying beyond.

That is so still. We know immeasurably more than our forefathers knew; yet our knowledge is still swathed in mystery. In no one direction do we ever get to the bottom of things. Door after door of knowledge is opened; and still beyond lies mystery. Depth after depth is sounded, yet still below stretch fathomless depths.

By 'a mystery' we simply mean something, the nature of which at the present moment we are not able to grasp. Not something which never can and never will be understood; but only something, the full meaning of which is *now* veiled from us. By-and-by the veil may be lifted; and then the mystery will cease to be a mystery.

Many things, which in the past were profound mysteries to our forefathers, are now quite simple and everyday matters to us, most easily accounted for; and many other things, which now are to us entirely mysterious, will by-and-by doubtless in like manner become clear.

In olden days, the daily rising and setting of the sun was a mystery, accounted for by divers theories, none of which were right; and the march of stars across the midnight sky was a complete puzzle; and an eclipse of sun or moon was a fearful perplexity; and the tides of ocean were a great bewilderment. These things are mysteries still to barbarous nations, but they perplex us no longer, because we have found out the mode in which such movements, or appearances of movement, are brought about through the action of quite natural causes.

An illustration of this matter of mystery lying beyond mystery, may be seen in the Milky Way, visible overhead any clear night.

A band or irregular stream of soft light is perceived, with stars at intervals dotting its surface. We get an opera-glass, and look through it. Behold! many more stars are visible; with the band of light still beyond. We get a small telescope, and look through that. Very many more stars yet may be counted; and still the band of soft light shines behind. We go to an observatory, where a large telescope may be found; and through its great tube countless stars gleam forth, hundreds and thousands of them, where first with the naked eye we saw only a few twinkling specks; yet still the band of light shines on behind, unchanged. Lastly, we go to America, and observe the Milky Way with the most powerful telescope yet made; and a wondrous company of innumerable stars glitter forth; yet still, still, beyond and behind, we have, as ever, the dim soft light, not even now done away, not even now resolved wholly into stars.

Some day, with improved powers, we *may* get to the end of this matter, we *may* sound the last glimmer of the Milky Way. But the depths of mystery, found on all sides in Nature, will be finally sounded by no human intellect in this life. Delve and search as we may, the gentle gleam of a Divine and inscrutable Mystery will ever shine still beyond our most marvellous discoveries.

CHAPTER II

THE GREAT MISTAKE

As a first step, in earliest times, the journey of the Sun by day, the journeys of Moon and Stars by night, across the sky, could hardly fail to arrest attention.

Very early, too, the stars were grouped into constellations, definite figures and names being attached to each. Many of the constellations are now known to us by names which belong to prehistoric ages.

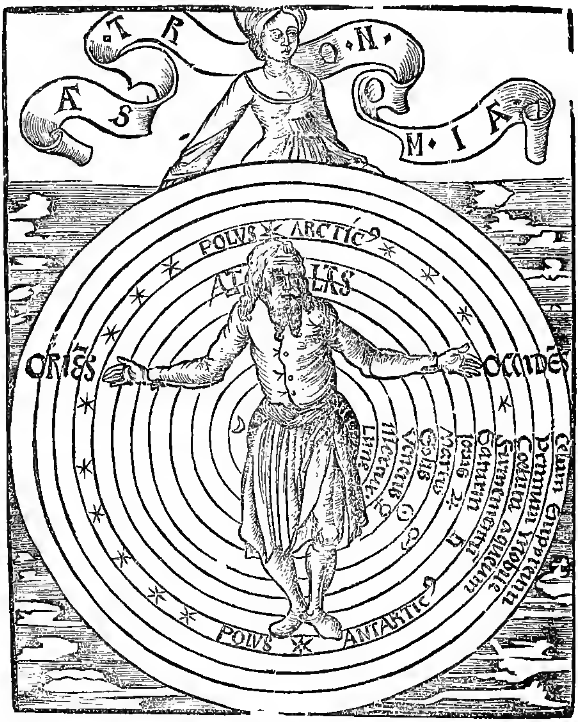
The stars were known as 'fixed,' because they continued unchangeably in their relative positions,—that is, in the position held by each star with respect to its neighbour-stars—although the whole array of them moved nightly in company; constellations rising and setting at night, as the sun rose and set in the day.

Ages may well have passed before the planets were recognised as distinct from the fixed stars; ages more before any definite plan was noted in their wanderings. In the course of time men's attention was directed to these matters; and one fact after another, of daily or monthly or yearly occurrence, was observed and commented upon, and became familiar to the minds of people. Very slowly the first beginnings of systematised know-

ANCIENT NOTION: EARTH SURROUNDED BY CRYSTAL SPHERE.

ledge took shape and grew, one discovery being made after another, one explanation being offered after another, one theory being started after another.

But an essential difference existed between the infantine science of those primitive days, and the matured Astronomy of these later days. The whole ancient science was built upon a huge mistake.



OLD DIAGRAM OF PLANET-ORBITS AND SURROUNDING HEAVENS: EARTH HIDDEN BY FIGURE OF ATLAS.

Men held, as a fact of absolutely unquestionable certainty, that this Earth of ours—this small whirling globe, less than eight thousand miles in diameter—was a vast and immeasurable plain, extending to perhaps infinite distances, and firmly fixed upon immovable foundations. They held that around this great and motionless centre circled the other heavenly bodies—a little sun, a little moon, a few planets, and a few thousand tiny stars, all placed near, for the sole purpose of lighting and warming our mighty Earth.

The one entirely accepted fact being that of our Earth as the moveless centre of all things, other matters had to fit in with that theory as best they might. The study of the skies was long hopelessly hampered by this one stupendous error.

It is singular to glance through records of early astronomical notions, and to see the variety of theories which arose, one following another, all designed to explain the things which were seen to happen, all hopelessly wrong, because of this one foundation mistake.

The early Greeks at one time steadfastly believed the sun to be a torch, the stars to be candles, by turns lit and put out. One of their philosophers improved later upon the theory, by maintaining that the stars were a kind of meteors, an emanation from our Earth—a sort of 'terrestrial effluvia.'

Also the sun was worshipped by the Greeks as a god. Another explanation in vogue among them was, that our earth floated in a boundless ocean; and that when the sun vanished at night, he was boated by Vulcan round the north pole, behind certain lofty mountains, which served to hide his radiance, and so he reached the other side in time for next morning's due appearance. The punctuality of his boatman certainly called for high praise.

After a while it became evident to their minds that this explanation was hardly satisfactory. Then they conjectured that the earth, instead of floating on the waters of an ocean, was built upon enormous pillars, and that the sun really did go down at night underneath the earth, finding a passage among the said pillars, and coming up on the other side. There was an evident sense of necessity for something substantial to support the earth. What supported the pillars they were probably content to leave in uncertainty.

The Greek philosopher, THALES [about 600 B.C.], is said to have laid the foundations of the Grecian Astronomy; and PYTHAGORAS is stated to have been one of his disciples.

Though, in many respects, Thales wandered wide of the truth, he yet taught many correct ideas,—as, for instance, that the stars were made of fire; that the moon had all her light from the sun; that the earth was a sphere in shape; besides other facts respecting the earth's zones, and the sun's apparent path in the sky. Only, to Thales, and to many of his successors, that apparent path was a real path, and the earth, though a sphere, was at rest.

He was also one of only three ancient astronomers who were able to calculate and foretell eclipses.

After him came numerous astronomers, of greater or less merit, in the Grecian and in other schools. They watched carefully; they discovered many things of interest; they held divers theories. But one truth never took firm root among them, although several of them dimly apprehended it—and this was the very foundation-truth, for lack of which they were all going hopelessly astray—the simple truth that our earth is *not* the centre of the Universe, and that our earth *does* move.

Yet it is not surprising. No wonder they were slow to grasp such a possibility.

Anything more bewildering to the mind of ancient man than the thought of a solid substantial world floating in empty space, supported upon nothing, upheld by nothing, can hardly be imagined. As yet little was known of the controlling laws or forces of Nature, and that little was with reference only to our earth. The very suspicion of Gravitation as a universal law lay in the far-distant future, waiting for the intellect of a Newton to call it out of apparent chaos; and the delicate balance of forces, by means of which the Solar System may almost be said to exist, could not be so much as guessed at.

So men still clung to the thought of earth as the centre of all things, and still believed in a little sun, busily circling round her once in every twenty-four hours.

The science was then, indeed, as Mr Pater writes in his volume on Plato, 'an astronomy of infant minds, . . . in which the celestial world is the scene, not as yet of those abstract reasonable laws of number and motion and space, upon which, as Plato himself protests in the seventh book of *The Republic*, it is the business of a veritable science of the stars to exercise our minds, but rather of a machinery, which the mere star-gazer may peep into as best he can, with its levers, its spindles and revolving wheels, its spheres, he says, "like those boxes which fit into one another;" and the literal doors "opened in Heaven," through which, at the due point of ascension, the revolving pilgrim soul will glide forth and have a chance of gazing into the wide spaces beyond, "as he stands outside on the back of the sky"—that hollow, partly transparent, sphere which surrounds and closes in our terrestrial atmosphere.'

A vivid brief description this, bringing before the mind's eye what the ancients of Plato's day really did think and feel. Plato lived in the fifth century B.C., or more than a century later than Thales.

Perhaps the greatest of all ancient astronomers was Hipparchus, about 150 B.C., who did more than any other in those early times to gather together the scattered facts of Astronomy, and to arrange them into one united and orderly whole.

He it was who discovered the Precession of the Equinoxes. He studied eclipses and the motions of the various planets. He made elaborate and valuable astronomical tables and star-catalogues; but he, like others, failed to discover the gigantic error which lay at the root of the whole ancient science.

Despite this great mistake, still persistently believed in, and despite the crude notions of early astronomers on many points, it is marvellous how much they did manage to observe and to learn for themselves—as to the sun and his apparent path; as to the moon and her path; as to the five then known planets and their paths; as to eclipses and other phenomena.

By all such careful watching, although they to some extent missed their aim, and fell into mistakes, yet they paved a way to later discoveries and to fuller knowledge. Their work was not thrown away; their trouble was not lost; for out of their very errors grew the fair form of Truth.

A word more as to the uses of scientific theory. You sometimes hear people say, 'O that is mere theory. I have no patience with theories! Give me facts.'

Now this is all very well in the abstract; but some facts can never be reached except through theories. It is quite right never hastily to accept a new theory, as if it were a proved truth; but neither is it to be desired that we should impatiently fling all new theories aside, merely because they are new, as if they were certain error.

Suppose that you are walking at night through a dark wood in a strange country, trying to find your way. You see some dark object looming ahead, and you say, 'I think it is a man.' Coming nearer, you have to give that theory up, for you find the object to be, after all, only a bush. Or you say, 'I think this little side-path will lead me right.' And you try it; and presently you find that it brings you back to exactly where you stood before. So the theory of that path being yours has also to be given up. Yet you could hardly walk through such a forest and *not* form a few theories, some wrong, some right, unless you sat down with folded hands and made no advance at all.

Our ancestors might have done this. They might have said, 'Oh! we don't know anything about the stars. No use to trouble ourselves. We have no patience with mere theories. Give us facts.'

Then they would have been at a complete standstill in their ignorance. Then Modern Astronomy, which is largely built upon the ruins of past dead theories, would have suffered long delay.

Suppose that, instead of being in a wood, you were on a wide sea at night in a small boat; and suppose that around you, at divers distances, were many other little and large boats, each carrying its small light. Suppose that you and they were all moving silently in circles, each around a centre,—some faster, some more slowly,—some in wider, some in narrower circles. Can you not imagine how bewildering the effect would be; how some unreal motions, due to your own motion, would seem to be real; and how some real motions would seem to be unreal?

If, in addition to all this, you suppose that your own movements are quite unknown to yourself; that your boat travels so gently and softly as all the while to seem to be at rest, then the matter becomes still more complicated in its effect on the mind. Then *all* changes of position among the other boats are laid by you to the score of their own movements, while many of them are in reality due to your movements. This was actually the mistake made by our ancestors, and persisted in through ages, with respect to our earth and other heavenly bodies.

To early observers there was immense difficulty in accounting for the motions of the planets, viewed, as was then supposed, from an Earth at rest.

Mars, for example, would be seen, first to make steady and quick advance, day by day; then to slacken his pace; then to come to a complete pause; then actually to go backward; then again to come to a standstill; then again once more to advance.

It is not difficult for us *now* to understand these complex motions.

Imagine that you are in a moving train, after dark, on a line of rail, with another parallel line at a short distance. Your train is going moderately fast, and on the other line another train, somewhat faster than yours, is coming up behind.

Looking out of your window, you see the coloured light of that train, first at a short distance behind, seeming not to move, because you and it are journeying at so nearly the same rate. Gradually it draws nearer; and by-and-by you seem for a short interval to be at rest, side by side. Then slowly it creeps ahead, and you are left in the rear.

Now this appearance is, of course, a *mixture* of your train's motion and of the other train's motion. If you were at rest, you would see that train rush past at a great rate. Or if you were moving the most rapidly, you would see it seem to lag behind, and even seem to stand still.

The same thing becomes still more apparent, if we revert to the thought of boats at sea. Think of three or four boats rowing in large circles, well apart, round a central ship, after dark. You are in one of those boats, with a light; and you see the gleaming lights of the other boats, moving this way or that.

In reality you may be all moving in the same direction, round and round one centre. But to you it does not seem so. If you watch a boat on the same side of the ship as yourself, you see it to be going the same way as yourself. But if you, moving faster and in a smaller circle, get round to the other side of the ship, leaving that other boat behind, its light will seem first to be stationary, and then for a while it will actually appear to be moving in an opposite direction to your own.

Mars journeys round the sun in an orbit outside the orbit of our earth. Sometimes Earth and Mars are on the same side of the sun together, going the same way. Sometimes Earth is on one side of the sun, and Mars is on the other side; and then of course we see him apparently going the reverse way to ourselves.

This is clear enough to us now, and is indeed an absolute necessity of the case. But so long as our earth was reckoned to be the motionless centre of the Universe, any reasonable explanation of these confusing motions was most difficult to find—not only with regard to Mars, but with regard to all the planets, more or less, which were then known.

CHAPTER III

FROM THE SECOND TO THE SIXTEENTH CENTURY

NEARLY three hundred years after the time of Hipparchus came the famous PTOLEMY—famous, not, like certain other Astronomers, for stupendous genius, or for the brilliancy and accuracy of his observations, but rather noted for the ingenuity of his explanations, and for the adroit manner in which he systematised such knowledge, on the subject of the heavenly bodies, as was then in the possession of mankind.

Ptolemy's name is best known in connection with what is commonly called 'The Ptolemaic System of the Universe;' and his greatest astronomical work is best known as the *Almagest.*

A great many of Ptolemy's leading notions, as well as the principal mass of facts upon which he worked, were doubtless borrowed from Hipparchus. The latter is said to have explained the movements of the Sun and of the Moon by means of small epicycles, travelling round the Earth on circular orbits; and even Hipparchus did not originate this fundamental idea of the so-called 'Ptolemaic System,' which had indeed been held by the ancients in much earlier days. Hipparchus worked it out to some extent; and Ptolemy carried on the process much farther, giving forth the System to the world in such wise, that ever since it has gone by his name.

In those early and simple days, people were by no means so sensitive as we are now with respect to 'plagiarism' or 'stolen ideas.' If a man were writing a book, and came across a few pages in somebody else's book which pleased him, and which said clearly just what he wished to say, he would immediately transcribe the whole, word for word, without any thought of inverted commas or foot-notes of explanation. Inverted commas had not yet been evolved out of the imagination of man; and books were few; and original ideas were not known to have a mercantile value. If a man were so happy as to give forth an original idea, he no longer accounted it his own property. It belonged to the world in general, to be used as that world should choose.

Probably no book of ancient date can be named, which does not contain such quoted passages, quite frankly and innocently incorporated, without the slightest idea of unfairness or wrong-doing. In fact, in those days the thing was *not* wrong, was *not* unfair. The then laws of literature allowed it fully and freely.

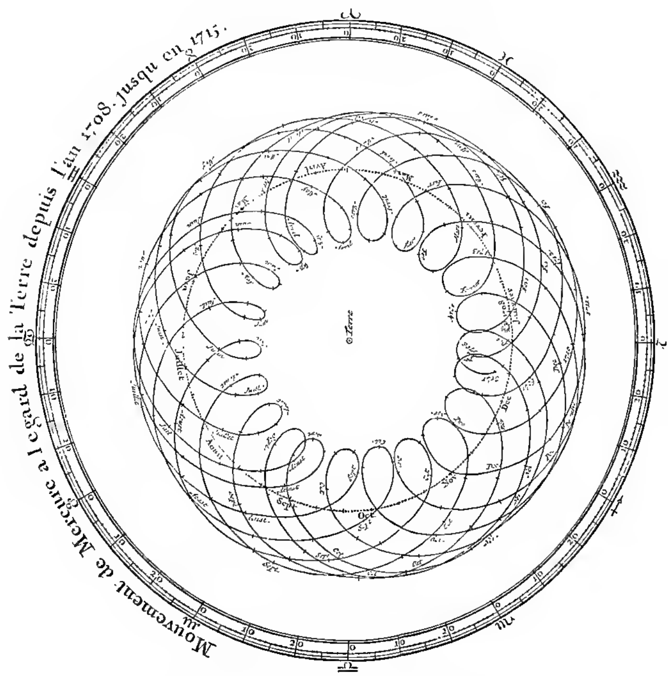
So when Ptolemy used the facts and tables and observations and theories and explanations of Hipparchus, improving on them to the best of his power, and sending the result forth as his own 'system,' he intended no wrong, and he did no wrong, to Hipparchus. He only did what all men were then free to do, and what no other would have hesitated to do in his place.

Although, therefore, the name of Ptolemy was given to the System, it had begun to take shape in men's minds long before Ptolemy lived; and after his death it continued to develop in the hands of other astronomers.

At one time a notion had been held that each planet was carried round and round our earth, fixed in a sphere of crystal, so transparently pure that stars could be readily seen through several such sky-envelopes. 'The music of the spheres' was the melodious noise, supposed to be made by these crystal spheres as they revolved; and certain of the ancients believed that they could hear at times the music. After a while, however, this crystal-sphere notion, never very widely held, was entirely given up. It had, in fact, to abdicate in favour of epicycles.

The main difficulty was always then, as stated in the last chapter, with respect to the Planets,--those most erratic and perplexing wanderers. And the olden notion of epicycles, carefully worked out by Ptolemy and his successors, really did serve largely, though by no means perfectly, to explain the complicated motions of the planets.

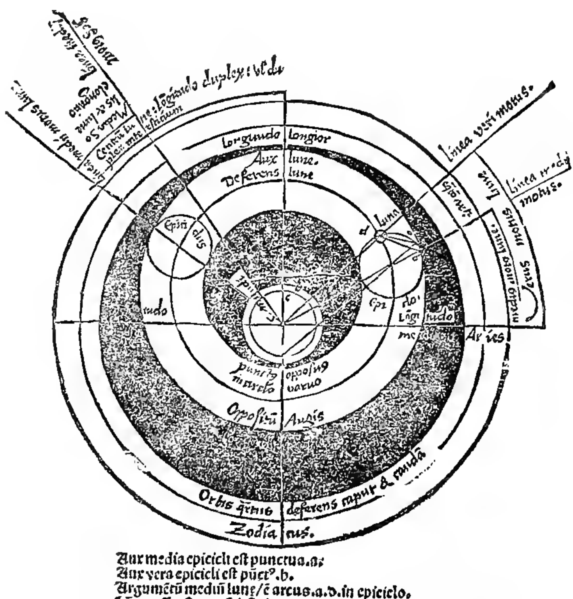
Still, as ever, the earth was regarded as the immov-



DIAGRAM, illustrating the complicated movements of Mercury, *as seen from Earth*, during the years 1708-1715.

able centre. Round the earth went moon and sun and stars, and round the earth went also the planets. Each planet was supposed to travel in a small circle, known as an epicycle; and the central point of that epicycle travelled on a large circle round the earth.

By this curious arrangement the puzzling back-



OLD DIAGRAM OF CYCLES AND EPICYCLES.

ward and forward motions of the planets could be partly accounted for. Venus, for instance, when going on one side of her little epicycle, would seem to Earth to be travelling forward; when going on the other side of her little epicycle, she would seem to Earth to be travelling backward. Yet all the general movement of the whole epicycle, carrying Venus with it, would be forward—round the central earth, upon the large cycle or circular pathway.

Venus was conjectured to be fastened to the sun by a kind of invisible bar; and the sun was conjectured to be fastened to the earth by another such bar. This looks almost like a dim early foreshadowing, in men's minds, of the great force of Gravity.

The one virtue of Ptolemy's extraordinary system is that it really did, to some extent, fit in with the apparent movements of the sun and the planets. Not, indeed, by any means perfectly, but enough to have satisfied people fairly well, in an unscientific and inaccurate age. The system, with its cumbrous arrangement of cycles and epicycles and invisible bars of attachment, was long looked upon as an established truth.

King Alphonso of Castile, a lover of Astronomy in his day, might well say that 'if he had been consulted at the Creation,' he could have done the thing better. Had he known the grand simplicity and magnificent orderliness of the Solar System, as we now know it, he would have been tempted to make no such pungent remark.

The theory of cycles and epicycles lasted long—lasted from the time of Ptolemy in the Second Century to the time of COPERNICUS in the Sixteenth Century, —not to say a good deal longer in the minds of the mass of mankind.

It could not last always, for it was founded upon error. But while, like many another mistake, it was to be an actual stepping-stone to truth, it could only become a stepping-stone through its own failure.

Early in the sixteenth century—that age of awakening thought and of quickened intellectual life; that time of resistance to bondage, and of wrestling for liberty—a great revolution was begun in the already old yet undeveloped science of Astronomy.

Copernicus inaugurated the revolution. Kepler, Galileo, and others carried it through. Like most reformations, it came, not as a thunderbolt falls, without warning, but gradually, urged on by irresistible forces, through one man and another in succession, till finally established.

The effect of this revolution or reformation in Astronomy was, that in the course of time, slowly, cycles and epicycles were given up; Earth was dethroned from her lofty position as centre of the Universe, to become only one little whirling world among many; and the Sun regained his rightful position as centre and controller of his System.

Copernicus, it appears, did not originate this idea of a fixed sun and a moving earth, but only revived a very ancient old-world notion, held nearly two thou-

COPERNICUS.

FROM AN ENGRAVING BY J. FALCK.

sand years earlier; and he did good work by such revival.

He was born in Poland, nearly thirty years before the close of the Fifteenth Century, and he lived until A.D. 1543, or late in the reign of our King Henry VIII.

Without being precisely a great genius, this quiet and thoughtful monk seems to have been wise, far beyond the age in which he lived, and remarkable for his independence of mind. He had a 'profound sagacity,' and a wide general grasp of scientific subjects.

The extremely complicated and cumbrous nature of the Ptolemaic system appeared to his judgment hardly compatible with the harmony and simplicity elsewhere characteristic of Nature. Moreover, he was impressed and perplexed by the very marked changes in the brilliancy of the planets at different seasons. These changes *now* are no difficulty at all. Venus, Mars, Jupiter, when on the same side of the sun as ourselves, are comparatively near to us, and naturally look much more bright, in consequence of that nearness, than when they are on the opposite side of the sun from ourselves. But, under the Ptolemaic system, each planet was supposed to revolve round our earth, and to be always at about the same distance from us; therefore, why such variations in their brilliancy?

Copernicus, in his classical reading, came across the notion—an old idea, at that time lost sight of—the notion of a central motionless Sun, and of a revolving earth;* and it entirely fascinated him. As he thought the matter out, he saw more and more clearly that it was capable of explaining much which before had been unexplainable. He saw that a simple and easily understood scheme might be put in the place of the cumbersome and awkward system then in vogue.

During thirty-six long years he patiently worked out this theory, and during part of those thirty-six years he wrote the one great book of his lifetime, explaining the newer view of the Solar System which had taken hold of his reason and imagination. This book, named *De Revolutionibus Orbium Cœlestium*, which came out only a few hours before his death, was dedicated to the Bishop of Rome—a little touch of worldly wisdom which doubtless staved off for a while the opposition of the Vatican.

It is not to be supposed that mankind generally was at once convinced of the truth of the Copernican doctrine. Far otherwise. The reading world in those days was small; the scientific world was smaller still; and information travelled with exceed-

* He himself mentions Heraclides and Ecphantes, both Pythagoreans, and Nicetas or Hicetas of Syracuse, as having believed in the rotation of our earth on her axis. Moreover, Pythagoras considered the sun to be the centre of the Universe, and believed that the earth had an annual motion in the ecliptic; and Philolaus, a pupil of Pythagoras, is said by his biographer to have affirmed that the earth moved in a circle. In fact, the idea of the movement of the earth, either movement of rotation, or movement of translation, or sometimes both of them together, occurs more or less clearly in many ancient authors.

ing slowness. Besides, men do not so readily give up their old beliefs, whether true or false; and truth is seldom received kindly when it steps in the face of long-established error.

When Copernicus had passed peacefully away, leaving his book behind him, and when other men took up the new teaching, working it out, proving it, endeavouring to bring it before the minds of people generally, then the struggle began.

Man objected not a little to giving up the pleasant belief that he resided on the most important spot in the whole Universe. He had been accustomed to think, if not exactly, '*L'univers c'est moi!*' certainly, '*L'univers c'est l'homme!*' The new stand which had to be taken was by no means flattering to human dignity.

We now in these days know far more than Copernicus ever dreamed of, as to the exceeding littleness of Earth, compared with the immensity of the Universe. But also we realise more that mere size and position do not mean everything. What man is, in his mental and spiritual being, may perhaps place him on a level which no other inhabitants of other worlds can excel or even rival. This is a mere 'perhaps!' We do not *know*. But at least we have learnt now that we do not know, and that the mysteries and possibilities of the unseen spiritual Universe may infinitely transcend the utmost mysteries and possibilities of the material Universe. To assent to the material smallness of our earth does not lower mankind in our eyes, as it did in the eyes of the contemporaries of Copernicus.

The question then seemed an exceedingly simple one. Our world had been the centre of all things; and Copernicus wished to relegate her to a position of no importance whatever. To this people strenuously objected; and they were much more anxious to prove themselves in the right, than to learn what really *was*. What they did not 'like,' they declined to believe.

No doubt the very thought of such a restless whirling globe, where all had been reckoned as absolute fixity, was startling to the imagination, until men grew used to it. Rome also was against this teaching, because Rome had always taught the opposite doctrine; and Rome, no less than individuals, disliked to be found in the wrong. Besides, Aristotle had not held the Copernican theory; and Aristotle, at that time, could not be otherwise than right.

So the new theory had to make its way slowly, against the dead weight of unreasoning public opinion, and against wrongly reasoning hierarchical opposition.

In time, gradually, despite all resistance, the truth made its way, and was generally received; though not till Galileo had been forced, under peril of his life, to deny his belief. All the same, Copernicus, Kepler, Galileo, were right; public opinion and the Vatican were wrong; the earth did move, and was

TYCHO BRAHE.

FROM AN ENGRAVING BY J. FALCK.

not the fixed Universe centre; and, by-and-by, those who lived on earth had to acknowledge the same. Rome ceased to discharge her thunders; and Aristotle was discovered to be not quite unimpeachable on questions of science.

The succession of these great men is interesting to note.

Between the two shining lights, Hipparchus and Ptolemy, nearly three hundred years intervened—or as long as from the days of Queen Elizabeth until now. But as the history of the world advances, we find brilliant scientific minds appearing more quickly, one following close upon another, instead of their being divided by long intervals of blankness.

Within thirty years from the death of Copernicus, were born two mighty men of science—

KEPLER, who lived till our Charles I. had been about five years king; and

GALILEO, who lived till 1642, when England was plunged in civil strife.

A third may also be mentioned—TYCHO BRAHÉ, born three years after the death of Copernicus. He lived till 1601, or nearly to the end of Queen Elizabeth's reign. But Tycho, though a splendid observer, was not a theoretical astronomer of any weight. He read no new secret of the laws of the heavens; and he was not convinced of the truth of the Copernican system.

Then, in the very year when Galileo died, an old and persecuted and broken-hearted man, forced by harsh treatment, in the weakness of old age, to deny his own belief,—in that very year was born the great SIR ISAAC NEWTON, whose work it should be to establish, on a firm basis, those truths for which Galileo had seemed to fight in vain.

Galileo was a man to whom truth as truth was dear; and it must have appeared to him, in his sad old age, that his life's work had been thrown away; that his efforts were a dead failure. He could not know of the little baby, soon to come, who, in mature years should do all, and far more than all, that Galileo would fain have done. He could not guess the height of honour to which his own name would be lifted in later generations.

For success is not always that which at the moment seems to be success; and apparent failure is not always failure.

Ptolemy's scientific work seemed to be of a far more successful nature in his lifetime, than the work of Galileo. But who now would dream of putting the name of Ptolemy before that of Galileo? The theories of Ptolemy have crumbled to dust. The theories of Galileo have been firmly established, and are held by the whole civilised world, as proven truth.

CHAPTER IV

THE WORK OF KEPLER

COPERNICUS, Kepler, Galileo, Newton; here is a constellation of brilliant names; stars of the first scientific magnitude; all shining within the little space of about two hundred and fifty years; all helping to establish the building of Modern Astronomy upon the ruins of the Ancient Astronomy.

Other scientific stars shone with and beside them; some, like Tycho Brahé, so brightly as to be even first-magnitude stars. But none certainly outshone the four above named. And to none others are we so deeply indebted for our present knowledge of the reasons and causes of things seen in the heavens.

It will, I think, be well to give here a slight general idea as to a very few of the leading discoveries, made in succession by these four mighty men of science, before going on to the more recent work of Astronomers, in connection with spectrum analysis. The growth of knowledge leads up to that, gradually, like the coming in of the ocean tide.

Of the main work of Copernicus you have already heard. Quietly, and with no stir or bluster, not like some man who does a little deed of mark, and is infinitely proud of the same, but rather as one who is possessed solely by love of truth for truth's sake—he thought out, and in the course of years reasoned out, and at the close of his long life gave out to the world, that which was to effect one of the most serious revolutions seen in the history of human knowledge.

Men of intellect before had been working upward to this point; and men of intellect later worked onward from it. Knowledge is usually slow in its development; and the mightiest revolutions are commonly brought about by a long succession of previous causes.

Copernicus did not stand alone. He was one in a long line of great men; some of them intellectually far transcending himself. But Copernicus was called to stand at a critical point, in a prominent position, where long preparation burst into action; where the collapse of the old science, and the erection of the new science, began together.

He was a 'quiet earnest patient God-fearing' man, and he did his life-work bravely, patiently, thoroughly; neither loitering nor hasting. Probably none in his days realised in the least how great was the task set him to accomplish. He struck at the very foundations of the olden science; and, though for awhile, the building still stood, it was tottering to its fall. He laid the foundations of the new science; and upon those firm foundations a right royal structure has since been reared.

Between Copernicus and Kepler came Tycho Brahé. Copernicus was a Roman ecclesiastic, born in Poland. Tycho Brahé was a wealthy Danish nobleman, an ardent lover of Astronomy, and a most patient and accurate observer.

But Tycho held fast by the old Astronomy. He was not convinced by the arguments of Copernicus. To him Earth was still the motionless centre of all things. He was willing to allow that the rest of the planets circled round the sun, as an explanation of things which he could not help seeing; but the sun itself had still, in Tycho's imagination, to revolve daily, with planets and stars and the whole sky round our earth.

As an explainer of causes, therefore, Tycho rose to no lofty heights. The real good which he did was in watching and noting actual phenomena; not in trying to explain how those phenomena were brought about. This was left for one of his young pupils, a sickly German lad named John Kepler.

In later years Kepler made a grand use of his master's mass of careful and thoroughly dependable observations. These had really been gathered together by Tycho, with a view of disproving the Copernican theory, and of establishing the main features of the olden Astronomy with certain improvements. But Kepler used the accumulated information to *disprove* the old Astronomy, and to establish the truth of the new Copernican system which Tycho had rejected.

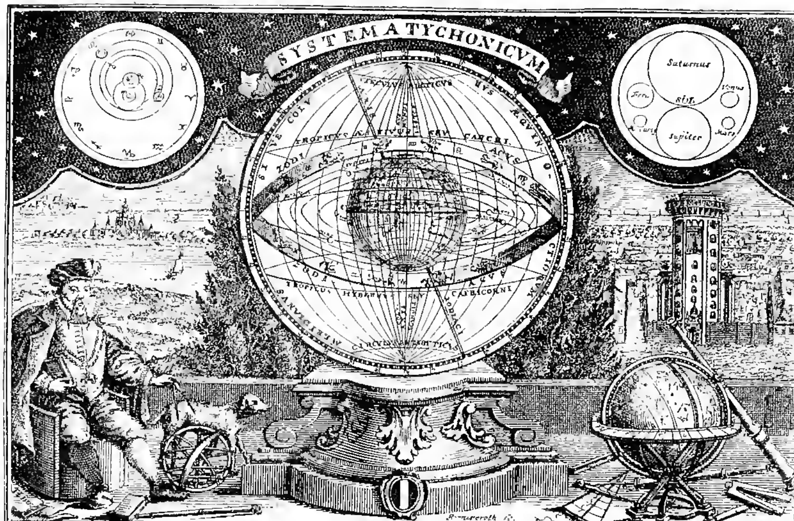
Here, briefly, is the change which was then in process.

Before the days of Copernicus, our earth was regarded as the fixed Universe centre; while around the earth travelled sun and moon and stars, and also the planets, revolving in epicycles. The Ptolemaic System reckoned sun and moon as two of the planets, making up the full number to seven.

After the days of Copernicus, the earth was dethroned from her central position in favour of the sun; and round an absolutely fixed and motionless sun travelled the earth and the planets, in *circular* orbits.

Copernicus, however, could not manage quite to get rid of epicycles. The movements of the various planets would by no means fit in with this notion of perfectly circular orbits; and the idea of elliptic orbits—that is of orbits, not perfectly circular but slightly oval in shape—never occurred to his mind. It was left for Kepler to sweep away epicycles altogether. Copernicus, in spite of himself, reverted to them, as the only explanation which he could come across for the motions seen.

He lessened the size of the epicycles, which was so far an improvement; and by placing the sun at the centre by making our earth merely one among many



THE SYSTEM OF TYCHO BRAHE.

revolving planets, he took the first great necessary step in the revolution of scientific belief then impending.

When Kepler came on the scene, he found a vast advantage ready to his hand in the collection of careful observations systematically worked out by Tycho in his Observatory, during many a long year. And Kepler did not fail to use his advantage.

The planets still refused, as they always had refused, to keep to the paths marked out for them by astronomers. Kepler threw himself into this question, and grappled with the difficulty. He particularly turned his attention to Mars, that near neighbour of ours, in which we are all now so much interested.

A long series of close observations of Mars' movements, made by Tycho in the course of many years, lay before him; and he knew that he could depend upon the absolute honesty and accuracy of Tycho's work.

With immense labour and immense patience he went into the matter—still clinging to the old idea of a circular pathway round the sun. He tried things this way and that way. He placed his orbit in imagination after one mode and another mode; he conjectured various arrangements; he tested and proved them in turn, comparing each plan with observations made; and still Mars defied all his efforts; still the little world went persistently wrong, travelling contrary to every theory.

Thus far, nobody had ever thought of an orbit of any other shape than a circle. When a straightforward journey round a circle was found impossible, then epicycles were introduced to explain the planets' perplexing notions. No one had dreamt of an elliptic pathway.

But suddenly a gleam of daylight came upon this groping in the dark. What if Mars travelled round the sun—*not* in a circle, but in an oval?

Kepler flung himself into calculations, complicated and difficult in kind. He tried anew this oval and that oval, comparing observations past, testing, examining, proving or disproving, with unwearied patience. And at length he found, beyond dispute, that Mars actually did travel round the sun in a yearly pathway, which was shaped, not as a circle but as the kind of oval known as an *ellipse*; and, further, that the sun was not in the exact centre of this ellipse but to one side of the centre, in one of the foci.

If you wish to draw a circle, you may fix a pin in the centre of a sheet of paper, slip a loop of thread over the pin and over a pencil, and then, having the pin firm and the pencil upright, guide the latter round, drawing a circle with the point as you move it. The pin is the focus of the circle, and is at an equal distance from each part of the surrounding circle.

But if you wish to draw an ellipse, you will require to fix *two* pins ; and the loop of thread must pass over both pins as well as round the pencil. Then if, as before, you hold the pencil upright, point downwards, gently tightening the thread, and draw a line all round, —that line will be no longer a circle, but an oval in shape ; an ellipse, in fact. The two pins will be the two *foci*. If the foci are very near together, the ellipse is more nearly circular in form ; if they are far apart, the ellipse is more elongated.

Kepler found that all the planets journey in elliptic orbits, and that in each case the sun is one of the two foci, not in the middle point of the oval orbit. He is in the centre of his system, as a *whole ;* but he is not in the centre of each particular planet's pathway.

One step further would have led Kepler to the knowledge that comets also travel in elliptic orbits—only, in very long and narrow ones, generally. But he had quite made up his mind that all comets merely paid our sun one visit, and never by any chance returned ; so he did not trouble himself to enter into calculations with respect to them. This taking for granted of ideas long held was a very common practice in those days.

The above wonderful discovery of elliptic orbits, in place of circular orbits, was only one among many made by the illustrious Kepler,—discoveries not carelessly hit upon, as one might pick up in the street a valuable stone which somebody had dropped, but earnestly sought for, and found with toil and diligence, as gems are first found in foreign lands, after much seeking and long patience. Casual discoveries in science are rare. Attainment is far more usually made through intense study, through hard work, through profound thought, through a gradual groping upward out of darkness to the point where daylight breaks forth.

The three well-known Laws of Kepler, of which I have explained only the first and simplest, still hold their own as absolute scientific truths, and still lie at the very foundation of the modern System of Astronomy.

CHAPTER V

THE STORY OF GALILEO

STILL, however, the world was not convinced of the truth of the Copernican System. One man here or there saw and acknowleged its reality. The mass of mankind continued firmly to believe that they dwelt at the Universe Centre,—continued utterly to scout the idea of a moving Earth. Indeed, it may be very much doubted whether, not merely the mass of mankind, but even the most civilised and cultivated portion of that mass, had, as yet, to any wide extent heard a whisper of the new theories. Knowledge in those days travelled from place to place with exceeding deliberation.

Another great man arose, contemporary with Kepler; a man whose story seizes more strongly upon our imagination than that of the severe and successful studies of Kepler.

Successful, that is to say, in so far as Kepler found some of the weighty truths for which he so earnestly sought. From the ordinary worldly point of view, he would hardly be looked upon as altogether a successful man. He was poor, and in sickly health. His chief book was promptly prohibited by Rome,—then a power in the whole reading world of Europe, to an extent which can hardly be realised in these days of freedom. Kepler's book was placed in the forbidden category, side by side with the dying publication of Copernicus. This checked all hope of literary gains; and life with Kepler was one long struggle. But if he could have looked ahead two or three hundred years,—if he could have foreseen the time when not a few wise men of science alone, but all the civilised world, including the very Roman Church which condemned him, should meekly have accepted and endorsed his discoveries,—then he would have been able to gauge the measure of his own real success.

Moreover, with all his troubles, Kepler was so happy as to escape absolute persecution. He lived in a country which knew something of liberty as an ideal; he was left to write and work freely; and, at least, no public recantation of what he held to be truth was forced from him.

Galileo's was a sadder tale. A Florentine of noble birth, he turned early to science, as the needle turns to the north; and before the age of twenty-seven he already occupied a foremost position as mathematical lecturer at Pisa. There it was that he direfully offended the philosophers of the day, by proving Aristotle to be in the wrong.

Aristotle had declared that if two weights—the one being ten times as heavy as the other—were dropped

GALILEO.

FROM A DRAWING BY LEONUS

together from a height, the heavier weight would reach the ground ten times as quickly as the lighter.

Everybody believed this; and nobody had ever thought of putting it to the test of actual trial. Aristotle had said so; and Aristotle was endorsed as a whole by the Vatican; and what more could possibly be wanted by any reasonable human being? But Galileo was not so easily satisfied. He looked into the matter independently; bent upon finding out, not what Aristotle had thought or what Rome might support, but simply what actually *was*.

Then in view of many observers, called together for the occasion, he dropped, at the same instant, from the top of the leaning tower of Pisa, a shot weighing one pound and another shot weighing a hundred pounds. And behold!—both reached the ground simultaneously. There was not a fraction of difference between the two.

To prove Aristotle wrong was to prove everybody wrong, Rome included. Men calmly declined to believe their own eyes, and Galileo was in very evil odour.

From falling bodies he went on to subjects of yet wider interest to people in general. He read about and eagerly embraced the Copernican system. Not only did he accept it himself, but he vigorously set to work to teach and convince others also.

This, as might only be expected, aroused vehement opposition. But Galileo was still in the heyday of his powers, and he was not to be easily silenced. In those cheery days he could afford to press onward, in the teeth of resistance, and to laugh at men who would not listen.

When at Venice a report reached him of a certain optician in Holland who had happened to hit upon a curious 'combination of lenses' through which objects afar off could be actually seen as if they were near. Galileo promptly seized upon the notion; and within twenty-four hours he had rigged up a small rough telescope out of an old organ-pipe and two spectacle-glasses.

Thus the first telescope was made; a very elementary affair, formed of two lenses—convex and concave—and capable of magnifying some three times. A mere child's toy, compared with telescopes of the present day, but of exceeding value and interest, because it was the very first, because in all the history of the world no telescope had ever been manufactured before.

This earliest effort was speedily improved upon. The next trial produced a tube which could magnify seven or eight times, and in a little while Galileo had a telescope magnifying as much as thirty-two times.

Even thirty-two times does not sound very startling to us; but in those days the revelations of such an instrument came upon men like a thunderclap.

Through it could be seen clearly the broken nature of the moon's surface; the craters, the shadows, the mountains. Through it could be seen the phases of Venus, which no man had ever yet detected, but which Copernicus had declared must certainly exist, if indeed his System were a reality. Through it could be seen the four moons of Jupiter, and their ceaseless journeyings. Through it could be seen spots upon the face of the sun, the movements of which showed the rotation of the sun upon his axis. Through it could be seen the very curious shape of Saturn, caused by his rings; though a much stronger power was needed to separate the rings from the body of the planet.

Of all these discoveries, and many others also made by Galileo, none seemed worse to the bigoted schoolmen of his day than the preposterous notion of black spots upon the sun's face.

Rather curiously, no human being seems ever before then to have noticed such spots, though often they are quite large enough to be detected by the naked eye. A general belief had been held that the sun was and must be perfect,—an absolutely spotless and unblemished being; and the said discovery went right in the teeth of deductions drawn from, and lessons founded upon, this belief. Therefore the schoolmen held out and determinately resisted, and would have nought to do with Galileo or his telescopes, shutting their eyes to marvels newly revealed.

But Kepler was a true scientist, a man who earnestly pursued truth, and sought to discover it at any hazard. He and Galileo were contemporaries, and they held communication on these subjects. Some of Galileo's discoveries went quite as much in the teeth of some of Kepler's most dearly-loved theories, as they did in the teeth of the schoolmen's most dearly-loved doctrines. Yet, none the less, Kepler welcomed them with great delight and eagerness, showing thereby his true greatness of character.

Till after the age of fifty, Galileo was allowed to go on undisturbed, or at least not materially disturbed by opposition in his career of success; observing, learning, theorising, calculating, explaining, teaching; a prominent figure indeed. Not only did he take a large share in establishing firmly the Copernican System of Astronomy, but some of the principal laws of motion were discovered by him. He first found the uses of a pendulum; and there is strong reason for believing that the first microscope, as well as the first telescope, was from his hands.

He is a singularly dazzling figure as he stands forth in those comparatively ignorant and unscientific days.

But, after the age of fifty reverses came, and one blow succeeded another. Rome had been gradually waking up to the true sense of all that was implied by his discoveries and his teaching, and at length she let loose her thunders; impotent thunders enough, so far as regarded any permanent checking of the progress of truth, but by no means impotent to crush one defenceless victim—the champion of scientific truth in that country and age.

Years of greater or less opposition, amounting often to persecution, were followed by an imperious order commanding him to Rome. There he was examined and severely 'questioned'—one knows too well what the 'questioning' may have meant;—and recantation was forced from him, worth as much as such forced recantations commonly are worth.

Even then he did not cease from the work that he loved; even in prison he carried it on; even when he might not write, nothing could stop him from thinking.

But his health was broken; his liberty was taken away; illness followed illness; his favourite daughter died; his eyesight gradually failed; the last book that he wrote might not for a long while be printed; and at last he passed away, mercifully set free from those who, in an essentially bigoted and intolerant age, were incapable of appreciating his greatness.

They would fain *then* have denied him even a respectable grave. Now all the civilised world unites to honour the name of GALILEO.

CHAPTER VI

SIR ISAAC NEWTON

In the very year of Galileo's death, Isaac Newton was born.

Copernicus, Tycho Brahé, Kepler, Galileo—all belonged to other countries. But Sir Isaac Newton was an Englishman, and we may well be proud to call such a man our own.

He was the son of a Lincolnshire farmer, and was born in the year 1642, in the reign of Charles I. When that unhappy king lost his head on the scaffold, Newton was a little boy still, under eight years old.

Long before he reached the age of thirty, his brilliant genius was recognised by able men. But he was not a genius only; he had also the ballast of patience, perseverance, and immense powers of work. Somebody has defined 'genius' as being 'an unlimited capacity for taking pains.' This is wrong. There is in true genius a spark of Heaven-sent power, the place of which can be supplied by no mere painstaking. On the other hand, true genius is very

SIR ISAAC NEWTON.

AFTER SIR GODFREY KNELLER.

often indeed allied with this marked capacity for taking pains. It seems as if the power to do a certain thing brought commonly with it a love for doing that thing. Genius *without* the power of persistent toil is of small avail. Genius *with* 'an unlimited capacity for taking pains' is the greatest of gifts.

Isaac Newton had the Heaven-sent spark—an unusually brilliant one—and with it he had unbounded capacities for work. He began early to think, to toil, to calculate, to invent, to look into the causes of things, to conjecture possible explanations, to search and examine and test, to prove or disprove this or that, with absolutely untirable patience. And the outcome of it all was a career of such success as has seldom been equalled.

A certain story is often told about Newton. It is said that, as he sat in a garden, an apple fell from a tree, and that its fall set him thinking; and that, in consequence of this train of thought, he found out all about the Law of Attraction or Gravitation.

The apple is stated to have dropped from a particular tree in a particular garden, at a place called Woolsthorpe, in the year 1666, when Newton was under twenty-four years old, at the time of the Great Plague and the Great Fire of London.

To people living then it would, no doubt, have appeared that the fact of a young man—a farmer's son—sitting in a garden, thinking about the laws which govern the Solar System, was a most unimportant matter, compared with the awful sufferings of the plague-stricken City, and of the terrific fire following. And in a sense, no doubt, it was so. Yet to us in these days, more than two hundred years later, the discoveries of Newton, and the mighty impetus which he gave to the growth of scientific truth and of general knowledge, have probably far more widespread results than even the Great Plague and the Great Fire.

The story of the apple as above stated cannot be entirely correct. To begin with, the fall of an apple could not possibly have set Newton thinking, because he had already been thinking long and hard upon these difficult questions. Indeed, it was *because* he had been so thinking, *because* his mind was in a watchful and receptive condition, that so slight a matter as a falling apple should, perhaps, have suggested to him a useful train of ideas.

Newton was a man who really did think, and who really did think intensely. He was not, like the ordinary run of people, one who merely had a good many notions walking loosely through his brain. He would bend his mind to a subject and be absolutely absorbed in it; later in life so absorbed that he would forget to finish his dressing, and would be unable to say whether or no he had dined. This sort of forgetfulness does sometimes spring from vacancy of mind; but with Newton it arose from fulness of thought.

Another assertion in the story as given above is untrue, and this is, that Newton found out the law of gravitation from the fall of an apple.

An apple falls, of course, as a stone or any other body falls, because the earth attracts it. Otherwise, it might as easily rise and float away into the sky.

But this was known perfectly well long before Newton's days. It was clearly understood that the earth had a curious power of drawing all things towards herself. People could not explain why or how it was so; neither can we explain now; but they were fully aware of the fact.

So men knew something of the force called Gravity; but they knew it mainly, almost exclusively, as having to do with our earth, and with the things upon our earth. They had not begun definitely to think of gravity as having to do with bodies in the heavens; as being a chief controlling force in the whole Solar System; much less as reigning throughout the vast Universe of Stars. It had not come into their minds with any distinctness that, just as the earth pulls towards her own centre a mountain, a horse, a man, so the sun pulls towards his centre the earth, the moon, and all the planets.

Certain glimmerings of the notion had, indeed, begun to dawn on the horizon of learning. Horrocks, Borelli, Robert Hook, Wren, Halley and others had *glimpses* of Universal Gravitation; but only glimpses. A gifted English philosopher late in the sixteenth century, Gilbert by name, went so far as to speak of earth and moon acting one upon the other 'like two magnets.' He also saw the effect of the moon's attraction in bringing about ocean tides, though he oddly explained that the said attraction was not so much exerted upon ocean waters as upon 'subterranean spirits and humours,'—whatever he may have meant by such an expression.

Kepler, not long after Gilbert, made further advance. He gained some definite notions as to the nature of gravity; and he saw distinctly that the moon's attraction was the main cause of the tides. The following remarkable statement is found in his writings:—'If the earth ceased to attract its waters, the whole sea would mount up and unite itself with the moon. The sphere of the attracting force of the moon extends even to the earth, and draws the waters towards the torrid zone, so that they rise to the point which has the moon in the zenith.'

Here is a distinct enough grasp of the fact that gravity can and does act through distance, between worlds separated by thousands of miles.

Yet though both Gilbert and Kepler saw so much, they failed to go farther. Neither of the two had any clear knowledge of the modes in which gravitation acts, or of the laws which govern its working. Gilbert and Kepler alike, while dimly recognising, not only the moon's attraction for Earth's oceans, but the mutual attraction of Earth and moon each for the other, were utterly perplexed as to what force could possibly hold the two bodies asunder. Gilbert could seriously talk of 'subterranean spirits and humours.' Kepler could soberly write of an 'animal force' or some tantamount power in the moon, which prevented her nearer approach to earth.

Galileo was equally vague on the subject. With all his brilliant gifts, and while acknowledging the earth's attractive power over the moon, he would not even admit the existence of *mutual* attraction, and talked of the moon as being compelled to 'follow the earth.'

Unquestionably there are times when the moon does 'follow' the earth, and that is when the earth, like the famous Madame Blaise, happens to 'go before.' But quite as often it happens that the moon goes before, and the earth follows after.

All these great men were groping near the truth, yet none managed to find the clue that was wanted. They left the unfinished process of thought to be carried on by the master-mind of Newton. And Newton set himself to think the question out. He used Kepler's observations. He sought to penetrate the secrets of a Solar System in mysterious and inviolable order. Some reason or cause for that order he knew must exist—if only it might be grasped! He pondered deeply; lost in profound cogitation, through stormy days of civil strife, of plague and loss and suffering. The then object of his life was to discover, if so he might, what power or what forces retained the different worlds in their respective pathways; in short, what manner of celestial guidance was vouchsafed to the planets.

For although men had now learnt the shape of the planet-orbits, and even knew certain laws which helped to govern the planet-motions, they had not discovered one supreme controlling law. They did not dream of gravity in the heavens as a prevailing force. There was absolutely no reason, with which men were acquainted, why each planet should preserve its own particular distance from the Sun; why Mars should not wander as far away as Jupiter; why Mercury should not flee to the position of Saturn; why our own Earth should be always about as near as she always is.

It may well be that, as Newton pondered this perplexing question while seated in the garden, an apple dropping to the ground might have sufficed to turn his wide-awake and ready mind in the direction of that familiar force, gravity, which draws all loose bodies towards earth's surface. The apple fell because of gravity. Quite naturally the question might have arisen in Newton's mind,—'Why not this same gravity in the heavens also? If the earth draws an apple towards herself, why should not the earth draw the moon? Why should not the sun draw the earth? Nay, more, why should not the sun draw all the planets?'

Newton did not hastily speak his thought. It was not his mode, neither was it the mode of his day, to fling half-fledged notions into the mouth of a gaping public. He considered the matter, and he went into complicated calculations. Supposing gravity to be the force which binds the moon to the earth, then the 'fall' of the moon towards the earth—that is, the exact extent to which she is pulled out of a straight line by the earth's attraction, and is forced to travel in a curve, —must, according to certain known laws, be a definite amount each minute. Newton set himself to work out this problem, allowing for the distance of the moon from earth, and for the bulk and weight of both earth and moon.

And because the answer was *not* precisely what he had looked for, he put the calculation aside, and waited for years. It seems that he mentioned his conjecture to no living person.

After many years he took it up again, and worked it out afresh. By this time new measurements of earth's surface, and new calculations of earth's size had been made, and Newton had fresh figures to go upon. This time the answer came just as he had originally hoped, and the truth of his surmise was thus proved.

Gravity held the moon near the earth, preventing her from wandering off into unknown distances. Gravity held Earth and Moon, Mars, Venus, Jupiter, each planet, in its own pathway, within a certain distance of the Sun. Gravity held many of the comets as permanent members of the Solar System. So strong, indeed, was the drawing of gravity found to be, that only the resisting force of each bright world's rapid rush round the sun could keep the sun and his planets apart.

Newton had discovered the long-sought secret. He had found that 'every particle of matter in the universe attracts every other particle.' He had found also the main laws which govern the working of that attraction—that it depends, first, upon the mass or amount of 'matter' in each body; that it depends, secondly, upon the distance of one body from another. He found, too, how far attraction increases with greater nearness, and decreases with greater distance. All these and countless other questions he worked out in the course of years. But first he had grasped the great leading principle, after which men had until then groped in vain, that by the Force of Gravity the sun and his worlds and their moons are all bound together into one large united family or System.

Further than this Newton did not progress—in this particular direction, at least. To him, as to others in his day, the Sun was still an absolutely fixed and motionless centre—not only centre to the Solar System, but centre to the Universe. The real Universe of Stars, as known to us now, lay outside of and apart from these calculations. Gravity had not yet been thought of as working among them also.

CHAPTER VII

SOME DISCOVERIES OF NEWTON

FROM his great discovery that Gravitation, instead of being merely a little local law of Earth, was a wide and general law, working throughout the whole Solar System, Newton went on to other discoveries also.

Happily for him, his lot was cast in a land where fresh light was more or less welcomed, and where the advance of knowledge was at least not systematically checked. No Vatican thunders sought to silence his voice; and if he did not escape a certain amount of jealous opposition, yet, on the whole, his long life, lasting from the reign of Charles II. to that of George II., contained abundance of appreciation and showers of honour. Both leisure and means were his for the working out of countless difficult problems, the finding of countless wonderful truths.

He it was who first explained clearly the action of the Moon in producing ocean tides—a matter which had been dimly perceived before his time by Kepler.

He it was who first included some of the comets as permanent members of the Solar System.

He it was who made the first reflecting telescope—all earlier telescopes having been refractors.

He also it was who went anew into that complicated question—the PRECESSION OF THE EQUINOXES. We must pause to think about that now for a little while.

The earth, as we all know, revolves perpetually on her axis once in about every twenty-four hours; and, as she so revolves, her north pole points ever steadily towards the Pole-star.

It was, however, found early in historical times that the axis of our earth is not absolutely fixed in one direction. There is a movement—a very slight, very slow movement of it,—a kind of wobbling motion akin to that which one may note in the axis of a spinning-top; only the latter is very fast, while the former is exceedingly slow. Through this motion the north pole—and also correspondingly the south pole—describes a little circle in the course of over 26,000 years. Therefore, the north pole does not always, continuously through countless ages, point to exactly the same spot in the northern sky.

The fact itself was discovered by Hipparchus, that early astronomer, so long ago as about one hundred and fifty years before Christ.

In the days of Hipparchus, the Pole-star was farther away than now from the celestial north pole—that is, from the point in the sky which lies precisely over the north pole of Earth. And in the course of the next hundred years, the Pole-star will creep nearer than it is now to the pole—after which, again, another slow retreat will begin.

But these movements are no movements of the Pole-star. They are earthly motions, not starry motions. The apparent approach and retreat of the Pole-star to and from that spot in the sky which lies just over our north pole is due entirely to the wobbling motion of Earth's axis. The stars remain where they were in our sky; but our north pole travels slowly round in a tiny circle, pointing in the course of thousands of years to ever fresh points in the heavens. So, when the Pole-star seems to alter its distance from the celestial pole, this only means that the celestial pole alters its distance from the Pole-star. The north pole in the heavens is just where our north pole points; and our pole, as you see, does not always indicate the same spot.

The bare fact was discovered by Hipparchus; but Hipparchus failed to find any adequate cause. He knew nothing whatever about the effects of gravity upon the heavenly bodies.

It was left for Newton to search out the truth that this Precession of the Equinoxes is really due to gravity—that all-pervading and universal law, the simplest and the most mysterious of all known forces.

The earth is not a perfect sphere, but is flattened at the two poles, and bulged out at the equator—which means a longer diameter through the centre, from side to side, at the equator than at the poles. *This* means more substance, more material, in the equatorial regions than farther north or south. And the attractions of sun and moon so act upon the inequality of shape—the bulged-out middle—as to cause that slight slow wobbling motion of the whole body of the earth, which results in the Precession of the Equinoxes.

But what *is* the precession of the equinoxes itself? We have been talking of the cause of the thing; while not everybody knows exactly what the thing itself is.

It is what it says it is. You know what the equinoxes are—these two dates in the year when days and nights are of equal length over almost the whole of the earth. There is a spring equinox in March, and an autumn equinox in September.

The word 'precession,' as explained in a dictionary, means *the act of going before.* It means, in fact, movement or change. The equinoxes slowly move—slowly change their time—as thousands of years pass, in consequence of this slow movement of Earth's axis.

Each year the vernal equinox—and of course the autumnal equinox also—is about *twenty minutes earlier* than the year before—earlier, that is to say, in respect of its position *among the stars;* not in respect to *solar time.*

In twelve thousand years the vernal equinox will be in the present position of the autumnal equinox, so far as has to do with the stars. Yearly time, as regards the sun himself, will show no change. But the background of stars behind the sun, at the time of earth's spring equinox, will then be — not the constellations which now lie behind him at that date, but those constellations which now form his background at the autumnal equinox. Twelve thousand years later still, things will have returned once more to their present condition.

This is what is meant by the Precession of the Equinoxes.

One more great discovery of Newton's must be noted.

It has a peculiar interest for readers of this little book, the main intention of which is to teach popularly a few of the leading facts connected with SPECTRUM ANALYSIS—to show a little of the wonderful work which is being accomplished by that modern instrument of research, THE SPECTROSCOPE.

For Newton found out something which lies at the very foundation of Spectrum Analysis — something without knowledge of which no Spectroscope could ever have been made.

Not much was known before Newton's days as to the nature of Light. Certain laws by which Light is seen to act—laws of Reflection and laws of Refraction—were indeed studied early; and the ancient astronomer Ptolemy wrote a very famous work on Optics. But such knowledge as men then had on the subject was exceedingly slight and fragmentary.

A common notion among the ancients, and one which lasted during long ages, was that men saw by means of a kind of projection from the eyes themselves—a sort of invisible *feelers*—a something, as has been suggested, not altogether unlike the feelers of insects, only, of course, intensely etherial in make. How such feelers could by any possibility reach to sun and moon, even at the limited distances then ascribed to heavenly bodies, imagination is quite unable to picture.

It has been remarked, also, that until about 350 B.C. nobody seems ever to have asked the puzzling question why, if such were truly the mode whereby men saw, they could not see just as well in darkness as in light?

Colour was through ages looked upon as a definite part of an object; no less characteristic of it than its square or round shape, its hard or soft or heavy make. That colour is actually a property of *light*, and is only, as it were, lent by light to objects for the time being, had occurred to the mind of no man. Light was regarded as always the same,—the same throughout, perfectly simple in make, colourless and homogeneous.

Newton overturned this theory once and for all. He it was who discovered the complex character of a Light-Ray—whether ray of sun or star, of lamp or candle. By passing a Ray of Sunlight through a slit in a shutter, and then through a prism, he separated the single ray of white light into divers sub-rays of many-coloured light; letting them lie upon the wall, side by side, in successive bands, from red to violet, like rainbow-hues.

This had been doubtless done before, many a time. Before Newton's day men knew that a prism would cast strips or bands of many colours upon wall or floor. But other men had been content to see the sight, and to know no cause, to deduce from it no truth. Newton was not so content. With his, as with other great and observant minds, the first question was always and naturally, 'Why?' and he could not rest till he had found some kind of answer.

In the report made by him of his own researches, Newton speaks of 'the celebrated phenomena of colours,' and of the 'very pleasing *divertisement*' which the study of it afforded. But it was not '*divertisement*' alone that he sought. With him pleasure commonly meant hard study.

He used one prism and two prisms; he put them this way and that way; he carefully noted and measured how the rays travelled and how they fell;

he became convinced that some of the olden notions were wrong; and he tried experiment after experiment, earnestly seeking to find what it all might mean.

The outcome of these efforts was the gradual dawning on his mind—and through his mind upon the world at large—that 'light is not similar or homogeneal'—not, as we should say now, simple or homogeneous—'but consists of *difform rays*, some of which are more refrangible than others; so that . . . some shall be more refracted than others; and therefore that, according to their particular degrees of refrangibility, they were transmitted through the prism to divers parts of the opposite wall.'*

Here was another revolutionising step in science. Here was another man of genius, doing what hundreds of men had done before him, using what anybody might have used, seeing what multitudes had seen without being any the wiser; while he, with his spark of Heaven-sent genius, and his no less Heaven-bestowed 'capacity for taking pains,' had drawn to light another wondrous secret in Nature,—a secret this time of LIGHT itself.

A light-ray was no longer homogeneous—or homogeneal—that is, simple in make, the same throughout; but complex, complicated, a mysteriously-woven bundle of lesser rays. No longer was a light-ray purely white. As a whole it is white; but its separ-

* Letter from Newton to Oldenburg.

ate rays are coloured; and only by the union of them all into one do we obtain whiteness.

The sub-rays are 'difform' in nature; different in make, or differently formed. Some are more refrangible than others. 'Refrangible' merely means 'bendable.' What a prism does is to *bend* a ray of light out of its direct course. All light-rays travel straight forward, unless some power bends them out of the straight path. When so bent by a prism, the ray is broken up or divided; and some of its sub-rays being less bendable than others, they fall upon different parts of the wall or floor beyond.

Those which are the least bendable lie most nearly opposite to the hole in the shutter. Those which bend the most lie farthest away from that spot. Thus a row of colour-bands are seen, one beside another.

By this discovery, as already stated, Newton laid the foundation for modern spectroscopic researches, little thinking the while how weighty a discovery he had made.

It was but a first step, and much, very much, remained to be searched out before any idea of a Spectroscope and its uses could occur to the mind of man; still, it was a first step of crucial importance, and upon it hung all after-growth of knowledge in that particular direction.

For want of a better theory, Newton and other able men in his day adopted what is called the

Corpuscular Theory of Light. It supposed that every object shot outwards, in all directions, innumerable *corpuscles* — inconceivably minute bodies, all moving with inconceivable rapidity—and that the cannonading of the eye by these tiny pellets caused the sensation of sight. A difficult theory to accept now, when one realises what would be meant by such a perpetual rush, at enormous speed, of even the most infinitesimal corpuscles which could possibly exist.

It was, however, the best theory then to hand—at least far more reasonable than the olden notion of invisible eye-feelers put out to any distance. Newton held it as probably a true explanation. Like Ptolemy's epicycles, it did explain a good many things, otherwise unexplainable; and it served *pro tem.* till the present Undulatory Theory of Light arose to take its place.

CHAPTER VIII

THE PROBLEM OF SUN-DISTANCE

MANY Astronomers of note followed at intervals after Sir Isaac Newton; but hardly one who could in any sense be termed his peer, until the coming of SIR WILLIAM HERSCHEL. He, too, was to break out suddenly in the sky of science as a star of the first magnitude. What Newton had done for the Solar System, Herschel was to do for the Stellar System. The door which Newton had opened was to be flung yet wider by Herschel, revealing a magnificent universe of possibilities.

Flamsteed, Bradley, Halley, and other great men in turn appeared, shone, and shone brightly; each taking his part in the study of the heavens.

But no second Isaac Newton arose as years passed on. These men, coming after him, had the gifts of enormous painstaking, of unwearying energy, of keen insight, of ardent love for truth; but they had not that peculiar spark of Divinely-given genius which Newton had; or rather, perhaps, the spark in them was a good deal less dazzling than in him.

Each, however, contributed his quota to the gathering pile of knowledge; and the onward march of Astronomy still continued—if not always by leaps and bounds, at least in a steady progression.

One question had long occupied the minds of scientific men without the finding of any satisfactory answer, and this was the Distance of the Sun from our earth.

At length the Sun had fully gained his rightful position in the minds of men as centre and controller of the Solar System; and Earth was fully dethroned from her olden false position. In point of fact, the sun had gained *more* than his rightful position; since he was now looked upon very much as the earth had been formerly looked upon; since he was regarded practically as the motionless Universe-Centre. The earth might and did move—people had grown used to that idea—but the sun, at all events, was fixed. The sun, beyond turning upon his axis, was motionless. Time would reveal this error; and, meanwhile, very much had been learnt.

Still, as to the true distance of the sun from ourselves, ignorance reigned.

Tycho Brahé had made a great advance on earlier notions by placing the light-giver 4,000,000 miles away in imagination. Kepler, a quarter of a century later, increased this to 14,000,000. Galileo afterwards reverted to the 4,000,000. All this, however, was sheer guesswork.

Not till well on in the seventeenth century did Cassini make a definite attempt at actual measurement of the sun's distance, and this attempt gave as a result some 82,000,000 miles—not far removed from the truth. But at the same period other observers gave results of 41,000,000 and 136,000,000; so for years the question still remained swathed in mist. Better modes and better instruments were required before it could receive settlement.

The measurement of the distance of objects a good way off, though simple in plan, is in practice far too complex to be fully explained in a book of this kind. A slight idea, however, of the principle of such measurements, and of what is meant by 'parallax,' may be offered.

Take your stand a yard or two off from a lighted lamp, in a room otherwise dark. Hold a pencil upright, about half-way between your eyes and the light. Shut the right eye, and you will see the pencil against a certain part of the lamp-globe. Open the right eye and shut the left, without stirring your head, and you will see the pencil against a different part of the lamp-globe. Move the pencil farther from your eyes and nearer to the lamp, still keeping your head quite motionless, and the distance between the two 'views' of it will lessen. Bring the pencil nearer to your eyes, and the distance between the two 'views' will widen.

Or you may let another person hold the pencil upright for you in the middle of a room in daylight.

You may look at the pencil with both eyes from one corner of the room, and then you may look at it from another spot two or three yards distant from that corner. The pencil, as seen from the two different positions, will appear to lie against totally different backgrounds of window or furniture or wall-paper.

In precisely the same manner, if you are gazing at a church-tower a mile or two off, you see it against a certain background, against a particular part of the scenery. But if you walk into another field and look at it again, the steeple will lie against a new background, against another part of the scenery.

Now, the straight line between your two positions in those two fields, and the straight line between each of those two positions and the steeple itself, form, all three together, a *triangle*. Of this triangle, the straight line between your first position and your second position is the *base;* and the two angles are given by your line of vision to the church-steeple at each end of that base. That is to say,—as you stand in one field and look at the tower, the line of your sight and the base-line together make one angle; and as you stand in the other field and look at the tower, the line of your sight together with the same base-line makes another angle. And the exact form of those angles you may, if you will, and if you know how, draw upon paper.

The base-line may be long or short. It may be as long as the line from each end of it, which reaches to the tower. Or it may be very short indeed; and the two lines to the tower may be by comparison extremely long. That does not matter at all. You might measure the distance of a tower one mile off, from a base-line one mile long. Or you might measure the distance of a tower twenty miles off, from a base-line half-a-mile long.

What does matter is this: that when in any triangle of any description we have *two angles*, and also the exact length of *one side*, it is then perfectly easy to calculate with absolute certainty the remaining angle, and the lengths of the *other two sides*. It is a mathematical question; and the answer is sure.

So, if you are looking at a church-tower some distance off, and if you do not know its distance, you may find it out by this mode; provided, of course, that you have the right instruments for observation and measurement, and provided that you know enough of mathematics to make your calculations correctly. There is no guesswork in the matter. It all depends on correct measurement, correct observation, and correct calculation; and the answer then is just as certain and dependable as that two and two make four.

Of course the whole calculation rests upon one thing,—upon an exact knowledge of the *length of your base-line*. If you observe the tower ever so carefully from one field, and then observe it ever so carefully from another field, and then get a wrong measurement of the base-line between those two spots,—it does not matter how accurately your sum may be worked out. The answer will be wrong; because it rests upon a wrong basis, because it is reckoned from a mistaken length of base-line.

This kind of measurement of distances is not confined to our earth's surface alone. The distances of bright bodies in the heavens may be calculated after just the same method, provided only that the heavenly body is not too far distant to be made to change its seeming position in the sky.

Suppose you wished to find out how far off the Moon is. You would have to make your observation of the moon's exact position in the sky,—of just that spot precisely where she is to be seen, among heavenly scenery, at a particular moment. And you would have to get somebody else to make a similar observation, at the same time, from some other part of Earth, at a good distance from your post.

There are no hills or woods in the sky for the moon to be seen against; but there are plenty of stars, bright points of light far beyond the moon. If you look at her from one place, and your friend looks at her from another place a good way off, there will be a difference in your two 'views.' You will see her very close to certain stars; and your friend will see her not quite so close to those stars, but closer to others. This difference of view would give the moon's parallax.

If your observations were very careful, very exact; and if you had the precise distance between the spot where you stood, and the spot where your friend stood, —then, from that base-line, and from the two angles formed by its junction with the lines from the two ends of it straight to the moon, you might reckon how many miles away the moon is. The greater the distance between the two places of observation the better,—as, for instance, at Greenwich and the Cape of Good Hope.

Practically, this is not nearly so simple a matter as it may sound, because our earth is always on the move, and the moon herself is perpetually journeying onward. All such motions have to be most scrupulously allowed for.

So the actual measurement of Moon-distance requires a great deal of knowledge and of study. Many other difficulties and complications beside these enter into the question, and have to be overcome.

Now the Sun is very much farther away than the Moon, and the stumbling-blocks in the way of finding out his distance become proportionately greater and more numerous.

It is easy to understand, with regard to the pencil which you looked at from two parts of the room, that if it were half-a-mile away, instead of only three or four yards away, your walking from one corner of the room to a few feet off would not make any difference in your view of the pencil. And if the church tower had been twenty miles off, instead of only one or two miles off, your going into another field close at hand would have made little or no change in its apparent position.

The Sun is at so enormous a distance, that to observe him from two parts of England, or from two parts of Europe, would give him no parallax. That is to say, there would be no change of position on his part apparent to us.

I do not say that there would be no change at all; but only that it would be so tiny as to be quite unseen by human eyes, even with the help of most careful and accurate measurement. A very long base-line is needed to make the sun distinctly appear to change his position, ever so little. Only the very longest base-line which can be found on earth will do for this,—nothing less than the earth's whole diameter of nearly 8000 miles. And I think you will see that the success of the calculation would then depend, not alone on most careful observation from two posts at the opposite sides of earth; not alone on mathematical gifts and powers of close reckoning; but also, essentially, on a true knowledge of our earth's diameter; that is, of *the exact length of the base-line* from which the whole calculation would have to be made, and upon which the answer would largely depend.

For a long while the earth's diameter was not well known. As time went on, fresh measurements were again and again made of different portions of earth's surface, fresh calculations following therefrom; and gradually clear conclusions were reached. A very important matter it was that they should be reached! For the semi-diameter of our earth has been adopted as a 'standard measure' for the whole Universe; and the slightest error in that standard measure would affect all after calculations.

When actual observations of sun-distance came to be made, innumerable difficulties arose.

Foremost stood the huge amount of that distance. This made precise observations more difficult; and at the same time it made every mistake in observation so much the worse. A little mistake in observing the moon might mean only a hundred miles or so wrong in the answer; but a mistake equally small in observing the sun would lead to an error of many millions of miles.

Again, to observe the sun's exact position among the stars, as with the moon, was not possible; because when the sun is visible the stars are not visible.

Again, the dazzling brightness of the sun baulked the needed exactitude.

Halley had a brilliant thought before he died. He could not carry it out himself, but he left it to others as a legacy.

A little earlier I spoke of holding a pencil against a lamp, and noting its displacement with your two eyes, using each eye separately. By this mode, if you knew how, you might reckon mathematically the distance of the lamp from your eyes.

We have no enormous pencil suitable for holding up against the sun. But now and again, at long intervals,—twice in the course of about 112 years,—the little dark body of Venus passes exactly between the sun and the earth.

At the suggestion of Halley, on the first opportunity—which was not till after his death—the above mode was tried of measuring the sun's distance. Not by one man watching Venus with his two eyes alternately; but by two or more men, in different parts of Earth, watching the transit of Venus.

A certain observer, stationed on one part of earth, saw the tiny dark body of Venus take one particular line across the sun's bright face. Another observer, standing on quite another and a far-off part of earth, saw the little dark body take quite another line across the sun's bright face. Not that there were two little dark bodies, but that the one body was seen by different men in different places.

It was very much the same thing as when your two eyes saw one pencil lie against two different portions of a lamp-globe. There was one sun, and there was one Venus, but there were two different *views* of Venus.

From these separate views of the path of Venus across the face of the sun, in connection with what was already known of the earth's diameter, and therefore of the length of base-line between the two places, the distance of the sun was reckoned to be about 95,000,000 miles.

Since that date many fresh attempts have been made, and errors have been set right. Mercury as well as Venus has been used in this matter, and other newer modes of measurement have also been successfully tried. We know now, with tolerable accuracy, that the Sun's greater distance from Earth is between 92,000,000 and 93,000,000 miles.

CHAPTER IX

THE PROBLEM OF STAR-DISTANCE

A CURIOUS illustration of Sun-distance has been offered by one writer.

Sound and light, heat and sensation, all require *time* for journeying. When a child puts his finger into a candle-flame he immediately shrieks with pain. Yet, quickly as the cry follows the action, his brain is not really aware of the burn until a certain interval has elapsed. True, the interval is extremely minute; still it is a real interval. News of the burn has to be telegraphed from the finger, through the nerves of the arm, up to the brain; and it occupies time in transmission, though so small a fraction of a second that we cannot be conscious of it.

Now, try to imagine a child on earth with an arm long enough to reach the sun.

His fingers might be scorched by the raging fires there, while yet his brain on earth would remain quite unaware of the fact for about 130 years. All through those years sensation would be darting along the enormous length of arm, exactly as fast as it darts from the finger-tips of an ordinary child on earth to that child's brain.

If the scorching began before he was one year old, he would have become a very aged man, 130 years old, before he could know in his mind what was happening in the region of his hand. Moreover, if, on receiving the intimation, he should decide to withdraw his hand from that unpleasantly hot neighbourhood, another 130 years would elapse before the fingers could receive and act upon the message, telegraphed from the brain, through the nerves of the arm.

So much for the distance of the Sun from our Earth!

But the STARS! How far off are the stars?

The distance of the moon is a mere nothing. The distances of the planets have been found out. The distance of the sun has been measured. But the Stars—those wondrous points of light, twinkling on, night after night, century after century, unchanged in position save by the seeming nightly pilgrimage of them all across the sky in company, caused only by our earth's restless continual whirl—

What about the distances of the Stars?

In the last chapter we went into the question of PARALLAX. You will remember the explanation given.

Suppose you are looking at two church-towers out of a window. One tower is near; the other is very much farther off. You see each of them against a particular part of the country beyond—against a field, or a wood, or a certain spot on the horizon.

Then suppose that you go to another house, near your own, and look out of a window there upon the same towers.

You will see a change. Both towers have seemed to move a little. Each of them will appear to lie against a different part of the country from where it lay before—against another field, or another wood, or another spot on the horizon. The towers have not really moved, but you yourself have moved; and this movement of yours gives them a 'parallax,'* or makes them seem to have changed their places.

If you are watching carefully you may notice one thing more. You will see that the nearer tower seems to move *most;* and that the farther tower seems to move *least.* In other words, the nearer tower has the larger parallax; the farther tower has the smaller parallax.

This mode of measurement was tried successfully on the moon, on the planets, and on the sun.

But when it was tried upon the stars, from two stations as far apart as any two stations on earth could be, the attempt was a failure. Not a ghost of parallax could be detected with any one star.

* Definition of 'parallax':—'In the most general sense, "parallax" is the change of a body's direction resulting from the observer's displacement.'—Prof. YOUNG.

Not the faintest sign of displacement was seen in the position of a single star, when most critically and carefully examined.

Then arose a brilliant thought!

What of Earth's yearly journey round the Sun? If a base-line of 8000 miles were not enough, compared with the great distance of the stars, this at least remained. Our earth at midsummer is somewhere about 185,000,000 miles away from where she is at midwinter, comparing her position with that of the sun, and reckoning him to be at rest.

In reality, the sun is not at rest, but is in ceaseless motion, carrying with him wherever he goes the whole Solar System, with as much ease as a train carries its passengers. Those passengers are truly in motion, yet, with regard merely to the train, they are at rest. So each member of the Solar System—attached to the sun, not by Ptolemaic bars, but by the bond of gravity—is borne along by him through space; yet, with respect to each member of that System, the central Sun is always and absolutely at rest.

At one time of the year our earth is on one side of the sun, over 92,000,000 miles distant. Six months later the earth is on the other side of the sun, some 92,000,000 miles away from him in that opposite direction. Twice 92,000,000 comes to 184,000,000. This line, therefore, the diameter of the earth's whole yearly orbit, may be roughly stated as about one hundred and eighty-five millions of miles in length.

Here surely was a base-line fit to give parallax to any star, or rather, to make parallax visible in the case of any star. For it is, after all, a question not of fact, but of visibility; not of whether the thing *is*, but of whether we are able to *see* it.

As the earth journeys on her annual tour round the sun, following a slightly elliptic pathway, the diameter of which is about 185,000,000 miles, each star in the sky must of necessity undergo a change of position, however minute, performing a tiny apparent annual journey, in exact correspondence with the earth's great annual journey.

The question is not, Does the star do this? but, Can we *see* the star do this? Its apparent change of position may be so infinitesimal, through enormous distance, that no telescopes or instruments yet made by man can possibly show it to us.

The star-motion of which I am now speaking is purely a seeming movement, not real. Be very clear on this point in your mind. *Real* star-movements, though suspected earlier, were not definitely surmised—one may even say 'discovered'—until the year 1718, by Halley. And though Cassini in 1728 referred to this discovery of Halley's, yet very little was heard about the matter until the days of Herschel. Only *apparent* star-motions were generally understood and accepted.

The first and simplest of such seeming star-motions is one which we can all see—the nightly journey of the whole host of stars, caused by our earth's whirl upon her axis.

The second is also simple, but by no means also easily seen. Astronomers reasoned out the logical necessity for such an apparent motion, long before it could be perceived. As far back as the days of Copernicus it was felt that, if the Copernican System were true, if the earth in very deed travelled round the sun, then the stars ought to change their positions in the sky when viewed from different parts of earth's annual journey.

Observations were taken, divided by six months of time, and by one hundred and eighty-five millions of miles of space.

And the Stars stirred not!

Stupendous as was this base-line, it proved insufficient. So much *more* stupendous was the distance of the stars, that the base-line sank to nothing, and once again parallax could not be detected. Not that the seeming change of position in the star did not take place, but that human eyes were unable to see it, human instruments were unable to register it.

There lies the gist of the matter. If the change of position can be observed, well and good! The length of the base-line being known, the distance of the star may be mathematically calculated. For the size of the tiny apparent path, followed in a year by the star, is and must be exactly proportioned to the distance of the star from that base-line. If the tiny oval be so much larger, then the star is known to be so much nearer. If the tiny oval be so much smaller, then the star is known to be so much farther away.

But when not the minutest token could be discovered of a star's position in the sky being in the least degree affected by the earth's great annual change of position, astronomers were at a loss. There was absolutely nothing to calculate from. The star was a motionless point to earth. The whole yearly orbit of earth was a motionless point to the star. One slender beam of light united the two. Reckoners had nothing to stand upon.

It is interesting to know that Copernicus had actually, long before, suggested this as a possible explanation of the absence of star-parallax. He thought that astronomers might fail altogether to find it, because the stars might be 'at a practically infinite distance' from our earth.

CHAPTER X

ABERRATION OF LIGHT

ONE of the most earnest searchers after star-parallax was the third Astronomer-Royal of England, by name JAMES BRADLEY.

He was born a few years before the end of the seventeenth century, when Sir Isaac Newton was about fifty years old. He died after the middle of the eighteenth century, when Sir William Herschel was not yet a quarter of a century old. Bradley was not one of those radiant stars which occasionally blaze forth in scientific skies, such as the two great men above cited; yet he may be taken as a very worthy link between them.

Like other able astronomers in those days, Bradley failed to detect the star-parallax, which he ardently sought; but in the course of his search he accidentally stumbled upon another discovery, which has made his name for ever famous.

He discovered the ABERRATION OF LIGHT. And, more or less in connection with it, he also arrived at some idea of the VELOCITY OF LIGHT.

While carefully observing a certain star, he hoped that at length he really had found the much-desired star-parallax. For that star certainly appeared to move. Month by month it distinctly changed its position, and by the end of one year it had returned to its starting-point—that is to say, to the point at which he had begun to observe the star.

Nor was this a peculiarity of one star only. All stars in the sky were found to behave in the same manner; and here was the real perplexity.

In one part of the sky, stars journeyed uniformly in tiny circles. In another part of the sky, they journeyed uniformly in little ellipses. In yet another part, they moved uniformly to and fro. In each case the motion was exceedingly small, in each case it lasted exactly one year, and in all cases those stars which lay near together, in any one part of the sky, made precisely the same movements.

Now these motions could not possibly be due to parallax. It was not to be imagined for one moment that all the stars of heaven in any one direction, as seen from earth, could be at exactly the same distance from us. And if they were *not* all at the same distance, but some nearer and some farther, then each individual star would have its own individual parallax, greater or smaller; each particular star would have its own particular movement, not identical with the movements of neighbouring stars.

Bradley gave much study and deep thought to this matter. The very same question had been previously raised with respect to certain perplexing motions of Jupiter's moons; and half a century earlier a Danish astronomer named Roemer had conjectured a possible explanation.

He had put forth a suggestion that Light, instead of being as was then supposed everywhere at once, really travelled with very great rapidity from place to place, and occupied time in its journeying. But although this suggestion actually met the difficulty, he could only conjecture; he could not prove his point; and the idea was not for some time taken up by leading men.

Bradley was the first to revert to the notion, and to adopt it as his own. He found that the tiny annual motions of all the stars above described were not true star-movements. Nor were those gentle stirrings caused by the longed-for parallax. They were entirely owing to what is known as the Aberration of Light.

Light, like sensation, takes TIME for its journeying. Roemer had proposed this explanation; and Bradley found the proposition to be true. Light travels with exceeding rapidity; but it is not everywhere all at once, instantaneously and simultaneously.

Have you ever gone in a fast train through a heavy downpour of rain; a downpour without wind, so heavy that the rain did not slant at all in its descent, but fell straight to the ground?

When the train was at rest, you would have seen the rain to fall thus, straight downwards. But when the train was in quick motion, and you were rushing onward to *meet* the falling drops, then they would have seemed to you to come slanting-wise; not to fall, as they really did fall, just from overhead, but to fall, as they really did not fall, from some little distance in advance. Such an appearance would be the result of two real motions—the straight downward fall of the rain, and the onward rush of your train.

It is in this way that Aberration of Light is the cause of seeming movements of the stars, as viewed from our earth,—and also of Jupiter's moons, not to speak of other heavenly bodies.

Starlight travels to Earth with tremendous speed; not very much less than 200,000 miles each second. At the same time our earth is hurrying along on her orbit round the sun at a rate of some nineteen miles each second—one way one part of the year, and another way another part of the year, as she happens to be on opposite sides of the sun.

Sometimes Earth is hastening to meet the starlight which keeps arriving from one particular part of the sky; and sometimes she is moving sideways to the light from those same stars; and sometimes she is hastening away from it.

All these varying motions on the part of our earth combine with the ever-arriving starlight to *displace the stars.* Not, of course, to make them really move, but to make each one go through a little series of seeming motions; due to the fact that sometimes we are running to meet the starlight, and so receive it earlier; sometimes we are running away from the starlight, and so receive it later.

Since each star must always *appear to us* to be exactly where its light *seems to come from*, a tiny apparent yearly journey is the result of this 'aberration' or 'wandering' of starlight. The true wandering is, however, not on the part of the star or of its light, but on the part of our earth.

Although the discovery of the aberration of light was not what Bradley had set his heart on, it was a discovery of very great interest and importance.

Soon afterwards he made another weighty discovery, known as 'nutation.'

The word 'nutation' signifies 'nodding.' You will remember hearing, in an earlier chapter, about the precession of the equinoxes, and the curious slow 'wobbling' motion of earth's axis, which causes the said precession. Well, nutation simply means another little movement of earth's axis, both smaller and quicker in kind than that from which springs precession. It is a kind of nodding motion taking place, not once in about 25,000 years, but once in about 19 years; and this, too, is brought about by the moon's attraction acting upon the bulged-out equator of the earth.

To readers of this little book, however, Bradley's discovery of the Speed of Light is, of all that he found out in Astronomy, the most full of interest and the most full of suggestiveness. For, through that which he definitely learned—the fact of Light taking time to travel from place to place—another forward step was made towards the new modern branch of Astronomy included under the head of SPECTRUM ANALYSIS.

There are singular points of likeness between the aberration displacement of a star and the parallax displacement of a star. By 'displacement' I mean its *seeming* displacement in the sky,—its seeming slight alteration of position, brought about by these two causes.

In both cases the motion of the star is only apparent, not real. In both cases it is due to Earth's own journeying. In both cases it lasts exactly a year. In both cases the star seems to perform a complete little annual journey,—either a circular or an oval or a to-and-fro journey, according to its position in the sky.

But in the one case the motion is uniform among all stars lying near together, and then it is due to aberration of light. We often actually see the star where in reality it is *not*, either because the travelling ray of light from that star is met part-way by us, or else because it has a lengthened distance to travel before overtaking us.

In the other case the motion is not uniform. Each star performs its own little journey—a larger or a smaller journey, according to its precise distance from us, and quite irrespective of what its neighbour-stars in the sky may do. Then it is due to Parallax,—in other words, to its being seen by us from two different positions widely separated. It changes its place in the sky when viewed from those two positions, precisely as a church-tower changes its place in a landscape when viewed from two different houses.

Only, with the stars the parallax or apparent change of place is so exceedingly minute, from the star's great distance, as to be detected with extreme difficulty.

It is somewhat like looking at a penny, a mile or two away, out of the window of one room, and then looking at the same distant penny out of the window of the next room. If the night were pitch dark, and if the penny shone with dazzling brilliancy, it might doubtless be seen; at all events, with the help of a telescope. But to make out the slightest difference in the position of that penny, consequent upon your own change of position from the one window to the other, would be a matter of extreme difficulty.

In the time of Bradley, and, indeed, for long afterwards, no man could detect the parallax of any one star. Every attempt was a failure. Until the present century there was no really successful measurement of star distances.

Meanwhile, Sir William Herschel came, to shine as a radiant first-magnitude star in the skies of science.

CHAPTER XI

THE DAWN OF STELLAR ASTRONOMY

FREDERICK WILLIAM HERSCHEL, commonly known as Sir William Herschel, was born in 1738, and died in 1822.

He lived through the French Revolution, the upheavals and dislocations of nations, the usurpations of Napoleon, the life-and-death struggles of the Peninsular War, and the culminating triumph of Waterloo. But these stirring events lay greatly outside his life—a life spent mainly in contemplation of the heavens.

Though by birth a Hanoverian, he became practically an Englishman, so far as a lifetime spent in England could make him one. He rose to be the greatest Astronomer of his age, and one of the greatest Astronomers of all ages; a man whom kings delighted to honour.

There are many who count William Herschel 'the Founder of Siderial Astronomy,' and in a certain sense, though not in an unlimited sense, this is a true estimate of him.

He was one of those who possess not only the brilliant spark of genius, but also the attendant 'unlimited capacity for taking pains.' Herschel's powers of work were simply prodigious; and the sum-total accomplished by him in the course of his long life was almost past belief.

In later years his ardent labours were shared by his sister, Caroline Herschel. Night was willingly turned into day, and the claims of society were flung to the winds, in the passionate delight of this life-pursuit—the study of the heavens. It was a pursuit to which he turned early; a pursuit which, after the age of forty, dominated his intellect and filled his time.

We read in different writers of his 'enormous labour,' of his 'real and genuine enthusiasm,' of his 'flashes of genius,' of his 'sublime ambition,' of his 'unrivalled powers of observation,' of his perpetual craving to 'observe, observe, observe;' but to realise all or even one-half that he did is no easy task.

Until the days of Herschel, little attention was bestowed upon the Universe of distant Stars. Before his advent the interest of astronomers had been mainly centred in the sun and his revolving worlds. The 'fixed stars' were indeed studied as such, with a certain amount of care; and numberless efforts were made to discover their distances from earth. But the thought of a vast Starry System, in which our little Solar System should sink to a mere point by comparison with its immensity, had not yet dawned.

SIR WILLIAM HERSCHEL.

FROM THE MEDALLION BY WEDGWOOD.

The whole SIDERIAL SYSTEM had then, in people's minds generally, the characteristic of absolute repose, absolute changelessness. Having once given up the notion of revolving heavens, having once perceived that our earth's motion alone was responsible for the nightly journeyings of the stars, men no longer expected the stars to move at all.

Why, indeed, should they? How, indeed, could they? Century after century they had remained in unvarying groups. They were, therefore, doubtless fixed for all ages in those groups. The stars did not move. Our sun did not move. Only the earth and the planets, the moons and the comets, were restless travellers through a rigid and unchanging Universe. But with the labours and the genius of Herschel it might be said,—'*Nous avons changé tout cela!*'

He was a great maker of instruments with his own hands, including numbers of reflecting mirrors and some eighty complete telescopes. This was only one item in the tale of his labours.

He wrote papers innumerable, and this was another item. With larger and yet larger telescopes of his own making, he studied the whole Solar System, and especially the nature of sun-spots; the rings of Saturn; the various motions of attendant moons; together with countless other details. He enlarged the System by the discovery of another planet outside Saturn—the planet Uranus, till then unknown.

These were only first steps. The work which he did in respect of the Solar System was as nothing compared with the work which he did among the Stars. His work in our System was supplementary to other men's labours ; his work among the Stars was the beginning of a new era.

Like many before him, he too sought eagerly to find star-parallax, and he too failed. Not yet had instruments reached a degree of finish which should permit measuring operations of so delicate a nature.

Although he might not detect star-parallax, he sprang a mine upon the older notions of star-fixity. He shook to its very foundations the Siderial Astronomy of the day,—the theory, long held, of a motionless Universe, motionless stars, and a rotating but otherwise motionless sun. He did away with the mental picture, then widely believed in, of vast interminable fixity and stillness, extending through Space, varied only by a few little wandering worlds.

As he swept the skies, and endeavoured to gauge the fathomless depths, and vainly pursued the search for the parallax of one star after another, he made a great and unlooked-for discovery.

This was in connection with Double-Stars.

Double-Stars had long been known, and were generally recognised. But whether the doubleness were purely accidental, due merely to the fact of two stars happening to lie almost in the same line of sight, as viewed from earth ; or whether any real connection existed between the two; no man living could say. Indeed, so long as all stars were regarded as utter fixtures, the question was of no very great interest.

But light dawned as Herschel watched. He found the separate stars in a certain pair to be moving Each from time to time had slightly, very slightly, changed its place.

Then at least, if all other stars in the Universe were fixed, those two were not fixed.

He watched on, and gradually he made out that their motions were steady, were systematic, and were connected the one with the other.

That was one of the first steps towards breaking down the olden notion, so widely held, of a fixed and unchanging Universe.

Another double-star, and yet another, responded to Herschel's intense and careful searching. These other couples too were revolving, not separately, but in company; journeying together round one centre; bound together apparently by bonds of gravitation, even as our Sun and his planets are bound together.

You see how men work outward, from one step to another, in the pursuit of knowledge.

First, gravity is found to be a power here on Earth; all objects being steadily drawn earthward by it. Its nature cannot, indeed, be explained, then or later, but its effects are manifest.

Next, under the genius of Newton, the scope of that controlling force is widened; and gravity is found to reign, not on earth alone, or between earth and moon alone, but throughout the length and the breadth of the Solar System.

Lastly, by the brilliant insight of Herschel, the scope of that controlling power is still further widened. Gravity is found to extend, not only throughout the Solar System, but among the distant Stars; even throughout the realms of the enormous Stellar System.

This, seemingly, it meant! Gravity everywhere! Gravity throughout Space! The same Divinely-appointed laws far away in those distant depths, as here on our little earth.

If one pair of stars be held together by attraction, why not other pairs of stars? If other pairs of stars, why not all stars? Thus it appears to be, in these later days of science. Each star in the Universe is believed to attract each other star.

Sir R. Ball writes with reference to this prevailing law of gravity:—'Before Herschel's discovery we never could have known whether that law was not merely a piece of local legislation, specially contrived for the exigencies of our particular System. This discovery gave us the knowledge, which we could have gained from no other source. From the binary stars came a whisper across the vast abyss of space. That whisper told us that the law of gravitation was not peculiar to the Solar System. It told us, the law extended to the distant shores of the abyss in which our island is situated. It gave us grounds for believing that the law of gravitation is obeyed throughout the length, the breadth, the depth and the height, of the entire visible Universe.'

And Herschel was the first to hear the whisper. Herschel was the first to translate it into the language of Earth.

Not that the observed motions of double-stars *alone* could entirely convince us of gravity existing in those distant regions. In absolute strictness we could perhaps only say that those motions do not contravene the universality of gravitation. But, taking into account the revelations of the spectroscope as to the universality of matter similar to earthly matter, we cannot but believe that gravitation also is universal, even as Herschel believed.

Other stars beside binary stars are found to move with a real and not merely a seeming movement.

Viewed carelessly, the stars do indeed appear to remain fixed in changeless groups; fixed even through centuries. But, to exceedingly close watching and accurate measurement, many among them are distinctly *not* fixed; many among them can be actually seen to move.

Of course the observed motions are very small and slow. One may be found to creep over a space as wide as the whole full-moon in the course of 300 or 400 years; and this is rapid travelling for a star in Earth's sky! Another will perhaps cross a space one-tenth or one-twentieth or one-fiftieth of the moon's width in one hundred years.

Such motions had never been carefully noted or examined, until Herschel came to do away with the old received notions of star-fixity. Happily Herschel was no slave to 'received ideas.' Like Galileo in earlier times, he wished to 'prove all things' personally, anxious only to find out what was the truth.

And he found that the stars were *not* fixed! He found that numbers of them were moving. He conjectured that probably all the rest were moving also,—that in place of a fixed Universe of changeless stars we have a whirling Universe of rushing suns.

Herschel could not, of course, watch any one star for a hundred years, much less for several centuries. But in a very few years he could, by exceedingly close measurement, detect sufficient motion to be able to calculate how long it would take a certain star to creep across a space as wide as the full-moon.

From step to step he passed on, never weary of his toil. He sought to gauge the Milky Way, and to form some notion of its shape. He noted a general drift of stars to right and to left, which seemed to speak of a possible journey of our sun through space, with all the planets of the Solar System. He flung himself with ardour into the study of Star-Clusters and of Nebulæ. He saw, with an almost prophetic eye, the wondrous picture of a developing Universe,—of nebulæ growing slowly into suns, and of suns cooling gradually into worlds,—so far as to liken the heavens to a piece of ground, containing trees and plants in every separate stage of growth.

These things were but a portion of his vast life-work; a life-work full of energy, full of enthusiasm, full of power, full of genius.

Herschel was a great observer and an independent thinker. He was not a great mathematician. Two famous men of a very different type were contemporary with himself, both being most eminent mathematicians,—Lagrange and Laplace. They entered into his labours and made use of his observations, much as Kepler had entered into Tycho Brahé's labours and had made use of Tycho's observations; and they worked out the results of Herschel's observations mathematically, as Herschel himself would not have been capable of doing.

The famous 'Nebular Theory,' or 'Nebular Hypothesis,' of which more will be said in later chapters, is commonly connected with the name of Laplace. He did not, indeed, originate the idea; but he gave it much consideration, adopted it as his own, and put it out in a fuller form than it had possessed before.

CHAPTER XII

MEASUREMENT OF STAR-DISTANCES

AND still the search for Star-Parallax went on, so long pursued in vain.

No longer base-line than that of the diameter of Earth's yearly orbit lay within man's reach. But again and yet again the attempt was made. Instruments were improved, and measurements became ever more delicate; and at length some small success crowned these persistent endeavours. The tiny sounding-line of earth, lowered so often into the mysterious depths of Space, did at last 'touch bottom.'

Herschel died, full of years and honours, in 1822; and some ten years later three different attempts proved, all to some extent, and almost at the same date, successful. Bessel, however, was actually the first in point of time; and his attempt was upon the double-star, 61 Cygni; not at all a bright star, but only just visible to the naked eye.

There are stars and stars enough to choose from. The difficulty always was which to select as a subject for trial, with any reasonable prospect of a good result.

Some astronomers held that the brightest stars were the most hopeful, since they were probably the nearest; and of course the nearer stars would show parallax more readily, because their parallax would be the greater. But certain very bright stars indeed are now known to be far more distant than certain very dim stars.

Again, some astronomers thought that such stars as could be perceived to move most rapidly in the course of years would be the most hopeful objects to attack, since the more rapid movement might be supposed to mean greater nearness, and so greater ease of measurement. But some stars, seen to move rapidly, are now known to be more distant than others which are seen to move more sluggishly.

So neither of these two rules was altogether dependable; yet both were, on the whole, the best that could be followed, either separately or together.

The star 61 Cygni is not one of the brighter stars, but it is one of those stars which can be seen to travel most quickly across the sky in the course of a century. Therefore it was selected for a trial; and that trial was the first to meet with success.

For 61 Cygni was found to have an apparent parallax; in other words, its tiny seeming journey through the year, caused by our earth's great journey round the sun, could be detected. Small as the star-motion was, it might, through careful measurement, be perceived. And, in consequence, the distance of the star from earth could be measured. Not measured with anything like such exactitude as the measurements of sun-distance, but with enough to give a fair general notion of star-distance.

One success was speedily followed by others. By a few others,—not by many. Among the thousands of stars which can be seen by the naked eye, one here and one there responded faintly to the efforts made. One here and one there was found to stir slightly in the sky, when viewed from Earth's summer and winter positions, or from her spring and autumn positions, in her yearly pathway round the Sun.

It was a very very delicate stir on the part of the star. Somewhat like the difference in position, which you might see in a penny a few miles off, if you looked at it first out of one window and then out of another window in the same house. You may picture the penny as radiantly bright, shining through pitch darkness; and you may picture yourself as looking at it through a telescope. But even so, the apparent change of position in the penny, viewed thus, would be exceedingly minute, and exceedingly difficult to see.

There are two ways of noting this little seeming movement on the part of a star in the sky.

Either its precise place in the sky may be observed,—its exact position, as in a map of the heavens. Or else its place may be noted, as compared with another more distant star, near to it in the sky, though really far beyond. Parallax, if visible, would make it alter its precise place in the sky. Parallax, if visible, would bring it nearer to or farther from any other star, more distant than itself from earth. The more distant star would have a much smaller parallax,—probably so small as to be invisible to us,—and so it would do nicely for a 'comparison star.'

The first of these methods was the first tried; and the second was the first successful.

To find star-distance through star-parallax sounds quite simple, when one thinks of the general principle of it. Just merely the question of a base-line, accurately measured; and of two angles, accurately observed; and of another angle, a good way off, accurately calculated,—all resting on the slight seeming change of position in a certain distant object, watched from two different positions, about 185,000,000 miles apart.

Quite simple, is it not? Only, when one comes to realise that the 'change of position' is about equal to the change of position in a penny piece, miles away, looked at from two windows in one house,—then the difficulty grows.

Besides this, one has to remember all the 'corrections' necessary, before any true result can be reached.

A penny piece, miles away, seen from two windows, would be difficult enough as a subject for measurement. But, at least, the penny would be at rest; and you yourself would be at rest; and light would pass instantaneously from it to you; and there would be no wobbling and nodding motions of everything around to add to your perplexities.

In the measurement of star-parallax, all these things have to be considered and allowed for; all have to be put out of the question, as it were, before any correct answer is obtained.

The refraction of light must be considered; because that displaces the star, and makes it seem to us to be where it is not. And the aberration of light must be considered; because, in a different way, that does the same thing, making the star seem to take a little journey in the course of the year. And the precession of the equinoxes, and nutation, have both to be separately considered; because they too affect the apparent position of every star in the sky.

To watch the star in comparison with another star is easier than merely to note its exact position in the sky; for the other star—the 'companion-star'—is equally with itself affected by refraction of light and by aberration of light. But then another question comes in seriously: whether or no the companion-star shows any parallax also; since, if it does, that parallax must be carefully calculated and allowed for.

So the measurement of Star-distance, even when parallax can be detected, is by no means a light or easy matter. On the contrary, it bristles with difficulties. It is a most complicated operation; needing profound knowledge, accurate observation, trained powers of reasoning and calculation.

Now, how near or how far would you imagine the Stars to be?

You know the distance of our earth from the sun—a matter of nearly 93,000,000 miles. A train, journeying ceaselessly night and day, at the rate of fifty miles an hour, might travel a distance equal to that which divides our Earth from the Sun in about *two hundred and ten years.* But the same train, journeying in like manner, at the same rate of speed, to the very nearest star of which we know, would take no less than FIFTY MILLIONS OF YEARS in transit!

The star 61 Cygni is not the nearest known to us; still, it is one of our nearer star-neighbours. It lies only about five hundred thousand times farther away from us than the sun. That is to say, it is some where about forty billions of miles distant.

The bare idea of 40 billions of miles is more than human brains can grasp. We say the words, and they convey no definite impression, beyond a general sense of immensity. We know that a thousand thousands make one million, and that a million millions make one billion ; and we are little the wiser for that knowing.

If one of our *nearer* neighbours is forty billions of miles away, what must be the distances of the farther stars?

Some few, indeed, are closer. Alpha Centauri, another double-star, is perhaps about two-thirds as far off as 61 Cyngi. But even twenty or thirty billions of miles are sufficiently startling.

Nothing short of what has been termed 'the terrific accuracy' of the present day could grapple with the truly tremendous difficulties of this problem of star-distance. It has, however, been grappled with, and grappled with successfully. We now know, not indeed with anything like exactitude, yet with reasonable certainty, the distances of a good many stars, as expressed roughly in round numbers of 'about' so many billions of miles. We have at least learned enough to gain some notion of the immeasurable distances of countless other stars, lying far beyond reach of earth's longest measuring-line.

The very thought of such unimaginable depths of Space, of suns beyond suns 'in endless range,' toned down by simple distance to mere quivering specks of light, is well-nigh overwhelming. These marvels of the Heavens ought to speak to us in no ambiguous language, if only we are willing to listen, of the immeasurable might of HIM who 'MADE THE STARS!'

Our outlook has verily widened since the days of Hipparchus, of Ptolemy, of Copernicus, of Kepler, of Galileo, of Newton, of Herschel.

As we pass in thought from name to name, each scintillating, star-like, with lustre, we catch glimpses of that ever-broadening horizon.

First, a motionless central Earth; and a revolving sky-sphere, with Sun and Moon and fixed Stars, all small and near at hand.

Then dawning notions of a possible System in the sky; of wandering worlds attached to the sun; worlds and sun all going round our earth—a motionless earth still—and a few changeless stars.

Then a revolution; a distinct Solar System believed in; the Sun in the centre; our Earth only one among many revolving worlds, all travelling round a fixed Sun; with fixed Stars still in the sky; an immutable Universe.

Next, a further development; the causes of these things searched into; the great prevailing force of gravity found to extend from our Earth throughout the limits of the whole Solar System. But still an outer Universe of fixed and changeless Stars.

Then another revolution—this time not with respect to the Solar System, but with reference to the vast Universe. A mighty Stellar System of moving Suns discovered; distances all vague, but great; speed immeasurable, but believed to be universal; and gravity throughout the Universe.

Lastly, the later Astronomy of measurement, of closer observation, of 'terrific accuracy,' of Star-parallax at length discovered.

Superimposed upon this, we come now to the marvellous new branch of the Science,—to sunlight and starlight, as examined, deciphered, analysed, through the SPECTROSCOPE.

PART II

THE SPECTROSCOPE AND ITS TEACHING

CHAPTER XIII

STARLIGHT

A STAR for us has no apparent size. It has no breadth. It has no length. It has no disc. Measurement of its actual size is not possible; at least, thus far it has not been found possible.

Each separate Star is one single point of light, which cannot be halved. We see the whole of a star; or we do not see it at all. A planet shows size, and may be measured. A planet grows larger when nearer, or when viewed through a telescope. But a star never grows larger, no matter how powerful the magnifier used. It grows brighter. It does not in appearance become any bigger.

One cobweb-line will utterly hide a star. Though the orb at which we gaze may be a huge and glowing Sun, perhaps scores of times as large as our Sun, yet the whole of its glorious radiance comes to us narrowed down to one single beam of light.

Still, although a star's size cannot be measured, we know with almost certainty that some stars are larger than others; that some must very far surpass our sun in bulk.

We know it in this way. The distance of a star is found out. It is then calculated that our sun, at the distance of that particular star, would certainly not shine half so brilliantly as that star does. Then, as a matter of reasonable belief, it follows that the said star, while possibly more bright and radiant than our sun, is also very probably larger than our sun.

All this is so far an affair of conjecture, not of actual measurement. No single star in the whole heavens, outside our Solar System, has as yet proved susceptible of measurement. The distances of a few, roughly, have been found out, though not till after long striving and innumerable failures. The sizes of all have been hitherto beyond our grasp. But this problem too, like the problem of star-distance, may in time yield to persevering effort and improved instruments.

We talk of star-magnitudes, and the term is wrong. A star of the First Magnitude is really a star of the First Order of Brightness. No question of size is necessarily involved. The brighter star *may* be the larger; or it *may* be only the nearer.

All, absolutely, that we know of a Star is built upon a Ray of Light.

Other senses fail us here. We cannot touch, we cannot hear, those distant orbs. No sound from them of roaring flames may ever reach our ears. For sound is carried by air; and a few miles, or at most a few hundred miles from earth's surface, air ceases. In solemn silence—silence so far as merely human powers of hearing are concerned—century after century the countless Suns of the Universe roll onward. SIGHT alone speaks to us of their wonders; and LIGHT alone can speak to SIGHT.

To some extent we may say the same of our Sun. But there we have bodily consciousness of heat, as well as of light; and the power of the sun is visible everywhere about us in an infinitude of ways. Even the paler and more insignificant moon makes herself felt as well as seen in our lives. Every time that we hear ocean's tides pouring in or out, we hear the utterance of moon-power.

Moreover, in the case of sun and moon and planets the rays of light are many, the surfaces to be examined are more or less extended. The sun has his spots and streaks; the moon has her mountains and plains and craters; the planets have their various characteristics of spots and bands and diverse hues.

With the stars all such landscape features are utterly lacking. Each Star, whether the brightest or the dimmest, has for us no surface, no disc, no shape, no apparent size; nothing but Light, brought down through exceeding distance to one slim indivisible shaft of radiance. Indivisible in one sense, not in another. More of this later. For the moment, think only of the fact that our whole knowledge of that far-off Sun is founded upon one continuous beam of brightness.

Where sight fails, the Stars for us cease to exist, except in imagination. We do not feel their heat, or see upon Earth results of their power.

In trying to picture to ourselves what is meant by Light, two sides of the matter claim attention in turn. First, the Ray of Light itself. Secondly, the Eye which receives and uses that ray.

Men, as stated in an earlier chapter, used to think of light as being instantaneously everywhere, as requiring no time to travel from place to place. But this was an error.

Light, when given out by a bright body—whether candle or lamp or reflecting surface, whether sun or moon or star—reaches us in what we are pleased to call Rays or Beams; and those rays or beams travel at a certain definite rate of speed. A ray starting from the sun, or from the moon, or from a star, is not immediately here, any more than a train starting from London is immediately at Liverpool. Time is occupied in either journey.

The speed of light, first discovered as a fact by Bradley, has since been repeatedly measured in divers modes; one result proving another, as when we add up a sum in two or three different ways to see if the answers agree. Slight corrections have been made from time to time, due to increased delicacy of instruments and increased accuracy of observation.

Here is the result of all these measurements:—

That light journeys at a rate of about 186,000 miles each second, or roughly, at the rate of SIX BILLIONS OF MILES EACH YEAR. In one second a ray of light flashes through a distance equal to seven times the circumference of our earth at the equator.

When you have seen a gun fired, or a rock blasted, at some little distance, you can hardly have failed to notice that the flash was first visible. Then, after a brief pause, followed the bang of sound. The same thing is observable in a thunderstorm. First, the lightning is perceived, then the thunder is heard.

And the reason for this is, that while sound and light both need time for their journeying, sound is very much slower than light. They start on their way at the same instant, but sound lags behind, and light speeds forward. Sound travels at the rate of 1140 *feet* in one second, and light travels at the rate of about 186,000 *miles* in one second. A very considerable difference! No wonder that the flash of an explosion reaches our eyes before the sound of it can reach our ears.

Nevertheless, extraordinarily rapid as light is in motion, it does journey; and it is not everywhere at the same instant; and it occupies a distinct time in its journeying.

Light coming from the Sun does not touch Earth at the identical instant that it quits yonder blazing surface. A ray of sunlight, which reaches London at precisely mid-day, left the sun at close upon nine minutes to twelve of London time. Through those nine minutes the ray has flashed onward through space at the rate of over eleven millions of miles each minute, till arrested by earth.

A moonbeam falling on your face or mine, quitted the moon less than one second and a half earlier. One might suppose that a beam from the dazzling sun would travel a good deal faster than a pale weak moonbeam. But no! Light, whether it springs from sun or moon, from lamp or candle, whether direct from a blazing body or only reflected from a dark body, journeys always at the same speed.

When we seek to realise the distances of the Stars, no better measuring-line can well be found than this of Light-speed. Nine minutes' journey from the sun means what we count to be an enormous space. Yet that great dividing gap sinks into a mere rift, beside the stupendous chasm which divides the Solar System from the Stars. Here we take for our 'yard-measure' not the speed of light each second—186,000 miles—but the yearly speed of light, six billions of miles; and we reckon the distances of the stars in so many years of light-journeying.

Viewed thus, we find that, while the Moon is less than one second and a half distant, and the Sun less than nine minutes distant, the very nearest known to us of all the 'fixed' Stars lies FOUR YEARS AND FOUR MONTHS AWAY.

Think what this implies.

We sometimes say, speaking of a certain town,—'Oh, it is one hour away,' meaning one hour of railway travelling, at perhaps forty miles an hour, with stoppages. In like manner one might say, 'Oh, the Moon is not two seconds away;' or, 'Oh, the Sun is nearly nine minutes off.' But of the Stars, in a more awe-struck tone we have to say,—'The nearest of them is almost four years and a half away.' And this nearest—the very nearest neighbour known to us in the whole Universe outside, our Solar family—this Alpha Centauri lies about ten billions of miles *closer* than any other star, the distance of which has yet been reckoned.

Of other stars it must be said that they are ten years off,—twenty years off,—thirty years off,—fifty years off,—a hundred years off,—the numbers rising till very soon, far too soon, we reach the utmost limits of our present measuring powers. Beyond that lie innumerable bright Suns, dim through distance, yet in themselves radiantly brilliant, the light of which may have been long ages on their journey hitherward.

CHAPTER XIV

THE NATURE OF LIGHT

A LIGHT-RAY, whether it springs from sun or star, from world or moon, from lamp or candle, from any kind of body either giving out or reflecting brightness, travels always in straight lines, unbending and unbroken, so long as it continues in one medium, or in different mediums of exactly the same density. But if it passes out of one medium, and enters obliquely another of different density, then it is bent or refracted into a new direction.

Water is a much denser medium than air; therefore a ray of light passing obliquely—that is, in a slanting manner—out of air into water, or out of water into air, is sharply refracted or turned from its former course in the act. Again, glass is much more dense than air; and a ray of light, passing obliquely from the one to the other, is once more refracted, or bent or diverted, out of its straightforward course.

Try a little experiment for yourself. Lay a penny in the bottom of a cup, and stand so that the coin is just hidden from your eyes by the cup-rim. Then, without stirring your head, pour, or get someone to pour, some water slowly into the cup. The penny will quietly rise to view, even while the rim of china is still interposed between it and your eyes. For the rays of light, which proceed from the surface of the coin, are bent out of their direct course at the moment of quitting water for air, and thus they reach your eyes.

Here you have a case of both reflection and refraction. The penny first reflects sunlight; and that reflected sunlight is refracted on its road from the penny to your eyes.

When we look on the Sun at the moment of his setting, we see his body after it has actually passed below our horizon. The rays of sunlight, as they journey from the ether of Space into our denser atmosphere, or from a less to a more dense layer of air, are bent or *refracted* out of their course, so that they reach our eyes over the intervening body of earth, which would otherwise quite hide the sun from us.

It is necessary to understand that whatever we see, we see, always and invariably, by virtue of its own brightness. We see it because of the light which it gives forth.

That light may be either intrinsic or reflected. A sun, a star, a lamp, a candle, shine by their own radiance, which radiance springs from their own heat. A planet, a world, a mirror and all imaginable bodies and surfaces of every description, which possess no intrinsic light of their own, shine by borrowed brightness. Rays of light proceeding from some shining body fall upon the dark body, more or less lighting it up; and rebounding thence they enter your eyes, rendering the object visible to you.

If you wish to see a pond, a house, or a tree, it is not in the least needful that the sun should shine upon your face. Such shining, in fact, would only hinder sight. It is only needful that the sun should shine on pond or house or tree, and that reflected sun-rays, rebounding from the object, should carry its picture to your eyes. Again, if you wish to read a book at night, it is quite needless for the lamp to cast its glare upon you. The lamp-light must fall upon the open page of your book; and those rays of lamp-light, rebounding, have to reach your eyes. The less you see of the lamp itself the better.

Even so, the sun shines upon the moon's dark body and lights it up. We perceive the moon by her own shining—which shining is, of course, a result of the sun's radiance. But we see her best when the sun is not visible. When he is, the glare of sunlight commonly prevents our noticing the moon at all.

This, then, is the rule. Upon whatever object light-rays fall from any kind of bright body, that object is made visible by means of the light which it gives forth again. Some substances reflect much more light than others, and consequently they become more distinct, even more brilliant. But if any body gave forth no light whatever, our eyes could not detect its presence.

A looking-glass or a polished shield in full sunlight will flash forth radiant beams; while a heap of earth in a dark cellar can barely be seen at all. Yet both are visible from the same cause,—visible because of the borrowed light which they give forth. Only, in the one case we have abundance of light and a good reflecting surface; in the other case we have very little light indeed thrown back from the surface.

When we talk of a ray of light journeying or being reflected, we are using a convenient term to help our understandings. But, in strict truth, light no more comes in separate rays than a river flows in separate drops. The ideal drop of water is infinitesimally small, and the ideal ray of light is infinitesimally slender. The tiniest surface which emits the faintest shining may be said to send millions of light-rays to the eye, to make its presence and appearance known. By magnifying that object, the so-called 'rays' may be magnified and divided to any extent.

As Light journeys through Space it is invisible. It becomes visible only when arrested by some object in its path.

Many people fail to grasp this fact. They picture the vast reaches of the Universe as everywhere more or less bright,—as lighted up by countless brilliant suns, like an enormous room lighted up by countless lamps and candles. Now, such a notion is entirely wrong. Not only is the hugest room that ever was built a mere speck compared with only one corner of the Universe; but also in that room there is something which does not exist in Space. I mean, the atmosphere.

The atmosphere carries and spreads about light. Each particle of matter suspended in it arrests and scatters sunlight. In the wide extents of Space we do, indeed, believe that *something* exists, which has been named 'subtle ether;' something exceedingly attenuated; something not to be compared with air in density; something without which light probably could not travel at all from star to star, or from our sun to this earth. But although ether may be a means of light passing from one object to another, it cannot *stop* the rays of light, as even one particle of floating matter can do, causing them to give forth their brightness.

Through every part of the Universe innumerable billions of light-rays are ever darting on interminable journeys from multitudinous suns. Yet the vast gaps of space between those suns are *dark*, lighted only here and there, it seems, by some world or comet or company of meteors, which intercept the hidden rays and make them visible.

Our Sun gives out an enormous amount of heat and brightness. They are poured forth on all sides from that great and radiant body with a perfectly astounding abundance. By far the larger proportion of his rays pass away into space, with, apparently to us, no particular use, no particular object. They are not seen; they are not felt; no planets, no comets, no meteors even, arrest their flight, and cause them to give forth their hidden virtues of light and heat.

With only his present expenditure, the sun could most easily light and warm and keep in vigorous life no less than *two thousand two hundred millions* of worlds such as ours.

If all the planets of the Solar System, all the moons, all the comets, all the meteors, were brought together, and the whole supply of solar heat and light received by them were subtracted, it would be found to be the merest fraction, compared with the sum-total that is lavishly flung away into Space. Flung away recklessly, flung away uselessly,—so we might feel disposed to say. But what do we know about the matter?

That which to our limited understanding seems like waste need not be waste. That which to us seems purposeless may have some profound cause underlying. If nothing else can be learned from this abounding outflow of heat and light, so much at least is apparent—the royal richness and fullness of DIVINE giving. Man may dole out his little gifts, weighed to a scruple or measured to a dram. God gives grandly to His Universe; enough and to spare.

Still, it would be the height of rashness on our part, to assert that for all this wealth of sunlight and sunheat no use does or can exist. We simply know nothing whatever about the matter.

CHAPTER XV

THE NATURE OF SIGHT

An eye is that organ by means of which a man perceives objects near or far, the existence of many of which he would not be aware of by means of any of his other senses.

True, those other senses can often be exercised in addition. When he sees a thing, he may also feel it, taste it, smell it, hear it,—any or all of these. But by sight alone he can learn that an object exists, which he is quite unable to hear or to smell, to taste or to feel. He can discover something of its size and colour, its shape and position, through sight alone.

Remember, however, that the eye is only an organ. The eye itself does not see. It is merely the 'camera or optical instrument' by means of which a man's brain is made aware of things outside himself; things often too distant for him to perceive in any other mode.

Moreover, that which your brain sees is not the object itself, but only a picture of that object, thrown upon the retina of your eye—more strictly still, only a message or idea of that image, telegraphed from the eye to the brain.

You say that you SEE the Moon. Yet the moon is not touched by your eye. No invisible feelers extend from your eyes to the moon, as once was imagined.

When you feel a table with your hand, the sensitive nerves of your finger-tips are in actual contact with the wood of which the table is made. When you taste sugar, the particles of sugar are within you, in actual contact with your nerves of taste. When you smell a rose, tiny specks of the sweet essence of the rose have floated into your nose, coming into actual contact with the olfactory nerve, the nerve of smell. In all these cases, though the brain receives a message, it is a message direct from the source, caused by positive *touch* between your nerves of sensation and the thing which is felt or tasted or smelt.

But with hearing and with seeing actual contact ceases. You may hear an explosion, miles away. You may see a sun, millions or billions of miles away.

Yet something analogous to the sense of touch still comes in. When you hear a gun fired half a mile off, the gun is not touched by your ear; nevertheless *something* is sent from the exploding powder to the nerves within your ears, by means of which a message of noise reaches the brain. When you see a moon tens of thousands of miles away, that moon is not touched by your eye; nevertheless *something* is despatched from the moon to the nerves of your eyes, by means of which a message of light reaches the brain.

What is this Something which travels to ear and to eye, like a telegraphic message?

Take the ear first. Sound journeys to the ear in waves of air. Any manner of concussion or of friction, however slight, produces such waves of air. One may even say that any manner of *touch*, however delicate, produces waves of sound.

Our ears are so formed as to hear only certain degrees of air-vibrations; but no doubt innumerable vibrations take place which we are quite unable to hear, because they are too high, or too low, or too gentle, to affect our organs of hearing. A fly cannot walk across the window pane without noise, though to us his footsteps are inaudible. A spider cannot crunch his victim without noise, though the crunching is unheard by us. A grain of sand cannot drop to the ground without noise, though finer ears than ours are required to detect the tiny jar. When a rock falls, or a lion munches, or a horse walks, our coarser sense of hearing is at once aware of the air-waves set thereby in motion.

It must not be supposed that waves of air, travelling from place to place, are at all the same thing as *wind*. Wind is air in actual motion; the literal particles of air travelling with greater or less speed from one place to another. But in a wave of air, although the *wave* journeys, the air-particles move very slightly and do not travel onward.

A wave of water out at sea does not mean a forward motion of the water. Close to shore waves break, and the water rushes a little way up the beach; but away from land, where the true nature of a wave becomes apparent, the water simply rises and falls. The wave itself travels onward; the water does not. The wave passes *through* the water, not carrying the latter along with it. It is a vibration or impulse, communicated from particle to particle of water. As the wave passes through the water, each little water-particle makes a tiny motion and returns to its former position. It just dances a little, in fact, with the stir of the passing vibration.

When at the sea-side, you may notice that a piece of seaweed, if floating at some distance from the beach, is not borne onward by the waves. It has from each wave a passing lift, and then it is left where it was.

And it is the same with Waves of Sound. Each wave is a vibration or impulse, which passes from particle to particle of air, giving each particle a tiny stir, but not sweeping it onward.

When rocks are blasted at a distance, and the crash of the explosion reaches your ears, you must not for a moment suppose that the air which was close to the blasted rocks has come rushing to you. That would, indeed, be a hurricane! All that the explosion has done with regard to sound is to set in motion *waves* of air, undulations or impulses, passing swiftly, far more swiftly than the most rapid hurricane, from particle to particle of air, and at last stirring the particles which happen just then to be within your ears. By means of these undulations or impulses, news of the distant explosion is conveyed through your ear-drums to your brain ; and after long practice your brain has learned to ascribe the air-waves in question to their true source.

We believe that Light also is conveyed by Waves, or by something analogous to waves; not waves of air, for our atmosphere is far too coarse a medium for those most minute impulses, but waves of luminiferous ether.

The ETHER of space has neither been seen nor felt; but that some such medium does exist no reasonable doubts can be felt.

Light appears to be carried by exceedingly small and exceedingly rapid waves of ether; waves set in motion by the clash of tiny particles in any very much heated and blazing body,—in somewhat the same fashion that sound-waves are set in motion by the clash or friction of larger bodies.

Sound-waves travel at the rate of about 1140 feet each second; and many distinct waves or vibrations enter the ear during one second of time, arriving from the source which causes the noise.

Musical waves, adapted to our powers of hearing, vary from about 16 waves each second to about 40,000 waves each second. That is to say, the lowest bass note which we are able to detect means 16 waves striking upon the ear-drum in the course of each second; while the highest treble note which we are capable of hearing means 40,000 waves striking upon the ear-drum in the course of each second.

Waves of sound, coming to our ears in the shape of 10 or 12 waves per second, or in the shape of 50,000 or 60,000 waves per second, are absolutely unheard by us. Any amount of such waves may be travelling through the air at any time and at all times; but to us they are inaudible.

Light-waves, journeying through ether, from sun or moon or star, dart onward at the rate of about 186,000 miles each second. If they come from lamp or candle or reflecting body on earth, their speed is the same; and they are still ether-waves. For ether not only fills distant Space, but also permeates our atmosphere, and lies between the particles of liquid and solid substances.

The number of distinct waves or vibrations of light which enter the eye each second is enormous, varying from 450 billions to 800 billions.

A good deal of likeness may be found between the Scale of Sound and the Scale of Light—that bright scale which we see spread out in the rainbow for our inspection. The larger and slower wavelets—*only* 450 billions in number each second,—mean Red

Light, low down in the scale, answering to the bass notes of sound. The smaller and quicker wavelets—amounting to 800 billions in number each second—mean Violet Light, high up in the scale, answering to the treble notes of sound.

Between red and violet lie all the different rainbow hues, each with its own particular number of wavelets per second. But although the waves of diverse colours differ in size, following one upon another with greater or less rapidity, light itself—the entire beam of light, made of all these lesser rays bound together—passing from place to place, does not vary in speed. A red beam, journeying, gets along quite as fast as a violet beam does; though, as red light is composed of larger waves than violet light, a smaller number of those waves must of necessity arrive in one second. The undulations of violet light being tinier, more of them have to arrive within a given time.

A few words now about the human Eye, which receives all these light-rays, and enables the human brain to make use of them.

The eye-ball of a full-grown person is usually an inch or so in diameter, and in shape almost a sphere. When we speak of 'large eyes' and of 'small eyes,' we really refer to the width of the opening through which the eye is seen. The actual size of the eye varies little.

As a whole, the human eye is an exquisitely beautiful and finished instrument, adapted in all parts to its work, guarded carefully from many dangers. Considering the extreme delicacy of the organ, and the incessant perils which surround it, one may well marvel, not that many people are blind, but that so many keep their sight through life.

Volumes have been written descriptive of the eye. We have only space for the merest glance at its structure.

Roughly speaking, the eye may be said to consist of three 'membranes,' one within another; and of three different 'humours.'

The outer coat or membrane is strong and protective. Four-fifths of it, known as the *sclerotic*, is opaque, and covers the greater part of the eyeball, inclusive of 'the white.' A small portion of it exactly in front of the eye, known as the *cornea*, is transparent.

Close within the sclerotic lies the next coat, containing a large number of blood vessels, and known as the *choroid*. The front portion of the choroid, just under the cornea, is called the *iris*.

Under the choroid again lies the *retina;* and in front, behind the iris, is the *lens*.

Everybody has noticed the coloured portion—black or blue, brown or grey—called the 'iris.' It may be regarded as a kind of tinted curtain, intended to shut out too much light from the delicate interior; and the dark hue, common to most hot countries, is doubtless because of the need for greater shelter from greater glare. Pale blue and pale grey afford less effective protection; wherefore northern nations, dwelling in less sunny climes, have an abundance of light-coloured eyes in their midst.

In the centre of this dark curtain is a small round hole or opening, through which every ray of light must pass which is to be of use in seeing. Rays from bright objects fall upon all parts of our bodies; but elsewhere they make no impression. Only as they enter the tiny eye-pupil can they communicate with the brain, and tell the story of whence they come. When light is strong, the sheltering retina-curtain draws closer together, lessening the width of the opening; and when it is weak, the curtain retreats, leaving a broader gap.

Between the cornea and the iris, in front of the eye, is the 'aqueous humour,' or watery humour; while the 'vitreous humour,' a jelly-like substance, fills the greater part of the interior of the eye-ball.

The most important of the 'humours' is the 'crystaline humour,' commonly known as the 'lens,' situated just behind the iris, and already referred to.

It is in appearance transparent as glass, in make firm yet elastic, in shape 'double convex.' Rays of light passing through the cornea and the pupil, fall upon the lens, and by it are caused to converge to a spot on the retina, forming a picture there of the object from which they come. The lens has a wonderful power of changing its shape, so as to suit the greater or less distance of objects under view. When it stiffens with age, the power of adjustment for near vision decreases; and if it becomes opaque, through the disease called 'cataract,' sight fails. In the former case, a new outside lens, in the shape of spectacles, will to some extent remedy what is wrong. In the latter case, the lens has to be removed, and its place altogether supplied by glasses.

Behind the vitreous humour we come to the most essential part of all—the retina of the eye. Most essential, because every other part of this complicated organ is for the express purpose of casting upon the retina a clear image of the object which has to be seen. The whole apparatus seems to be designed and contrived with this end in view.

The retina is infinitely complex, being formed mainly of innumerable delicate 'nerve fibrils,' or interlacing nerve threads of exceeding fineness. All these nerve fibrils, after spreading in a close network over the whole back of the eye, collect together in one spot, and pass out thence to the brain, as a slender bundle which is called the OPTIC NERVE.

Upon the retina are depicted all objects which happen to lie before the eye, if solid enough and bright enough to become visible. The optic nerve, which passes from the retina to the brain—and of which, indeed, the retina is actually made—has been said to positively *feel* these evanescent images or pictures, very much as the nerves of touch in our fingers feel irregularities on a roughened surface. It then conveys to the brain an idea of the image which it has felt; and the brain, through long use from babyhood, has learnt the meaning of the various shapes presented, so as more or less correctly to localise the things represented in their true distant positions.

A man blind from infancy, suddenly gaining his sight, has not this experience. Such a man has been known to complain that everything around seemed to press upon his eye-balls. In time and with practice he would learn to make the needful mental effort, and to project to a distance the object which had sent its picture to his brain.

One can well understand how any serious injury to the optic nerve, or to the retina, may easily prove fatal to the sight.

Does not all this appear strangely as if we ourselves—the true EGO of each one of us—were for the time literally imprisoned in the body, with only five outlets? Close utterly those five outlets, and no means whatever remain of possible communication for the imprisoned spirit with the material world.

CHAPTER XVI

THE MAKE OF A SUNBEAM

ALTHOUGH wave-motions in the air are essentially the same as those produced on the surface of water, there is one marked difference which should be clearly borne in mind. It is that, while the waves of water can only advance in *rings* or *circles* on its surface, waves of sound are sent forth *spherically* in all directions through the atmosphere,—upward and downward as well as sideways.

Precisely the same thing takes place with the rapid mysterious waves or impulses which flow from any source of Light.

Hold up a candle, and observe how the rays of candle-light pour outward in every direction simultaneously,—upward, downward, and on every side, except where your interposing arm checks the flow and casts a shadow; though even there some measure of light reflected from particle to particle of air creeps round it.

A candle which can brighten a whole room will, if placed out of doors, do visibly the same for only a very small space just around itself. Yet the sphere of pale light springing from it actually extends far—as far as the flame can be seen by any power of vision, not to say a great deal farther. It seem to us, looking through darkness at the tiny glimmer from a considerable distance, that all the light comes to ourselves in one single slender ray. Nevertheless, that ray is but a minute portion of the wide faint sphere of candle-light given forth in all directions.

Even thus shine the Stars in Space; Heaven's luminaries; radiant, burning, dazzling if seen near at hand; but at our vast distance all the light apparently narrowed down to one slim shaft of brightness. A ray, we call it! That ray is but a slip out of the enormous sphere of radiance, which spreads away and away through countless billions upon billions of miles on every side from the star.

'A main difficulty,' writes Miss Agnes Clerke, 'in getting star-light to disclose its secrets is that *there is so little of it.*' So little of it that we can get hold of. Any amount lavished broadcast through Space; but a very minute portion at any one time entering the pupil of a human eye to imprint upon the mirror at the back a picture of that far-off sun. There lies the difficulty; and, as Miss Clerke adds,—'Hence the absolute necessity in stellar spectroscopy for large telescopes. The collecting nets have to be widely extended to gather in a commodity so scarce.'

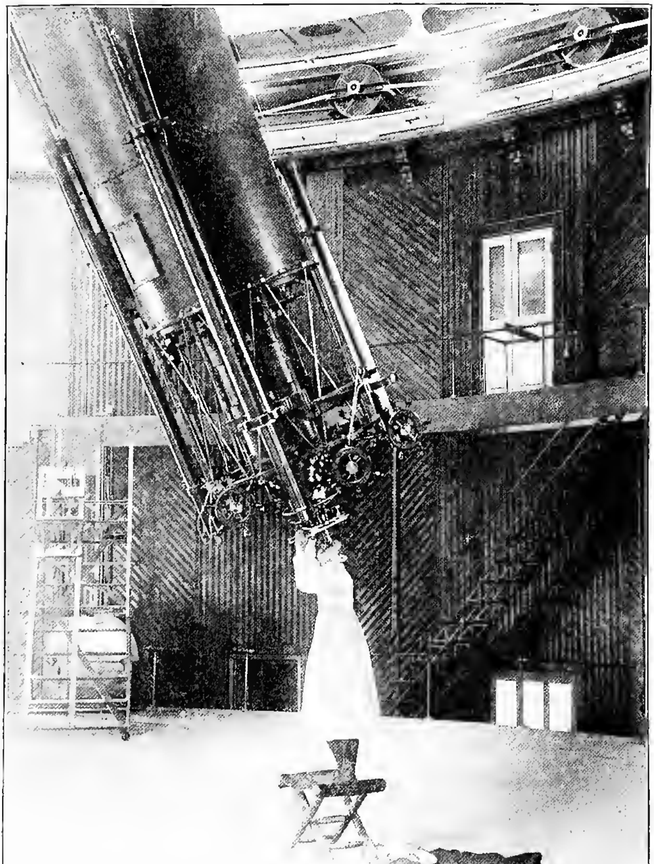
Did you ever think before of a telescope as of a *net* to fish in stray star-beams for the astronomer's use?

That is literally what it has to do. Millions of stars are ever sending out their billions of billions of tiny light-vibrations in each second of time; and the rays reach our eyes as we stand looking upward at a clear night-sky. But, except in the case of a few thousands of stars at the most, the images formed by those rays upon the retina of the eye are too dim to cause any sense of sight. The brain receives no message telling of the existence of such faint stars.

Now, the purpose of a telescope is to make visible stars brighter, and invisible stars visible. It grasps many more star-rays than the small human eye can compass,—in other words, it grasps a very much larger slice of the great sphere of starlight, and it brings that increased amount within reach of the human eye.

Two kinds of telescopes are commonly used; the Refractor and the Reflector. The first telescopes made were all refractors; and the very first of them was made, as you know, by Galileo. The first reflector was made in later days by Sir Isaac Newton.

In a refractor the rays of light, from a star or any other bright body, reach first a large object-glass, through which they pass, and by which, as they pass, they are caused to converge, narrowing, to a focus or point. From this point they widen slightly on



THE GREAT TELESCOPE OF THE LICK OBSERVATORY.

their way to the eye-piece. After passing through the eye-piece, by which they are once more straightened into parallel rays, they arrive at the eye.

Speaking broadly, the eye receives—actually sees—nearly as much of the starlight as if its pupil were the full size of the object-glass of that telescope; and the power of such an instrument depends upon the size of the object-glass. A refractor has been made with an object-glass forty inches across; and this, for the observer, means looking at a star with an eye-pupil more than three feet in diameter.

There are several forms of reflectors. With one form—the Newtonian—when it is pointed at a star, the rays of starlight fall direct through the telescope-tube upon a highly polished mirror, so shaped that rays of light reflected thence are caused to fall converging upon a small plane mirror in the centre of the tube, from which they are thrown, parallel to the side of the tube, to the eye-piece, which converges them to the eye.

The mirror of a reflector can be made very much larger than the object-glass of a refractor. The famous Lord Rosse telescope, which has a tube sixty feet long, contains a mirror no less than six feet in diameter. This, to an observer, is tantamount to looking at the stars with an eye so huge that its pupil alone would be nearly equal in size to the six-foot wheel of a steam-engine. It will readily be perceived how much more starlight can be grasped by such a fishingnet than by the tiny pupil of your eye or mine.

A main difference between the two kinds of telescope thus resides in the fact that the star-rays—or any other kind of light-rays—when first captured pass in one case *through* the glass on which they fall, and in the other case are thrown off *from* the mirror. In both cases the whole amount of light so captured is gathered into a small compass, so as to be available for human sight.

Once more, let me remind you, it should be always kept clearly in mind that every object that is seen by us, from a mote of dust to a sun, from a coal-scuttle to a star, is perceived purely and solely by the light which it gives out, either intrinsic or reflected light. Countless myriads of rays pass from the surface of the thing seen to our eyes, picturing there on the sensitive retina a fleeting vision of its form.

And how about the colours of various objects? Why are some stars red and some blue? Why are sunset clouds sometimes red, sometimes golden, sometimes purple? Why is a blade of grass green, and a rose-petal red?

We have talked of a single ray of light uniting a star with our earth,—a ray unbroken and indivisible.

No, not indivisible!

In one sense it may be called so, since no telescopic power can cut that light-ray into halves, rendering one part of the star visible, while another part is invisible. We see the star, or we do not see it, always as one point of brightness. If the star appears, the whole of it appears. If the star vanishes, the whole of it vanishes.

Yet that slender ray, as we have found, is part of a vast and far-reaching sphere of light emanating from the star. Moreover, the ray is absolutely *not* one ray only, but is interwoven out of many rays. It is not simple, but complex, in its make. It may be broken up, analysed, disintegrated, put together again. If not, we should have no variety of colours upon earth, but only one wearying uniform hue. The single ray of starlight is, in fact, a bundle of rays. Each of these sub-rays, these strands in the twisted Rope of Light, has its own colour, has its own formation. We have already noticed how violet rays are made of or caused by smaller and more frequent impulses than red rays. Both the violet rays and the red rays, together with rays of other colours, go to the making of one single starbeam, as of one single sunbeam.

See the light coming through a square of blue glass; it is blue light. Look at the light coming through a square of red glass; it is red light. Yet in both cases it is the same light — made red or made blue, you will perhaps say, by the hue of the glass. But the glass has no colour apart from sunlight. The red tint or the blue tint is not an integral part of the glass. It is lent to the glass by light, and it departs with light.

The blue glass looks blue to our eyes, because something in its make stops other coloured rays in the sunbeam which endeavours to creep through it, and allows only the blue ray to pass. Again, the red glass looks red, because something in its make stops all coloured beams in the sun-ray except the red one, and only allows that red one to pass.

So it is not at all a case of pure white light travelling through red glass or blue glass, and being made red or blue in the act of so doing; but of a bundle of many-hued rays trying to get through a certain colourless medium, and only partly succeeding. Some of the rays are held back; others are allowed to pass; and the transmitted rays alone, reaching our eyes, lend their hue to the glass.

This hindering or holding back of parts of a light-ray is spoken of as Absorption. The substance, through which the ray endeavours to go, absorbs some part of it, and so checks its progress. Sometimes the larger and slower waves are held back, while the smaller and quicker ones get through easily; and sometimes the bigger ones pass through, while the smaller ones somehow keep running against opposing molecules, and cannot make way at all. It is mainly a question of the particular make of the substance.

Our atmosphere is a good deal given to absorbing parts of the rays of sunlight.

This is not so clearly apparent when the sun is high overhead, and his rays come straight downward through a comparatively shallow depth of air. But when he is low down on the horizon, and his beams travel slanting-wise through great thicknesses of air, then the blue and violet rays are largely absorbed or held back, and only the red and yellow rays manage to reach our eyes. Therefore on such occasions we often see red and yellow clouds, and streams of crimson light. Once in a way, though not often, the atmosphere will absorb the red and yellow rays instead, and then the sun has been seen to look quite green.

Again, the rays of sunlight will fall upon a substance which is not transparent like glass or air, and which does not allow them to pass through. Instead of this, it absorbs or buries in itself, some parts of each ray, and rejects others ; that is to say, it absorbs some of the sub-rays and refuses to absorb the rest. *Which* it absorbs and *which* it rejects depends upon its make, in relation to the size and make of the tiny light-waves. Those rays which happen to be absorbed are lost to us ; those rays which happen to be rejected are reflected from the substance, and rebound to our eyes.

One substance, such as a blade of grass, will accept and absorb all rays except the green ones. Whereupon, the rejected green rays rebound to our eyes, and our brains forthwith decide that the grass is green.

Another substance, such as the petal of a rose, will absorb all rays except the red. These rejected red rays, springing away to our eyes, make the rose seem to be red.

For, after all, Light and Colour, as we see them, are literally sensations in our brains, not absolute existences apart from ourselves, although *caused* by things and movements outside of ourselves.

The Sun is there in the sky, far away in Space; and *something* perpetually travels from the sun to us, setting the ether in a eeaseless quiver of waves,—or, if not ether, then something tantamount to ether; and if not waves, then something tantamount to waves. We dare not yet be positive as to the exaet nature of that whieh goes on between the Sun and Earth, producing light and heat and electrieity. Only we know that something is going on, because we can feel it and see it. But light and colour, as we receive them, are distinctly impressions of the brain.

This is a singular thought, but it does not in any wise do away with the glory of light or the beauty of colour. Rather, I think, it enhanees the marvels of the Universe about us. At best, we have such a mere glimpse of what is really there.

A great many of the stars show different colours as they twinkle, and these varying tints are not intrinsic star-hues. Blue stars, red stars, golden stars, do exist; but when a star twinkles from red to blue, and from blue to red, it is merely an atmospheric effeet. As the ray of starlight travels through intervening layers of air, some parts of it are held back, while others hasten forward; and so we get alternating gleams of colour.

CHAPTER XVII

THE KEYBOARD OF LIGHT

THE ETHER-WAVES, or whatever those swift little quivering impulses may be which spring from the Sun, do much more for us than only to print passing pictures upon the retina of the eye.

There is a long range of them, wave beyond wave, larger and larger waves towards one end of the scale, smaller and smaller waves towards the other end of the scale. Our powers of sight are concerned with only a limited portion of this long scale, the whole of which we call THE SOLAR SPECTRUM.

Man's ear is fitted to hear no less than eleven octaves of sound-notes, but his eye is capable of distinguishing only one octave of light-notes.

This by no means implies that the entire scale is only one octave in length. Far from it. There are light-notes so low down and light-notes so high up that our eyes cannot possibly detect them; just as there are sound-notes too low and too high to be ever heard by our ears. The lower notes of the light-scale, that is, the larger and slower vibrations, outside the red,—the 'infra-red'—we commonly call Heat-rays.

The higher notes, or the smaller and more rapid vibrations, outside the violet—the 'ultra-violet'—were formerly called Actinic-rays.

Beyond the violet in the one direction, and beyond the red in the other direction, our eyes are aware of neither light nor colour. Yet, doubtless, both the heat-rays and the so-called actinic-rays are also light-rays, if only we had power to perceive them as such. Moreover, the light-rays which we do see are also to some extent heat-rays and actinic-rays as well. The whole Solar Spectrum is one in its main characteristics, although the different parts of it affect our senses differently.

It is by means of those rays of sunlight which are strong in producing chemical action that photographs can be taken. So the higher rays beyond the violet, which cannot make intelligible pictures upon the retina of a human eye, are quite able to do so upon prepared and sensitive paper,—which paper might be said to *see* the rays invisible to us, if only a brain lay behind the paper to make use of the view.

Photographs as likenesses of our friends have long been in vogue; but photography in astronomy has only of late years become a new and weighty branch of the science.

Photographs are now taken, not alone of the stars which we can see, but actually of invisible stars. The light from those distant suns comes too feebly to make our eyes aware of its presence, even with the help of the most powerful telescopes. But with the sensitive paper or plate of photography, matters are widely different. It never wearies. Minute after minute, up to one hour, two hours, even many hours, it may remain steadfastly exposed to that dim shining; and the faint continuous gleam slowly impresses its form upon the plate, as it could have no possible chance of impressing itself upon the retina of an eye, during the brief space of a human gaze. The photographic plate never gets dazzled, never needs to blink, never turns aside to rest.

Suppose, now, that you have a small hole in the wall of a room, and that somebody at a short distance from it plays upon a musical instrument, standing so that the waves of sound may pass direct through the hole. You might perhaps expect, if you had not tested and otherwise proved the matter, that the sound-waves, on reaching the hole, would pass through and onwards in tiny straight waves, waves just as small as the hole, and only to be heard in a direct line beyond it.

But the waves do no such thing. Immediately they have passed through, they spread out on all sides, vibrating from particle to particle of air, upward, downward, and to either side. So that, from any part of the room, the music—if sufficiently loud—can be heard; though of course it can be heard most clearly by an ear near to the hole, or in a straight line with it.

This spreading about of sound-waves, after passing through a small aperture, is called the Diffraction of Sound.

For a long while it was believed that light followed a different method or rule from sound. It was believed, in fact, that Diffraction of Light did not exist; and this to many was a stumbling-block in the way of their accepting the theory of light being conveyed by ether-waves. For, if light were carried by waves after the same manner that sound is carried by waves, then surely those waves, though smaller in size than the sound-waves, might reasonably be expected to behave according to the same laws.

And apparently light did not in one particular behave as might be expected, if indeed it were of the nature of waves. If one had an entirely dark room or cellar, and if one opened in the wall a little round hole to admit light, then that light on entering would travel in straight well-defined rays till it fell upon wall or floor in a round corresponding patch; and it would do almost nothing towards lighting up the surrounding blackness. The waves of light were not found to spread about freely on all sides, as the waves of sound in a similar case would do.

Plainly, therefore, men said, no such thing could be as Diffraction of Light.

But a certain small yet weighty difference between the two cases had been entirely overlooked; and this difference gradually dawned upon scientific minds. The hole which admitted sound-vibrations, in the experiments made, was *small* compared with the waves of sound; while the hole which admitted light-vibrations was *large* compared with the waves of light.

This altered the whole aspect of affairs. Experiments were tried anew, with a hole which was as small compared with light-waves as the first-named hole when compared with sound-waves. And immediately the light-waves were found to spread themselves about, just as the sound-waves had always done. No longer did one streak of light fall through the surrounding darkness, ending in a circular eye of light; but the brightness was diffused. Nay, under certain conditions, as in a camera-obscura, an actual picture of the outside world was conveyed through the hole and was produced on the other side, by the rays of light spreading themselves about so soon as they quitted the tiny hole of admission.

Everyone has seen a rainbow, the beautiful arc of colours in the sky, one band overlapping another in regular succession, from violet to red,—literally the Scale of Light-notes spread out before our eyes, made visible by falling drops of rain acting as a prism. We do not thus see the *whole* light-scale, because the heat-rays below the red and the actinic-rays beyond the violet cannot impress their images upon our eyes.

Rainbow over the Lake of Brienz.

Anybody may perceive the very same scale of colours,—that is to say, the one centre octave of visible light-rays,—thrown upon a wall or sheet, by allowing a ray of light to pass through such a hole as we have been discussing, and to fall immediately beyond it upon a glass prism. In such a case the prism does for the ray of light what a drop of water does for it in rain and sunshine. It splits up the ray into its constituent parts, and shows the separate strands of which that etherial rope is woven.

So long as light journeys through airless space, rays of all colours appear to travel at exactly the same rate of speed. But when they enter our atmosphere, some slight difference begins, albeit so slight as to receive scant attention. This difference is very much increased when the impulses of light have to travel through such a medium as glass, or wine, or water, *in addition to* its own natural medium of ether. For even in glass, in wine, in water, in any other substance through which light can creep, ether also is to be found between the interstices of the substance. Light cannot exist as light without the presence of ether.

We talk of one substance being transparent and of another being opaque, meaning that through the first light can journey, while through the second it cannot.

In point of fact, most, or all, substances would be translucent, even transparent, *if thin enough*; most, or all, substances would be opaque, *if thick enough.* A layer of clear water is transparent; we can actually see through it. A much thicker layer is translucent, letting light pass through, though not allowing images on the other side to be visible. But the depths of ocean are in pitch darkness, because the overlying water is far too thick to admit light.

Presumably, also, the purest glass could be so thick as to become opaque to the passage of light, though miles of thickness might be requisite for this. On the other hand, iron, which is opaque even when thin, might yet be brought to such a degree of exceeding tenuity as to admit the passage of light, perhaps even to become transparent. Gold-leaf has of late been actually rendered translucent through extreme thinness.

Some years ago the view was held that only three primary colours went to the making of a rainbow, or of the sunlight-spectrum thrown by a prism. This idea is now given up, since each colour is found to be original and primary. Each one of the rainbow or spectrum-tints has its own characteristics, its own especial number of light-waves in a second, and its own particular degree of refrangibility.

Thus, green in the rainbow or in the spectrum is not merely an accidental mixture of blue and yellow, but an original and independent band of green, travelling as such direct from the sun to us. If any three of the tints deserve the name of primary more than any others, because our eyes are more peculiarly sensitive to them, the three would appear to be Red, Green and Violet. However, each tinted ray has its own right to be considered apart.

By 'refrangibility' is meant that degree, that extent, to which a ray of light is bent or refracted, when passing from a less to a more dense medium, or *vice versa*, as from air to glass, or from water to air. A light-ray, as one whole and undivided ray, can be so bent or refracted, as we saw earlier in the experiment of a penny in a cup.

But when, by means of a prism, the entire ray is broken up into its lesser rays, then we find that those sub-rays of different colours are not all bent exactly alike. If they were, we should see no colours, but only one patch of white light.

As they pass through the prism, some are bent more, some are bent less; and in consequence of this they lie side by side on wall or sheet, as separate rays of divers hues, instead of being all united into one white ray.

The red ray, consisting of larger and slower wavelets, is the least bent of them all, and therefore has its position most nearly in a straight line from the prism. The violet ray, consisting of smaller and quicker wavelets, is the most bent of all, and therefore has its position farthest off from the straight line. The remaining colours, such as orange, yellow, green, blue, have each one a particular position between, dictated by the degree in which it is bent out of the direct line. So we say that violet is 'the most refrangible,' and that red is 'the least refrangible.'

This breaking up of a ray of light may be done in another and somewhat different mode from that just described.

Instead of using a prism, the ray of light may be allowed to fall, slanting, upon a number of very fine lines, drawn so close together that the distance between any two of the lines is small compared with a light-wave. A beam of light, allowed to pass through or reflected from the surface, will again be broken up and spread about, as after passing through a prism.

Lines are ruled on glass or metal for this purpose, so fine and so close together as to be only the twenty-thousandeth part of an inch apart. Thus, 20,000 lines can be crowded upon a square inch,—no easy matter to accomplish, even with all modern appliances for delicate work. Months may be spent in the making of a screw for the ruling-engine; and a year may pass in fruitless searching for a diamond point which will exactly do for such a task. Then, at the best, when all is prepared, five days and nights are occupied in the actual ruling of a six-inch grating, with 20,000 lines to the inch. To rule only 14,000 lines to the inch is, by comparison, an easy matter. Moreover, a glass grating is much harder to rule than a metal one, for in that case the diamond point is given to perpetually breaking down.

Verily, the pursuit of knowledge in Astronomy has to be made in the face of obstacles.

A ruled glass or metal of this description is known as 'a diffraction grating,' because by means of it the light-ray is *diffracted* or spread about, as by a prism. Diffraction gratings are now much used in spectroscopes, and for many purposes are more efficient than a train of prisms.

CHAPTER XVIII

MYSTERIOUS DARK LINES

WE come now to a very interesting part of our subject—to the DARK LINES in the Solar Spectrum.

Sir Isaac Newton knew how to break up a ray of sunlight by means of a prism placed close to a hole, thereby throwing upon the wall successive bands of colour. Repeated assertions have been made that he used only a round hole, never a slit; and if this were so, he could not possibly have detected the dark lines. Rays travelling through different parts of a hole of any width—such as a round hole—overlap as they fall upon the wall, and the slender black lines are entirely hidden. It is only when an extremely narrow slit is employed that they become visible. However, we know now that Newton did use a slit, and a fairly narrow one,—from one-tenth to one-twentieth of an inch in width. With such a slit he might have seen some of the lines; and most probably he did so, though we cannot be absolutely sure.

Whether Newton saw the lines or not, he seems to have paid no especial heed to them. In the year 1802, Dr W. H. Wollaston, using a slit one-twentieth of an inch in width, noted at least four fine dark lines crossing the solar spectrum. Supposing them to be merely 'natural boundaries' of the different colour-bands, he too inquired no further; and there still for a while the matter rested. Nobody yet suspected, even vaguely, what great future results lay enfolded in the casual discovery of these few slight lines.

Not many years later the matter was taken up by Fraunhofer, an able German optician. He must have been working quietly at the problem through years of European war and tumult. Crowned heads rose and fell; and nations changed hands; and tyrants were cast down; and brave men died by thousands for their countries; whilst Fraunhofer, in the midst of national seethings, calmly investigated the nature of black lines in sunlight.

With patience he went into the question, using the telescope as well as a very narrow slit; and soon he discovered that the dark lines were to be numbered not by units or by tens, but by hundreds,—or, as we now know, by thousands. Close examination was rewarded by the making out of lines upon lines; till, in the year 1814, that which witnessed the downfall of Napoleon and his banishment to Elba, Fraunhofer had mapped three or four hundred. Some were in the red; some were in the violet; some were in the intermediate bands; but each one had, and has, its own invariable position on the solar spectrum.

For, be it understood, these dark lines are constant, not variable. Where a line is seen, there it remains. Whenever a ray of sunlight is properly examined, with slit and with prism or diffraction-grating, that line will be found, always occupying precisely the same spot in the spectrum.

Some of the chief and more distinct lines were named by Fraunhofer, after certain letters of the alphabet; and by those letter-names they are still known. He began with A in the red, and went on to H in the violet.

Fraunhofer made a great many experiments connected with these mysterious lines, anxious to discover, if possible, their meaning. For although he now saw the lines, which had scarcely so much as been seen before, he could not understand them; he could not read what they said. They spoke to him, indeed, about the Sun, but they spoke in a foreign language, the key to which he did not possess.

He tried making use of prisms of different materials, thinking that perhaps the lines might be due to something in the nature of the prism employed. But let the prism be what it might, he found the lines still there.

Then he examined the light which shines from bright clouds, instead of capturing a ray direct from the sun. And he found the lines still there. For cloudlight is merely reflected sunlight.

Then he examined the light of the Moon; to see if perchance the spectrum might be clear of breaks. And he found the lines still there. For moonlight is only reflected sunlight.

Next he set himself to examine the light which travels to us from some of the Planets, imagining that a different result might follow. And he found the lines still there. For planet-light again is no more than reflected sunlight.

Lastly he turned his attention to some of the brighter Stars, examining one by one the ray which came from each. And, behold! he found the lines *not* there. For starlight is not reflected sunlight.

That is to say, the identical lines which distinguish sunlight were not there. Each star had a spectrum, as the sun has a spectrum; and each star-spectrum was crossed by faint dark lines, more or less in number. But the spectra of the stars differed from the spectrum of the sun. Each particular star had its own particular spectrum of light, different from that of the sun, and different from that of every other star.

For now Fraunhofer was examining, not sunlight, but starlight; not the light of our Sun, either direct from himself, or reflected from some other body, such as planet, or moon, or cloud, but the light of other

Suns very far distant, each one varying to some extent from the rest in its make.

The fact of the Stars showing numerous sets of black lines, all unlike those of our Sun, showed conclusively that those lines could not possibly be due to anything in our earthly atmosphere. Sunlight and starlight travel equally through the air, and are equally affected by it. If our atmosphere were the cause of the black lines in sunlight, it would cause the *same* lines in starlight. But the Sun and each individual Star has its own individual lines, quite irrespective of changeful states of the air.

Now, what are these fine black lines in the Solar Spectrum? What do they mean?

Briefly, for the moment, they mean this. The solar spectrum is the Keyboard of Light. And in that keyboard *many notes are missing*.

Let us state the matter shortly, afresh.

Sunlight, passing through an exceedingly narrow slit, reaches the other side as a slender line of light. But in that line of light, as already shown, are contained innumerable lines—sub-lines—of differently-coloured light; of rays diverse in their make; each sub-ray more or less refrangible, that is, *bendable*, than the rest.

A prism, placed just beyond the slit, will spread out the slender ray into the broad spectrum of sunlight; and then each particular sub-ray falls naturally into its own particular place. Or, to express the same thing in other words,—a prism spreads out the ray into the wide keyboard of sunlight, and each note drops into its right position.

When the slit is comparatively wide, bands of overlapping colours appear. But with a very narrow slit one sub-ray lies beside another, none overlapping. Then it is that gaps appear; slim black lines or breaks in the spectrum; missing notes in the solar keyboard.

Hundreds, even thousands, of these black lines, these tiny gaps, are found in the solar spectrum. Not merely in just that part of the spectrum which our eyes can see, reaching from the red to the violet; but in the infra-red and in the ultra-violet,—that is, in the parts down below the red and up above the violet.

Suppose a piano were made, with a keyboard of enormous length, containing our present piano keyboard and innumerable octaves above and below as well. Those notes in the bass, getting deeper and deeper in tone, would at length cease to be audible to our ears; and those very high up in the treble would do the same. For the sound-waves of the one would be too large and few, the sound-waves of the other would be too tiny and frequent, to affect our ear-drums, so as to cause any sensation in our brains.

Somebody playing a tune on that piano would produce a curious effect, unless he kept only to the middle octaves. If his fingers ran or leaped very high up and very low down on the lengthy keyboard, parts of his melody would die away into absolute silence; and our ears would be conscious of breaks or pauses in the music.

But, remember, this would not mean that no notes were struck, that no sound-waves travelled forth, that no created ears could hear them. It would only mean that we ourselves could not be aware by sensation of their existence.

Very much such a keyboard as this we have in the Spectrum of Sunlight.

One octave only of the spectrum is visible to our eyes; but many notes comprising other octaves are there also, above and below the limits of human vision; and we need not suppose that those higher and lower notes differ intrinsically from the notes of the middle octave. They are all sun-rays; doubtless, to at least some extent, all light-rays, all heat-rays, all colour-rays, all chemical-rays. We only do not see them all because of the defective nature of our own vision, which cannot perceive ether-waves, except within a certain definite boundary of size and rapidity.

It may be that an insect can hear shrill sound-notes which we cannot hear. It may be that many an animal can see dim light-rays which we cannot see. It is conceivable that beings may exist — if not here on Earth, then elsewhere in the Universe—

to whom what we call silence is perpetual sound; to whom what we call darkness is absolute radiance of light. For the waves are in existence here, there, everywhere; and only ears and eyes are needed capable of being affected by them.

So much for the visible and invisible portions of the spectrum,—the one octave which our eyes can see, and the additional octaves which are known to us by other modes than that of simply seeing. In all the octaves, visible and invisible, bands of colour are interrupted or crossed by innumerable tiny black lines or spaces of non-light and non-colour. We have now to find out to what these breaks in the spectrum of sunlight are due.

But—someone at this point may say—if the octaves above and below are invisible to us, how can we possibly know of the black lines being there? In the one middle octave we *see* those lines with our eyes. How can we ever see the others?

The answer is very simple. We know of those lines in the ultra-violet and in the infra-red by different modes; through certain instruments for detecting heat of low refrangibility, and also notably through photography. The unseen and unseeable rays of light, which are powerless to impress their fleeting image on our eye-retinas, can impress a lasting image on prepared paper or plate. Then the photographed octaves of light may be seen by our eyes, and their dark lines carefully studied.

So long as a century ago Sir William Herschel found the greatest heat of the whole spectrum to belong to the infra-red portion: and it is now some years since dark lines were first detected there, few in number. Recent researches by Professor Langley, with an especially sensitive instrument, have, however, enabled him to discover, and accurately to map, no less than two thousand such lines in this 'dark continent,' as he has termed the infra-red. As a proof of the extreme delicacy and sensitiveness of Professor Langley's instrument, the following fact may be mentioned. By it he is able, not merely to separate the two fine sodium-lines, commonly seen as one line, but also to perceive *between* them a nickel line.

I may take the opportunity to remark here that the appearance of *lines*, whether dark or bright—and you will soon hear of bright lines also—is due simply to the fact that the light is received through a narrow line-slit before being passed through the prism. Light travels in spherical waves; but a small slice or line of the sphere is selected and separated from the rest for our inspection.

CHAPTER XIX

TWO YELLOW LINES

EACH ray of light which comes to us from the sun comes pulsating and vibrating across some ninety-three millions of miles of space, set in motion there by the clash of glowing particles of matter; not of matter burning away as coal or wood burn away in our atmosphere, but matter so intensely heated as to glow with extreme brightness.

The main source of light is incandescence, and incandescence springs from heat.

A very low degree of heat is not apparent to any of our senses. It can neither be seen nor felt by us, though it can be shown by means of a delicate thermometer. It is then described as 'thermal heat.'

A somewhat higher degree of heat may be felt, but still cannot be seen; as when your hand finds a piece of iron too warm to be grasped, while yet the iron remains perfectly black.

Further increase of heat develops gradually a grey, and then a dull red glow; and, stage by stage, from this 'red heat' belonging to the lower end of the spectrum, more and more heat leads upward to the crowning brightness of 'white heat,' inclusive of all the hues in one. The progression of colours between the red and the white is not, however, apparent to us, owing to the nature of our eyes, which are not equally sensitive to all the tints.

In each successive stage the molecules or tiny particles of the heated substance move ever more and more rapidly, clash ever more and more vehemently one against another.

Solid substances, liquid substances, gaseous substances, may each and all undergo this gradual heating process, giving out in response first more and more heat, then more and more light with the heat.

With a large number of substances a certain degree of heat means transformation from the solid to the liquid form; a certain further degree of heat means transformation from the liquid to the gaseous form. Even then the gas may be hotter or cooler. A cool gas gives out no light visible to us, but an intensely-heated gas shines radiantly.

At what particular stage in this heating process, in the case of any one substance, light begins to appear, we may not venture to say,—if light intrinsic be considered. We can say how soon light become apparent to our eyes; though here again people have very different powers of vision, and one man can detect a glimmer where another sees only unmitigated darkness. Moreover, a degree of light, of which the retina of a human eye is utterly unconscious, can impress itself upon a photographic plate.

A kettle boiling in a dark room gives forth heat, of which we can be sensible standing near it. But also that kettle gives forth light, of which we *cannot* be sensible. Our eyes do not see those faint radiating gleams. Nevertheless, they can impress themselves upon a photographic plate, sketching there the image of the kettle from which they flow.

So also, as we have found earlier, countless stars in the sky, too dim and feeble for our sight to distinguish, will submit to be photographed,—to be *seen* by the prepared plate, if one may use such a term in connection with an inanimate substance.

Now I have to beg careful attention to what follows, since much hangs upon it.

The light from any metal sufficiently heated will give a spectrum, just as sunlight gives a spectrum, under the needful conditions. That is to say, there must be slit and prism, or slit and diffraction-grating for the light to pass through. But the kind of spectrum is by no means always the same.

Putting aside for a few minutes the thought of sunlight and starlight, let us look at the kind of rays or beams which are given forth by heated earthly substances.

Any very much heated substance sends forth its light in rays or beams; and any such rays or beams may be passed through a prism and broken up or 'analysed,' just as easily as sunlight may be 'analysed.'

Suppose that we have a solid substance first,—a piece of iron or of steel wire. If it is heated so far as to give out not only heat but also light, and if that light is made to travel through the slit and prism of a spectroscope, the ray will then be broken up into its sub-rays. They, like the sub-rays of a sunbeam, will form a continuous row of soft colour-bands, one melting into another.

This is the characteristic spectrum of the light which is given forth by a burning or glowing *solid.*

Next, suppose we take a liquid,—some molten iron or some molten glass, for instance. If you have ever been to a great plate-glass manufactory, like that at St Helens, not far from Manchester, you will have seen streams of liquid glass pouring about, carried to and fro in huge cauldrons, bright with a living light of fire from its intensity of heat.

If a ray of *that* light had been passed through slit and prism, what do you think would have been the result?

A continuous spectrum once more. The same as with the glowing iron or steel. The light-ray from a heated and radiant *liquid*, when broken up by a prism, lies in soft bands of colour, side by side.

Both of them a good deal like the solar spectrum, you will say. Only here are no mysterious dark lines crossing the bright bands of colour.

But how about gases?

Suppose we have a substance in the state of gas or vapour, as almost every known substance might be under the requisite conditions; and suppose that substance to be heated to a glowing brilliance. Then let its light be passed through the slit and prism of a spectroscope. What result shall we find this time?

Entirely different from anything seen before. Instead of soft continuous bands of colour, there are BRIGHT LINES, well separated, and sharply defined.

How many bright lines? Ah, that depends upon which particular gas is having its ray analysed.

Try Sodium first; one of the commonest of earthly substances. Enormous quantities of it are distributed broadcast in earth and air and water. More than two-thirds of the surface of our globe lies under an enfolding vesture of water, saturated with salt, which is a compound of sodium. That is to say, sodium enters largely into the make of salt. Every breeze which sweeps over the ocean carries salt inland to float through the atmosphere. Sir H. E. Roscoe writes:— 'There is not a speck of dust or a mote seen dancing in the sunbeam which does not contain chloride of sodium'—otherwise salt. The very air which surrounds us is full of compounds of sodium; and we cannot breathe without taking some of it into our bodies.

Sodium is an 'elementary substance.' By which I mean that it is one of a number of substances called by us 'simple,' because chemists have never yet succeeded in breaking up those substances, by any means at their command, into other and different materials.

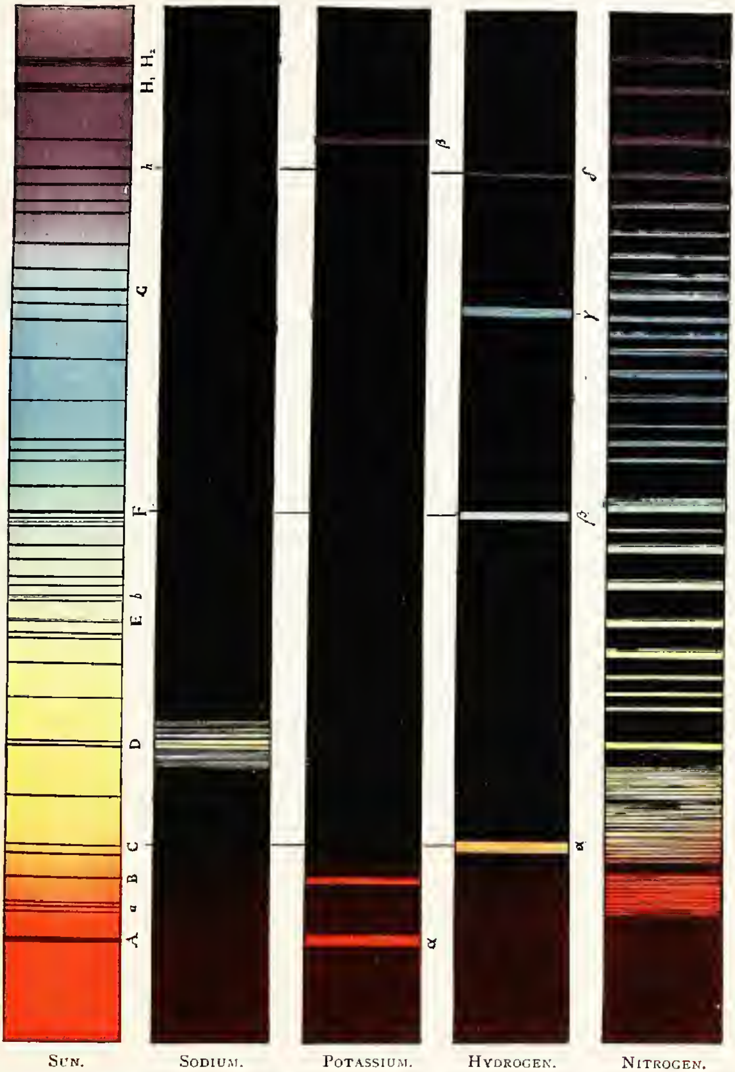
Iron is, so far as we know, a simple substance. It is found as iron in the earth. No chemist has ever been able to make iron by combining other materials together. No chemist has ever managed to separate iron into other materials unlike itself. Iron it is, and iron it remains, whether as a solid, as a liquid, or as a gas.

Gold is another simple substance, and so is silver. Sodium is another. All these we know best in the solid form. Mercury, another simple substance, we know best as a liquid.

Water is not a simple substance, for it can be separated into two different gases. Glass is not a simple substance, for it is manufactured out of other substances combined together.

We can speak quite positively as to such substances as are not simple. But with regard to so-called 'elements,' we may only venture to assert that, thus far, nobody has succeeded in breaking them up. Therefore, at least for the present, they are to us 'elementary.'

All the simple substances, and very many of the combinations of them, though often known to us only



SPECTRA OF THE SUN AND FOUR ELEMENTS.

in the solid form, may, under particular conditions, be rendered liquid, and even gaseous.

When gaseous, each substance may also conceivably be so far heated as to give out light. We may not have sufficient heat at our disposal; but if we had, the thing could undoubtedly be done. When it can be done, when the substance can be so heated as to shine with its own light, then the light which is given out may also be analysed. In other words, it may be passed through the prism; it may be broken up and examined. And it is then found that, in each separate case of each separate metal, the light-ray proceeding from it is entirely 'peculiar to itself;' that it is quite unlike the light-ray proceeding from any other substance; and that it is always and invariably a sign of this particular substance and of no other. Whether we commonly know the substance in a liquid or a solid or a gaseous form makes no difference in this respect. Let it be once turned into a gas, and heated to the shining point; the light given out, when examined, keeps always unchanged its own characteristics.

Suppose that we have sodium gas highly heated so as to give forth light,—what will be the distinctive character of the light-ray emitted?

Practically this; two fine bright yellow lines, close side by side.

These lines are *always* the token of the presence of sodium. Whenever a sodium flame is used, and its light is analysed, there are the two slender lines of yellow side by side, so close together that at first they were seen as only one line. They are invariably in the same position on the spectrum, never by any chance to be mistaken for anything else. The barest trace of the presence of sodium is at once made apparent in the spectroscope by these lines.

Another substance, lithium, shows a red line. Potassium also is distinguished by a red line, but in a totally different position upon the spectrum or keyboard of light, being less 'refrangible,' less bent by the action of the prism out of its straight path. The one red line is no more to be taken for the other red line, than the note D on the pianoforte can be mistaken by a musician for the note E.

Other metals in a state of glowing vapour display other lines; some only two or three; some many, even up to hundreds. But in each case the lines are distinct, are peculiar to itself, are alike in number, in colours, and in the position of every line upon the keyboard.

CHAPTER XX

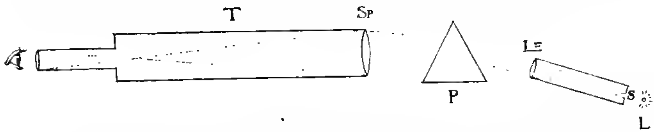
THE SPECTROSCOPE

A FEW words now are needful, before we go further, about the nature of a Spectroscope.

For the breaking up of a Ray of Light, more is not absolutely essential than a very fine slit in shutter or wall, a dark room, and a prism inside the room, behind the slit. The original work of Wollaston was accomplished with no better instrument than this. But such rough and ready arrangements, with which great discoveries were first made, have since given place to the delicate and finished instrument known as a Spectroscope.

A simple spectroscope need consist of no more than what follows:—1st, a box or case; 2d, at one side of it a tube, with a slit at the outer end, and a lens at the end within the box, this tube being called a 'collimator;' 3d, at the other side of the box a telescope, which not only serves to magnify the spectrum, but also enables the eye to receive the whole of the light; 4th, between the collimator and the telescope, a prism, placed so that the light may pass through it in a particular way. Numberless modifications and improvements have been grafted upon this simple spectroscope, most of them far too difficult and complicated to be explained here.

The collimator is, as above said, a tube, with a very fine slit at the one end, and with a lens at the other to bring the rays from the slit parallel. Through this slit must pass the Ray of Light which



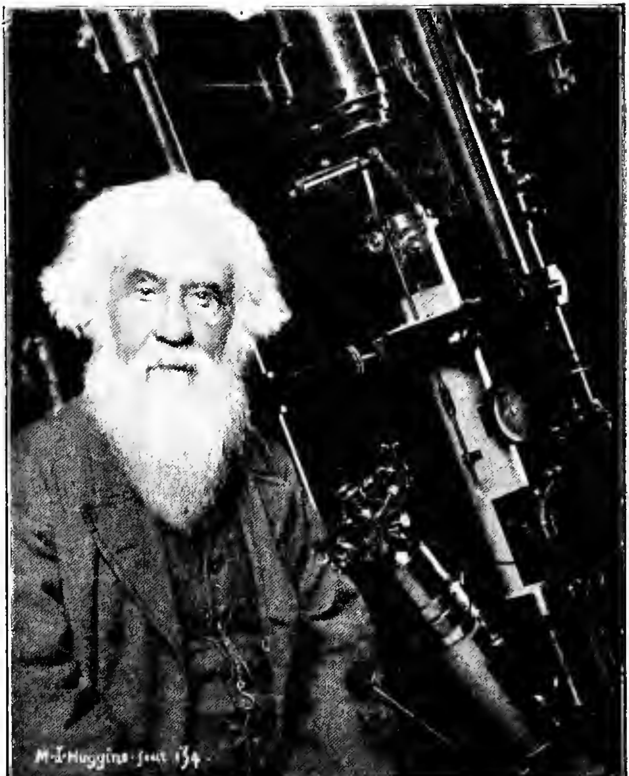
A SIMPLE SPECTROSCOPE.

L, Source of Light; S, Slit at one end of collimator; Le, Lens at other end of collimator; P, Prism; Sp, Spectrum of light-ray; T, View-telescope.

has to be examined; whether it be a ray of candle-light, of gaslight, of sunlight or of starlight.

Whatever the source of light may be, the collimator-tube is pointed towards that source—towards candle or lamp, sun or star,—and the light from it travels through the slit, down the tube, and through the lens.

There it falls upon the prism, and has to make its way through it. Or perhaps it has to traverse many prisms. Or perhaps there are no prisms at all, but a diffraction-grating; and the ray of light has either to pass through the grating, or else to be reflected from its surface. There are varieties of modes, but the object in any case is the same,—to break up the slender ray into its sub-rays of divers hues, that it may undergo examination.



DR. HUGGINS.

FROM A PHOTOGRAPH BY MRS. HUGGINS.

Besides the collimator with its slit, and besides the prism or grating, there is also, as above stated, the 'view-telescope' through which the observer gazes. This is generally about the same size as the collimator; each of them in an ordinary astronomical spectroscope being from about three-quarters of an inch to an inch and a half in diameter, and from six to eighteen inches in length.

When the ray of light has been broken up by the prisms or the grating, the many-coloured sub-rays enter the tube of the view-telescope. Converged by the lens, they pass up the tube, enter the observer's eye, and so deliver their message to his brain. The magnifying of the spectrum is usually an advantage.

The width of the slit can generally be regulated by a fine screw; and for astronomical observation it is seldom employed wider than from the two-hundredth to the four-hundredth part of an inch. A marvellous advance this on Newton's first efforts!

The spectroscope can be joined to the great tube of a large telescope for examination of heavenly bodies; and this union of instruments is known as a telespectroscope. Dr Huggins was the first to attempt the combination of spectroscope and large telescope in the year 1864, and it has long since become general.*

* On the opposite page will be found a photograph of Dr Huggins, with his newest spectroscope, kindly taken by Mrs Huggins in response to a particular request.

Suppose now that you have a spectroscope. You take your seat, and you gaze through the tube of the little view-telescope. The collimator-tube, with its narrow slit, is pointed towards a lamp. The ray of lamplight passes through the slit, travels through the collimator-tube, and either traverses the prism or is reflected from the grating. Then it enters the telescope-tube, into which you are looking; and the spectrum of that ray of lamplight, having been magnified, is duly presented for your inspection.

What do you see?

You see a band of colours, rainbow-like, shading step by step from the lowest to the highest visible notes of the scale of light, from red to violet, unbroken by a single dark line.

Next let the collimator, with its fine slit, be pointed towards the sun,—taking, of course, all needful precautions to save your eyes from too much glare, — and once again look through the telescope-tube.

What will you see of the light-ray, which has journeyed some ninety-three millions of miles from that dazzling orb, finishing with a brief passage through slit, collimator, prism and telescope?

You will see again a band of colours, rainbow-like, shading step by step from the lowest to the highest visible notes of the scale of light, from red to violet. But in this case it is not a band of hues unbroken. On the contrary, that scale is crossed by hundreds, ay, by thousands of fine delicate dark lines, some sharp and clear, others dim and soft in outline.

We are now at last drawing near the crucial question, around which we have long hovered.

What can be the meaning, what can be the cause, of those countless lines? Have they aught to say to us about the Sun? And if they have, what is it that they say?

Professor Kirchhoff was the first distinctly to recognise a clue in the matter.

Fraunhofer, after whom the lines were actually named, came very near the clue, but he failed to grasp it.

He noted that a certain pair of fine dark lines in the solar spectrum, marked by himself as D, were actually the same in appearance and in position as the well-known pair of fine bright yellow lines, always cast by the burning vapour of sodium upon earth. This was no difficult matter to discover.

Little more was required! He only had to allow the solar spectrum to occupy one-half of what is called the 'field of the telescope,'—that space upon which the observer gazes,—and below it to have the spectrum of heated sodium-gas; and in a moment, and quite unmistakably, he could not have failed to see that the two fine *black lines*, already mentioned, in the Sun's spectrum, occupy precisely the same position as the two bright *yellow lines* of sodium below. In fact, he could not but have perceived that the one pair was simply a continuation of the other pair. But Fraunhofer did not make this direct comparison, and he failed to recognise the absolute identity of the dark D pair in the Sun's spectrum with the bright sodium pair.

Here the matter rested for some time. Light upon such questions dawns slowly, not through one mind only, but through many minds in succession.

At length Kirchhoff caught sight of a possible clue; and he tested the matter of these sodium lines more fully than it had ever been tested before.

CHAPTER XXI

A PERPLEXITY SOLVED

NOW let us see how it was that Kirchhoff went into this question, and studied afresh the perplexing likeness between the sodium lines and the two corresponding black lines in sunlight.

First, he obtained a fairly distinct solar spectrum of coloured bands and of dark lines. He used sunlight, you understand, but not very *bright* sunlight. This is an important point. He saw the two black lines which Fraunhofer had named D; and they were pretty clear, but not *very* marked and black, because the sunlight used was not so strong as might be.

Then he placed a lamp-flame—a flame in which vapour of sodium was burning—between the slit and the sunlight. And instantly the two fine dark D lines in the sun's spectrum became brilliant and yellow.

You see the force of this? It was not that the sodium threw its distinctive yellow lines either near to or exceedingly close beside the dark D lines. It was that the dark D lines utterly *vanished*, the bright sodium lines appearing in their stead.

This of itself was practically enough to prove the identity of the two; to show that they were positively ONE.

But Kirchhoff went further. As an additional test, he next allowed a full blaze of brilliant sunshine to stream through the sodium flame into the slit. Thereupon, to the amazement of Kirchhoff, the bright sodium lines, overpowered, became once more black.

Thus, with extraordinary certainty, he had shown the complete identity of the double sodium-line with the double-line named D in the solar spectrum. It had been a trial of strength between lamp and sun. When the lamp-light was the stronger of the two, those lines were bright; when sunlight became the stronger, those lines were dark. But in both cases the lines were the same,—entirely identical; alike in position; alike in fineness; alike in nearness the one to the other.

No single metal, except sodium, possesses this peculiar characteristic double-line. Yet that very same double-line is found in the solar spectrum, as you have just seen,—only it is dark, not bright. The difference of colour is the sole difference.

And most naturally the question follows: Is not the cause the same in both cases? Surely, if sodium always causes the double bright line, sodium must have somewhat to do with the double dark line.

But does sodium, that very earthly substance, exist in the Sun? And if it does, how could it possibly make its presence there known to man here, across so vast a distance? And if sodium really has a voice in the problem, why and how should the sodium lines be dark, not yellow, as commonly upon earth?

Kirchhoff did not pause at sodium. He carried on the same experiment with other metals also, and again, and again, and yet again, the same marvellous coincidence became apparent,—a perfect oneness in character and position between the bright gas lines of divers metals when thrown upon the light scale, and various groups of fine dark lines crossing the solar spectrum.

Take iron, for example. Sodium has but two distinct and marked lines, with a very few fainter ones, not even discovered till later. Iron gas, made to glow and to send its gleam through slit and prism, has many lines, some brighter, some dimmer, to the extent of hundreds. Now, in the case of only two lines, there *might* be such a thing as purely accidental coincidence,—the two pairs lying on exactly the same spot of the spectrum, merely because they happened to do so, with no real connection between them. But such accidental coincidence is utterly out of the question in the case of fifty or a hundred lines. The unlikelihood is so enormous as to amount to practical impossibility.

Kirchhoff tested iron, as he had tested sodium ; and the result was the same, but to an extent both startling and amazing.

No less than 460 iron lines, carefully mapped out and accurately known, in the spectrum of glowing iron gas, were found to have their precise counterparts in the spectrum of the sun. Not merely line for line, not only dark line for bright line throughout, but faint dark line for faint bright line, and strong dark line for strong bright line. In the spectroscope this is most plainly visible: the dark lines of the solar spectrum above, occupying the upper half of the telescope field, the bright lines of the iron gas below exactly corresponding in position.

Iron, surely, in the Sun! This is the irresistible outcome of such a sight in the mind of a thoughtful observer.

'To those who have not themselves witnessed this coincidence,' writes Sir H. E. Roscoe, 'it is impossible to give an adequate idea, by words, of the effect produced on the beholder, when, looking into the spectroscope, he sees the coincidence of every one of perhaps a hundred of the iron lines with a dark representation in the sunlight; and the idea that iron is contained in the solar atmosphere flashes at once on the mind.'

Sodium and iron—those two earthly substances—actually there, in the far-off radiant Sun. So we read the meaning of the lines.

Not iron and sodium in their solid forms, as we best know them; at all events, the spectroscope does not tell us of that. I am speaking now of heated and glowing gases. If iron and sodium are present in the sun, in such a form as to cause these lines, it must be as iron gas and as sodium gas floating in the solar atmosphere.

But why should the lines be dark, not bright? A glowing gas on earth gives *bright* lines.

We have seen two things as to these spectra, produced by glowing metals. In the case of solids and of liquids, the spectrum consists of broad soft colour-bands. In the cases of gases, the spectrum consists mainly of bright clear coloured lines. An exception to the last rule is found in the case of very much compressed gas, which behaves like a solid. But let this pass.

Another state of things sometimes occurs. Suppose that a solid body or a liquid body were intensely heated, so as to give out brilliant light; and suppose that the rays of that light had to journey through a quantity of glowing gas, at a rather lower temperature —not quite so hot as itself—on its way to us. Suppose that the rays of light arriving thus were then examined in the spectroscope. What result should we find?

We should see — the conditions being properly arranged — a continuous spectrum of colour-bands *crossed by a certain number of fine dark lines.*

But why?

Because the cooler gas, through which the light-rays must travel, would absorb, or capture, or hold back, certain *parts* of the light-rays; and those missing parts could only show, on arrival, a *black* line each, where, otherwise, they would each have shown a *bright* line.

This is very singular, and at first sight not quite easy to grasp.

Imagine that a shining solid or liquid body is sending out rays into space; rays coloured by sodium and by iron, and by any number of other metals also, though we need not now consider them. The 'body' of which I speak is some kind of heavenly body; and the rays have to journey outward through a surrounding atmosphere, made up of glowing gases, very hot, yet not quite so fiercely heated as the 'body' itself. Among those glowing gases are great quantities of floating iron gas and sodium gas.

As the rays of light pass out from the body and through the surrounding atmosphere, the iron in the atmosphere absorbs or takes possession of just those parts of the light-rays which, on reaching the spectroscope, would, if luminous, give the hundreds of *bright* iron lines; and the sodium in the atmosphere take possession of just those parts of the light-rays which would, if luminous, give the *bright* sodium lines.

So then those parts of the entire Ray of Sunlight are missing in the spectrum; those notes are silent in the keyboard of light; and when the ray, having passed through slit and prism, gives its spectrum, only dark lines are perceived where — but for the atmospheric robbery—bright iron and bright sodium lines would have appeared.

What sort of a body is the Sun in its nature?

It has a surrounding atmosphere; a wide and deep and tumultuous ocean of fiercely-heated and raging gases. So much to some extent has long been supposed; though, until the spectroscope came to our aid, little beyond supposition was possible. Within that enveloping atmosphere is a body of some kind; enormous in size; probably not solid; possibly not even liquid; perhaps of highly-compressed gases, exceedingly heated and radiantly bright.

That portion of the Sun's body which we can see—though to gaze on it in its full splendour is hardly possible and most unsafe for the eyes—we call the 'photosphere.' It is believed to be an envelope of shining clouds; clouds formed, as our earthly clouds are formed, by condensation resulting from comparative coolness. Only, the solar clouds, floating in the solar atmosphere, are not made like ours, of tiny water-drops, but probably of heated and molten metals; while the atmosphere in which those awful clouds float is not, like ours, of cool gases, but of fearfully hot and incandescent gases, in a state of ceaseless convulsion.

Here we have a condition of things calculated to cause the Black Lines in the solar spectrum.

Radiant light leaves those glowing molten clouds to travel earthward; but on its road it has first to dart through a vast atmospheric depth of gases,—iron gas, sodium gas, and many others. As the rays pass, the cooler—not *cool*—sodium gas in the sun's atmosphere steals that part of the ray which luminous sodium-vapour gives as a double bright line; and the cooler iron-gas in the sun's atmosphere steals those parts of the ray which, when luminous, give bright iron lines. So when, here on earth, the ray of sunshine is analysed or broken up, we find, in what would otherwise be an unbroken spectrum of continuous brightness, innumerable slender gaps or dark lines, commonly known as 'absorption-lines.'

Perhaps this may be made a little clearer by an illustration taken from Sound.

We are familiar with the sympathetic response of a stretched string, or of a tuning-fork, to its own note. Now, suppose we wished to make two feeble notes—two *dark lines*, as it were—say at A and B in a full octave. We should make a screen of two sets of pianoforte wires, tuned respectively to A and B.

If, then, an octave of notes were played on the pianoforte to a listener on the other side of the screen, those particular notes, A and B, would sound feebler to him than all the rest. For those two alone would set into motion the wires tuned to A and B; and, in so doing, they would, of course, themselves become partially used-up or 'absorbed.' The faint murmur evoked from the screen of strings would be insufficient to make up for the loss of the original sound.

The above may be taken as a picture of what goes on in the atmosphere of the Sun. There, instead of a screen of pianoforte wires tuned to certain notes, we have a screen of, let us say, sodium-vapour. Instead of sound-notes travelling through, we have light-notes travelling through. And as the screen stops or weakens those particular notes to which it is tuned, so the sodium in the sun's atmosphere, acting like a screen, stops or checks or absorbs the light from the photosphere which — if one may so say — is *tuned* to sodium, because in fact it comes from sodium.

To express the matter differently,—the idea is this. If you have a harp of many strings, each of those strings will only respond sympathetically to that especial sound which it would itself give out if struck. Sound other notes, and the string is silent. Sound *that* note, and there is an instant response. Here we have an illustration, a picture, an analogy, of what goes on in the solar atmosphere, as revealed to us in the solar spectrum.

There is also in the sun's atmosphere an absorption of the spectrum generally, though of the blue part chiefly; so that the sun looks to us less bluish-white than he would do, if we had not to see him through *two* atmospheres—the solar atmosphere as well as our own.

The atmosphere of the sun is often spoken of as the sun's 'reversing layer,' because it serves to turn so many of the bright lines into dark gas lines.

But surely—at this point some one may say—if in the sun's atmosphere there are shining gases, such gases ought, like any other glowing vapour, to cast *bright* lines, not dark ones, when examined in the spectroscope.

This they actually do. The dark lines would really appear *bright*, if it were not for the intense light from the photosphere. In contrast with this overpowering brightness, their own light is dim indeed, and does next to nothing to make up for the absorption which they produce; and so they appear as dark lines to us.

If, then, by any possibility, the outer atmosphere of the sun could be examined, quite apart from the dazzling photosphere, we ought to be able to see the bright lines, where now we only perceive dark ones!

Perfectly true. This can be done, and this has been done; though only now and then for a few short seconds. When a total eclipse of the sun takes place, when the dark body of the moon creeps between and hides the sun,—then preparations have been made beforehand, and the spectroscope is adjusted in readiness. The slit has been pointed towards the solar atmosphere, outside the body of the sun ; and the moment is anxiously awaited, when the moon shall entirely cover the photosphere.

That moment comes; and with wonderful rapidity a change is seen. For a very brief space the photosphere-glare no longer travels earthward ; and the surrounding atmosphere can send to us its own light, no longer swamped, as it were, by the far intenser radiance of the photosphere. At once the true nature of the glowing gases in the sun's outer envelope becomes apparent.

Up to the last moment, while the tiniest rim of the sun's photosphere can still be seen, the countless dark lines of the sun's spectrum, visible in the spectroscope, remain unaltered, only a few beginning to wax dim.

But when the whole photosphere vanishes, then, in a twinkling of an eye, all is transformed. The entire array of black lines disappears likewise. And through the length and breadth of the solar spectrum, with extraordinary rapidity, radiant gas-lines flash into existence ; not only by hundreds, but by thousands ; crossing the red, the green, the orange, the blue, the violet, of the keyboard.

But the change is as short-lived as it is startling.

In two or three seconds all is over, and the dark body of the moon has blotted out that part of the solar atmosphere itself which has been under inspection.

To see these bright gas-lines at ordinary times is most difficult because of the shining of our earthly atmosphere, lit up by the dazzling photosphere. But further proof than this can scarcely be needed to convince us of the actual and literal presence in the solar atmosphere of numberless earthly gases and metals.

Another point of interest may be mentioned in connection with the same subject.

Above the 'reversing layer' just mentioned, magnificent eruptions of gases are often seen, commonly known as 'the prominences.' Since there is no photosphere lying *behind* those prominences which happen to stand out from the sun's 'limb' or edge, their spectrum consists of bright lines only. It was therefore possible in theory to see them with a spectroscope, notwithstanding the glare of our earthly atmosphere; because the continuous spectrum of the light of the sky would be greatly diluted or weakened on being spread out by the prism, while the bright lines would remain nearly as bright as before.

This was a tempting problem for spectroscopists. After the eclipse of 1868, Janssen in India and Lockyer in England had the honour, each independently, of being the first to see the bright prominence-lines *with an uneclipsed sun.*

Since then the study of those strange red protuberances has advanced by strides. It is no longer necessary to wait for the comparatively rare and brief event of a solar eclipse.

CHAPTER XXII

VARIETIES OF SUNS

SPECTRUM ANALYSIS speaks to us of Starlight, as well as of Sunlight, and in the same mode of speech.

For our Sun is neither more nor less than a Star near at hand. And the Stars, or at least very many among them, are neither more nor less than Suns exceedingly far away.

Those characteristic lines and bands, which tell us about the nature of a glowing metal on earth, or of glowing metals in the sun, tell us also about glowing metals in the stars. Both here and there—here on our earth, and away in the realms of Space—they are subject to the same laws.

A sodium-flame, whether on Earth, whether in the Sun, whether in Sirius, in Arcturus, in Aldebaran, whether in the Pleiades, casts always the same unmistakable pair of fine lines, invariably in the same position on the keyboard of light. Whether those lines happen to be bright or dark signifies little. The reading is in either case the same. If the shining vapour from which they come is the main source of the light received, then they are bright. If a stronger shining than that of the vapour comes from behind and travels through it, then they are dark. The note C on the pianoforte is the note C still, whether it be made to sound, or whether it remain silent. So with these spectroscopic lines; when dark they are as the silent piano notes; when bright they are as the notes that are struck.

In the case of many stars, as in the case of our sun, numerous dark lines are to be seen crossing the spectrum of light; not the same in number and arrangement as those of the solar spectrum, but more or less after the same mode. This shows such Stars to belong to very much the same category as our Sun in the classification of heavenly bodies.

It is now pretty well accepted that the sun in all probability consists throughout of heated and glowing vapours or gases, heavily compressed within by the force of gravitation. The central body is surrounded by a radiant envelope of condensed metallic clouds, floating in an atmosphere of glowing gases; fiery clouds in a raging atmosphere, though the latter is believed to be cooler than the photosphere, being nearer to outside space. No doubt the photospheric clouds are incessantly cooling on their outer surface, and perpetually having their heat renewed from the vast body of vehement heat within; heat so stupendous in amount that, notwithstanding the enormous pressure of gravitation, it is not easy to imagine substances as existing there in any form but that of vapour.

A large number of the stars, it is believed, may be described in much the same terms.

We now know, with what may be counted certainty, that very many earthly metals and other earthly substances exist in huge quantities on the surface of the sun. Only, instead of being solid, as the majority of them are with us, they are in the form of heated gases.

Sodium and iron are found there, and a great abundance of hydrogen ; also carbon and tin, silver and lead, calcium and manganese, cobalt and nickel, aluminium and strontium and cadmium, and divers others. About many substances we are still in doubt, only one or two perhaps of their many distinctive lines having as yet been discovered as dark lines in the solar spectrum.

Much caution is needed in asserting the existence of any metal in the sun's atmosphere ; and perhaps even greater caution is desirable in asserting the absence of a metal, merely because its tokens have not been detected. At the best, the latter is no more than negative evidence. In some cases, as with sodium and iron, the identity of dark and bright lines is so marked and strong as to be unmistakable. In many others, the reading can only be regarded as probable, perhaps only as possible,—much as in the deciphering of some blurrred and ancient manuscript in a foreign tongue.

One thing seems very clear—that these 'earthly' metals, so-called, are not 'earthly' at all in any distinctive sense, but are rather 'universal,' since apparently they are to be met with throughout the starry Universe.

Stars are Suns! This has been often asserted. Before the spectroscope came into use this was believed, though with little direct proof. Now the proofs have come to hand. Now we *know* that very many stars are actual suns, like in nature to our sun; vast bodies, clothed in radiant photospheres, with surrounding atmospheres of shining gases.

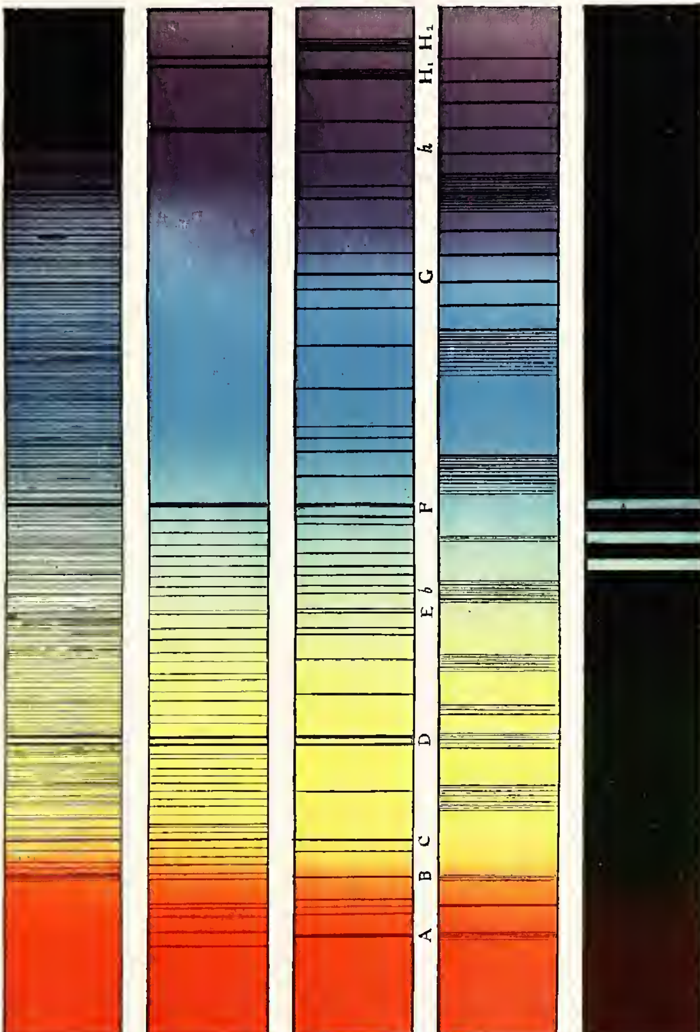
But all stars do not lie under precisely the same head. There are stars and stars in the Universe; and the light-gleams which travel from them to earth do not by any means tell all the same tale.

A true SUN, formed on the same model as our Sun, ought to show in the spectroscope rainbow-bands of various colours, crossed by dark lines, called 'absorption lines.'

Many of the stars do answer to this description; although no two of them have precisely the same arrangement of black lines. But other differences also may be perceived. In some cases the star's atmosphere is actually more brilliant than the photosphere within, and gives *bright* gas-lines, instead of causing dark ones. This might be brought about by an atmosphere far more vehemently heated than the atmosphere of our sun, so that it would outshine a photosphere as glowing as the photosphere of our sun. Or, on the other hand, in such a case, it may be that the atmosphere is about the same as our sun's atmosphere, while the photosphere has advanced far in its cooling, and is therefore the least heated of the two. Thus the star may be, not of a different make from our sun, but only a good deal more elderly, a good deal farther on its road towards becoming a cooled body.

Somewhere about eleven-twelfths of the stars show dark lines, more or less like in kind to those which cross the spectrum of our sun. These eleven-twelfths are divided into the two first and principal Classes of Stars,—the Class of White Stars, and the Class of Solar Stars.

The stars of the First Class are as a general rule brilliantly white, with sometimes a distinct tinge of blue; and their main characteristic seems to be an enormous preponderance of hydrogen over all other substances. Faint tokens of iron, of sodium, of magnesium, possibly of other metals also, may be detected in their spectra; but such tokens sink into insignificance, side by side with the remarkable prominence of the broad dark hydrogen lines. To this class belong Sirius, Vega, Altair, Algol, Canopus, Spica, Regulus, Castor, and innumerable others.



Type I.
White Stars.
Sirius. Vega.

Type II.
Yellow Stars.
Sun (orange).

Type III.
Red Stars.
Betelgeux.

Nebula.
Gaseous.

Spectra of Stars and Nebula.

The stars of the Second Class are inferior in lustre, as seen from earth, to the very brightest of the White Stars; yet they too are powerful and brilliant. Hydrogen exists in no mean quantity on their surfaces, though not to the prodigious extent which distinguishes the First-Class Stars, and leaves its mark upon the White Star Spectrum. To this class, as its name indicates, our Sun belongs; and Arcturus, Capella, Aldebaran, are among its numerous other members. They give, like the Sun, a spectrum of banded colours, with dark lines ruled on it from end to end, no one material especially predominating. The best typical specimen of Solar Stars is Capella; and that fair star seems to be in many respects a very close copy of our Sun Capella may, perhaps, be looked upon as the sun's twin-brother in the Stellar System; much as Venus may be looked upon as the Earth's twin-sister in the Solar System.

The Pole-star and Procyon, and most likely also our nearer neighbour Alpha Centauri, occupy a position somewhere about half-way between White Stars and Solar Stars.

Beyond those two leading classes, which contain the larger mass of known stars, we come to the limited Class of Red or Orange Suns, generally small in size; and also to Variable Stars, whose light alternately waxes and wanes in brilliance. Under the latter head may be included the mysterious class of Temporary Stars. Betelgeuse and Antares are good specimens of Red Suns; and Mira Cetiis one of the best known of the Variables.

It was at one time maintained that no sun could possibly shine with greater radiance than that of our sun. Now we pretty well know that the surfaces of some White Stars do markedly outshine the surfaces of some Solar Stars.

This does not necessarily mean that White Stars must be, on an average, larger than Solar Stars.

Sirius is no doubt an exceedingly bright star; not only brighter than any other stars in our eyes, because nearer to earth than the majority of them, but also because of his great size and his great intrinsic radiance. Careful examination of his light-giving power shows that Sirius actually pours forth somewhere about fifty times as much light as is poured forth by our sun. True, the weight of Sirius does not appear, as measured through the motions of his companion-star, to be much more than twice the weight of our sun; but this hardly touches the question of size, which depends chiefly upon the more or less diffuse condition of a star. There can be little doubt as to the huge size of Sirius; and Sirius is a member of the First Class.

But though Sirius is so brilliant an example of White Suns, it does not seem, judging from available materials, that the White Stars, in general, have greater mass or are brighter that the Solar Stars. There are, indeed, reasons for believing that the Solar Stars not only are as a class more dense than the White Stars, but also surpass them in mass and brilliancy.

Arcturus, for instance, a star belonging to the Second Class, is one of the brightest stars in our sky, after Sirius; yet his distance is held to be enormously greater. The light from Sirius is believed to reach us in less than ten years. The light from Arcturus, according to one rough estimate,—and it can only be a rough estimate, since Arcturus lies beyond reach of measurement by parallax,—may be as much as TWO HUNDRED YEARS upon its road. Yet Arcturus is one of our more radiant stars. Enormous size, and very great light-giving power, are surely both required in explanation.

CHAPTER XXIII

PHOTOGRAPHY OF STARS

IN an earlier chapter, Photography was spoken of as 'a new and weighty branch' of the science of Astronomy. Not only is it a useful handmaid to Astronomy as a whole, but also it is so peculiarly to that division of Astronomy with which we are now chiefly concerned,—to Spectroscopy.

A few pages may, with advantage, be given to the subject of celestial photography, before we go further in other directions.

Photography is, indeed, the greatest possible help to the astronomer. It pictures for him those stars which his eyes can see but dimly, or even cannot see at all ; it paints for him those light-rays, of which he would obtain but a passing glance, and which he could not accurately remember in all their details ; it maps out for him the wide heavens, which he unaided could never do with anything like equal completeness by eye and hand alone.

At this very time a vast photographic map of the whole sky is in progress. About eighteen different observatories in divers parts of the world have divided the task among them; stars down to the sixteenth magnitude being most carefully registered in a complete series of something like 1500 separate photographs. The whole result will be a grand achievement of the present century. Each individual star, in the entire heavens all around our earth, from the first to the sixteenth magnitudes, will have its exact position in the sky accurately known; and the smallest change in the position of any one of those stars may then be detected.

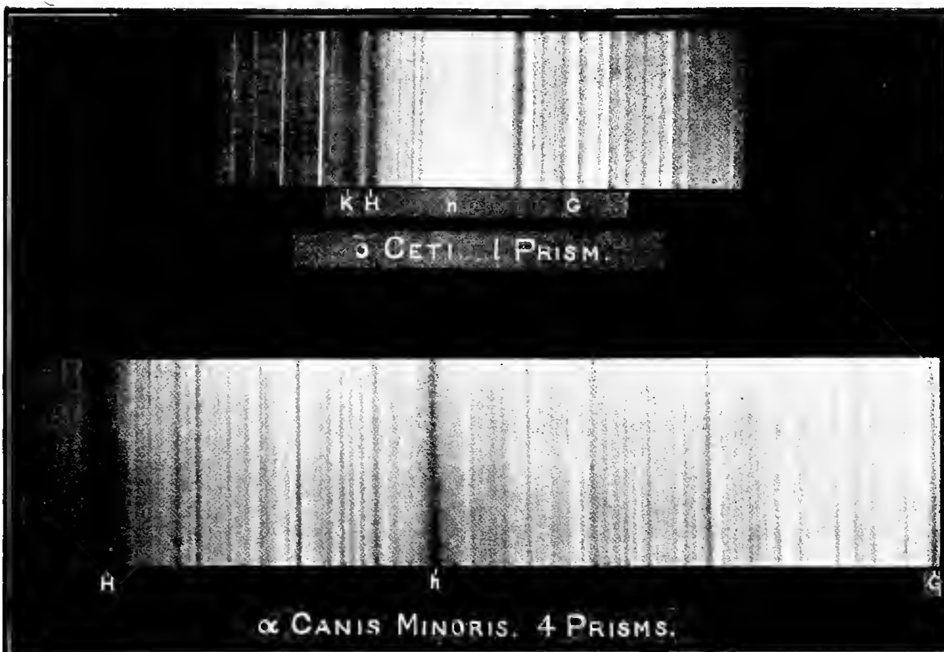
Even in the delicate and abstruse operation, earlier described, the measurement of star-distances through annual parallax, photography again steps in.

Dr Pritchard, the late Savilian Professor of Astronomy at Oxford, who not long ago passed away from our midst, full of years and full of honours, pressed photography into the service of this task also. Measurements for parallax were made, under his direction, upon photographic plates; a work of no small interest. Here, as elsewhere, peculiar advantages belong to the photographic method when it can be followed. Its records are lasting; the limited number of hours, which are fully suitable for direct astronomical work, may be employed in obtaining those records; and in broad daylight the examination of them can be carried on.

One very curious use is made of star-photographs, more especially of the photographs of unseen stars, that is, of stars too distant or too dim to be detected by the eye. These photographs, when taken, may be afterwards looked into further with a microscope. So, first, the far-off invisible Suns of the Universe are photographed on a prepared plate, with the help of a powerful telescope, this being needful to secure sufficient starlight; and then the tiny picture of those Suns is examined more closely with the help of a powerful microscope.

Spectroscopy has much to say to us. It tells us about the positions of the different stars. It tells us about the structure of the stars. It tells us about the various classes to which the various stars belong. And also it tells us about the MOTIONS of the stars; not mere apparent motions, caused by movements of our own earth, but true onward journeyings of the stars themselves through the depths of Space. More of this in the next chapters.

For by means of photography we do not obtain simple pictures of the stars themselves *only*, but pictures also of the *spectra* of the stars. An instrument is made, uniting the spectroscope with the photographic apparatus, and this is called a spectrograph. By its means the disintegrated or broken-up star-ray is photographed in its broken-up condition; so that an exact picture is obtained of the bands and lines characteristic of any particular star.



FROM PHOTOGRAPH OF THE VIOLET PORTION OF THE SPECTRA OF TWO STARS.

No easy matter, as may be imagined, are these spectroscopic observations and these spectroscopic photographings of the stars.

To bring the image of a star exactly opposite a slender opening or slit, perhaps only about the *three-hundredth part of an inch in width*, and to keep it there, is a task which might well be looked upon as practically impossible.

No sooner is a star found in the field of a telescope than it vanishes again. As the astronomer gazes, the ground beneath him is ever whirling onward, leaving the star behind; and although clockwork apparatus in all observatories of any importance is made to counteract this motion of the earth, and to keep the heavenly object, whether star or moon or comet, within view by following its apparent motion; yet, as can easily be imagined, to follow thus the seeming motion of a dim star through an opening so minute demands exceeding care and delicacy of adjustment.

It is not, indeed, for purposes of analysis, *always* needful to pass the light of a star through a narrow slit.

In the case of a nearer body, such as the sun or moon or one of the planets, light flows from all parts of the body, one ray crossing another; and for the examination of such light a slit is imperatively needed, all side-rays having to be cut off. But the whole of the brightest star in the sky is only one point of light to us; and a slitless telescope may be used, with no confused results. Where, however, direct comparison is required, the star-lines being made to appear, side by side or above and below, with the solar spectrum, or with the lines of earthly metals, then the slit becomes unavoidable.

By such comparison of the two, side by side—the light from an intensely-heated earthly substance and the light from a star, the rays of both being broken up in the spectroscope—the oneness or difference of lines in the rays can be easily made out.

One main difficulty in such observations arises from the diminution of starlight, caused by its passage through a prism. If a rope of a dozen strands is untwisted, each of those strands is far weaker than the whole rope was; and each strand of colour in the twisted rope of light is of necessity much more feeble, seen by itself, than the whole white ray seen in one.

Another difficulty in England is the climate, which gives so few days or hours in the year for effective work. Yet the full amount accomplished by seizing upon every possible opportunity is in the aggregate astonishing.

A third and very pressing difficulty attendant upon examination of star-spectra is caused by the incessant motion of our air, through which, as through a veil, all observations have to be made. The astronomer can never get away from the atmosphere; and unless the air be very still—that is to say, as still as it ever can remain—the spectrum-lines are so uncertainly seen as to make satisfactory results impossible. Dr Huggins has sometimes passed hours in the examination of a single line, unable to determine whether or no it precisely coincided with the comparison-line of some earthly substance. In *this* matter no leaping at conclusions is admissible.

The photography of stars would be easy enough if one could just expose a plate to the shining of the star, and there leave it to be impressed—there leave the star-ray to sketch slowly its own image.

But this is hardly possible. The unceasing motion of the earth, causing the star perpetually to pass away from the telescopic field, and the exceeding narrowness of the slit, opposite to which the star has to be kept in a stationary position, make the most accurate adjustment needful.

Clockwork alone cannot be trusted. If it could, the star and the photographic apparatus might be comfortably 'fixed,' and left to do their own work. Instead of which, while a photograph is proceeding, it is desirable that an observer should sit gazing patiently at the telescope-tube, where the image of the star is seen, ready at any moment to correct by a touch the slightest irregularity in the clockwork motion of the telescope, and so to prevent a blurred and spoilt reproduction of the star, or of its spectrum.

One hour, two hours, three hours, at a stretch, this unceasing watchfulness may have to be kept up; and no small amount of enthusiasm in the cause of science is requisite for so monotonous and wearying a vigil. Mrs Huggins, the devoted coadjutor of her husband during the last eighteen or nineteen years, co-worker with him in his labours, co-author with him in many of his published papers, could tell us from her own personal experience what such night-watches mean.

As noted earlier, it has been found possible, if the photograph of a star or nebula is not completed in one night, to renew the work and carry it on the next night, or even for many nights in succession. This is especially practicable in spectroscopic photography.

From four to five hours—sometimes from eight to ten hours—may be needful before the clear image of the star or of its spectrum appears; a dim little star, probably, to us, yet perhaps in reality a splendid sun, shedding warmth and light and life upon any number of such worlds as ours.

Eight or ten hours of photography at one stretch with a star are impossible; for the stars, ever seemingly on the move, do not remain long enough in a good position. For three to six hours a telescope may be made, by means of its clockwork machinery, to keep a star steadily in sight; and all that while the photograph is progressing. If further exposure is needed, the process has to be resumed the next night.

The more one considers the matter, the more plainly one perceives how enormously our powers of sky - observation are increased by photography.

It is not only that one photographer, with his apparatus, may accomplish in a single night the work of many astronomers who have to depend upon the power of the eye alone. It is not only that, with the help of photography, as much can now be done in a lifetime as formerly must have occupied many generations. It is not only that the photograph, once taken, remains a permanent possession, instead of a record more or less imperfect, in which otherwise the astronomer would have to trust.

It is not even only that in the photograph details come out which could not be detected by the eye ; and that stars are actually brought to our knowledge which no man has ever seen, which perhaps no man ever will see from this earth, with the assistance of the most powerful telescope. For the weak shining, which can by no possibility make itself felt by the retina of a man's eye, *can* slowly impress its picture on the photographic plate. Hundreds of stars, thousands of stars, utterly invisible to man, have had their photographs taken, as truly as you have had your photograph taken, and by the same process, only it has been a longer business.

But in addition to all this, we see reproduced upon the plate those ultra-violet and infra-red portions of the spectrum of light, which but for the handmaid, photography, would still be to us as things which have no existence. And, by means of photography, we can observe and study in those same unseen portions of the keyboard of light, when looking into a ray from sun or star, the innumerable dark lines, every one of which has its own tale to tell. To these tales we must have remained blind and deaf, but for photographic aid to our limited powers.

Look at some dim star in the sky, and try how long you can gaze without blinking. You will very soon find that you have done your best; and that to gaze longer only means a sense of fatigue in your eyes, a growing dimness in the star.

How different with the photographic plate! There no exertion is wasted, no weariness is felt. Faint though the light may be, which travels earthward and falls upon the plate, it is all collected, all used.

In the first second of time your eye receives as much light from the star as does the photographic plate in the same time. But during the course of one hour the plate receives and stores up about 3600 times as much light as it or you received in the first instant. There is the secret of the matter. The photographic plate does not only receive, it can also keep and treasure up the light; and that our eyes are not able to do.

If you magnify the amount received in one hour by five or ten, and remember that it is all retained, then you will begin to understand how feeble stars, unseen by man, should become known to us through photography.

CHAPTER XXIV

STAR JOURNEYINGS

FOR a very long while, as we found in earlier chapters, the Stars of Heaven were looked upon by mankind as entirely fixed and unchangeable, each one in its own constellation, each one in its own precise spot.

Then, by dint of close watching, some exceedingly small and faint movements were made out; which tiny movements, translated into miles, with full allowance for the Star's vast distance from Earth, gave no inconsiderable actual speed.

But all such motions were, without exception, SIDEWAY motions. This was inevitable, under the circumstances. Few star-motions could be detected at all; and of those few all were to right or to left, upward or downward. 'Line-of-sight' or 'end-on' movements, as they have been variously termed, were utterly imperceptible. A star might be rushing towards our earth, or fleeing away from our earth, at a rate of ten miles or twenty miles or fifty miles or one hundred miles, per second; but we could not possibly be aware of the fact, because to us it still occupied exactly the same spot in the sky.

The Spectroscope steps in with a different tale. By means of Spectrum Analysis such star-motions become apparent to us.

A ray of light from Sirius is analysed,—that is, it is broken up and examined,—and strong hydrogen lines are seen. This will serve for an example.

The hydrogen line, situated in the green band of the light-spectrum, is found to be very slightly 'shifted' towards the red end of the spectrum.

Or again, in the case of another star, just the reverse is noticed. The hydrogen-line, or some other well-known line, is found to be very slightly shifted towards the violet end of the spectrum.

A little matter this, you may suggest. But all appearances, all changes, all motions, in respect of the stars are minute in amount as they affect us, while often very great in meaning. The meaning here is great. The tiny waves of light are telling one more secret of the far-off sun from which they come.

Did you ever hear and note the shriek of a railway whistle, as the train rushed past? If so—if you were noting as well as merely hearing—you may have observed how, as the train approached, the pitch of the whistle changed, becoming more shrill; and also how, as the train passed away, the pitch of the whistle altered again, becoming deeper in tone. Yet the whistle itself was actually the same throughout.

You know what causes a note of sound to be, as we say, either 'high' or low.' If the note is 'high,' that is more or less treble, it is the result of a larger number of waves of air, following one upon another, and striking upon the ear-drum in a single second of time. If the note is 'low,' that is more or less bass, it is the result of fewer waves of air, following one upon another, and striking upon the ear-drum in a single moment of time.

In the case of the railway whistle, the very same result was brought about in a curious way. The whistle itself did not alter in pitch. It did not become first more shrill, and then more bass in tone. It remained the same from beginning to end.

But, as the train rushed nearer to where you stood, the waves of approaching sound were crowded together, and they came hurrying one upon another, as each one started from a spot nearer than the last. Therefore, they reached your ears in greater and greater numbers within the second, so as actually to produce the same effect upon your brain as a higher note would produce.

Then, again, when the train was rushing away, the waves of sound were, in a manner, pulled apart; were delayed on their road by the widening distance, as each wave started from a farther-off point than the last. Therefore they reached your ears in less and less numbers within the second, so as actually to produce the same effect upon your brain as a lower note would produce.

This same process takes place with *light*-notes, travelling earthward from the stars. It takes place also with nearer bodies, such as sun and moon and planets. But with the stars it has for us a very special interest.

You are aware how, with light-waves as with sound-waves, there may be a so-called 'higher' or a so-called 'lower' note; the violet tint corresponding to a treble note of sound, and the red tint corresponding to a bass note of sound. And you know how, with light-notes as with sound-notes, the *higher* note is caused by more wavelets arriving in one moment, while the *lower* note is caused by fewer wavelets arriving in one moment.

Only, these are wavelets of ether, not wavelets of air; and they do not affect the drums of our ears, but they affect the retinas of our eyes. The brain behind is the same, however. One brain both hears and sees, though it hears and sees through different openings.

Now, if a far-off sun is rushing *towards* our earth, then the waves of light which come from that star are hurried one upon another, and pressed together; each wave having a smaller distance than the last to traverse before it reaches the photographic plate. Just as it was with the sound-waves of the whistle. Thus a larger number of them arriving within one second of time produces exactly the same effect as would be produced by a higher 'note' in the scale of light.

And this, which would affect your brain, if your eyesight were keen enough to distinguish so delicate a difference,—as your ear *is* keen enough to distinguish that same difference in a sound upon earth,—this does affect the picture of the star-spectrum when photographed. It causes the hydrogen line, or some other slender dark lines characteristic of that star, to diverge very slightly towards the upper end of the spectrum. Which is tantamount to the raising of the note in the railway whistle.

If, on the contrary, the star is travelling *away* from our earth, an exactly opposite result is brought about. The waves, then, instead of being crowded together, are pulled apart. Each wave has a longer distance than the last to travel, before it can reach the photographic plate; and the effect produced is just the same as would be produced by a *lower* note in the spectrum of light. A slight divergence of the hydrogen line, or of other lines, towards the red end of the spectrum is observed. Which, again, is tantamount to the lower note in the railway whistle.

Dr William Huggins—well-named 'The Father of English Spectroscopy'—was the first who practically worked out and initiated this entirely modern and most remarkable line of research. It has already added amazingly to our knowledge of the heavens, in directions which, without it, must have remained closed to us. Perhaps no line of astronomical observation, as yet known, has so wide a future.

The method was tried upon a good many stars in turn; and in each case the minute change of position in the fine dark lines of the spectrum was reckoned to represent so many miles of star-journeyings towards us or away from us in one second of earthly time.

In these calculations other motions had, as usual, to be allowed for. There was the whirl of our earth upon her axis, as well as her annual revolution round the sun, to be taken into consideration. There was also the probable motion of the whole Solar System through the Siderial System. When, however, all allowances had been made, all needful deductions completed, a goodly amount often remained as the proper motion of the star itself. Some of the first observations were corrected in a year or two, with repeated trials and improved instruments. But the *mode* of measurement was established; and it has since been splendidly developed by the expenditure of infinite trouble and patience.

In all probability, not one of the tens of millions of Stars, which may be seen through telescopes, is in repose. This is a matter of conjecture, of reasoning from analogy, and of reasoning also from the working of known laws. We *know*, as a consequence of direct observation, apart from the new spectroscopic method, that at least hundreds are upon the wing. We *assume*, as a matter of the greatest possible likelihood, that all the millions besides, which cannot be actually seen to stir, are equally on the move.

Knowing what we do know of the laws by which the Universe of Stars is governed, it seems to us an absolute impossibility that any single star, amid the whole vast host, can be or could be permanently at rest.

If, by any means, a star were brought to repose,—what then would happen? It would inevitably start off again; drawn by the attraction of other stars. From whatever direction the strongest pull came, the impulse would be given. Lengthened repose would be out of the question. And this, it seems to us, must be true, not of one star only, here or there, but of every star in the enormous host of radiant Suns which make up the mighty Stellar System.

Our forefathers, one thousand years ago, could not measure the precise positions of individual stars, as astronomers now are able to do. They had no modern observatories, no telescopes, no spectroscopes, no photographic appliances. Their measurements at best were rough; their scientific knowledge was crude. Had we any such accurate observations handed down from one thousand years ago as are made in these days, we should no doubt see clearly many slight differences in the positions of many stars which are not now apparent. But even then we should see no changes sufficient in amount to affect the general outlines of the leading constellations.

A star which, in the course of a century, makes visible advance over a space in the sky equal to only a small portion of the breadth of the full moon, is looked upon as a fast voyager. One hundred times this degree of movement, if it took place in a considerable number of stars in our sky, would not in centuries very materially change the face of our midnight heavens.

And all motions which would in the remotest degree affect the shapes of constellations must be side-way motions. Those line-of-sight motions, of which the spectroscope alone tells us, could never have been discovered by simple observation of the sky. Until the new method came to light, we had no means whatever of perceiving such movements among the stars.

Suppose you are looking at two men in the distance, upon a wide flat plain. One of the two is walking very slowly *across* your line of vision. The second man is moving very slowly straight *towards* you.

If you watch with care you may find out both the movements. The sideway walking will be apparent first and most easily; because, as the man moves he has constantly a fresh part of the horizon behind him. But in time the advance of the second man towards you will also become apparent; for, although he is seen still against precisely the same spot on the horizon, he slowly occupies a larger spot on the retina of your eye,—in other words, he seems to grow bigger. And that, as you know from long experience, can only mean increasing nearness.

If a star seemed to grow larger as it drew nearer, we should then be able to perceive that movement also. But no star in the sky ever does seem to grow any larger. Every star is to us but one point of light. It may be rushing towards us at an enormous rate of speed; yet still as a single point it remains, always at the same point in our sky; therefore, we have no chance of perceiving its movement. Or rather, we *had* no chance, until the discovery of this new method. In fact, the very nearest known star is at so enormous a distance, that, supposing it to be coming towards us at the rate of one hundred miles each second, it would still gain in the course of a century only one-fortieth part more of brightness than it has now. It would not increase at all in apparent size.

When we leave behind us the thought of starry motions, as we faintly detect them at this great distance, and picture to ourselves the actual far-off whirl of all those glorious Suns, the effect upon the mind is overwhelming. Stars are found to be rushing hither and thither, at every degree of speed, in every imaginable direction; stars to right, and stars to left; stars towards us, and stars away from us; stars alone, and stars in company; all this and

CHAPTER XXV

FURTHER MARVELS

THE new method of reading line-of-sight star-journeyings was not at once widely taken up. New methods, perhaps, seldom are! It was, indeed, soon employed both at the Greenwich and at the Rugby Observatories, but, for various reasons, with not very satisfactory results; and, during some fifteen years, matters remained pretty well stationary.

This new method, first distinctly applied by Dr Huggins in 1868, was not in its essence absolutely new. So far back as 1841 an early glimmer of it had occurred to the mind of Doppler. Such previous glimmerings often occur to divers minds before some great discovery, seeming to herald its approach—even as 'cats' paws' on the ocean surface herald an approaching gale.

Doppler thought that, just as a *sound*, the source of which is quickly drawing nearer or going farther away, is affected by that motion, becoming more sharp or more flat to our ears,—so the two separate stars of a double-star might, from the same cause, show different colours; one colour higher, one colour lower, in the scale of light.

The two components of a 'double' often are different in hue; one red and the other blue, or one yellow and the other green, and so on. Also, when the two revolve together, travelling around one centre, they are often going different ways, the one approaching us, the other receding from us. This, Doppler imagined, might be the cause of the difference of colouring apparent to our eyes.

He was wrong in his reasoning; for, as Dr Huggins has shown us since, owing to the stores of invisible light at each end of the spectrum, the result which he supposed does *not* follow; and the varying hues of stars in a 'double' are due to other causes. But the main principle on which he reasoned was sound.

The same idea was taken up afresh in the year 1848 by Fizeau. He went a step farther; and, while frankly acknowledging the difficulties which stood in the way of demonstrating the truth of the theory, he confidently believed that some day, and in some manner, the principle would be applied.

That confident expectation was fulfilled in 1868, when the new method was worked out and inaugurated by Dr Huggins.

In the year 1874 a new Observatory was established at Potsdam, and there photography was for the first time combined by Dr Vogel with this method. It was also soon vigorously taken up at the Lick Observatory in America.

The old difficulty experienced in such observations, from the extreme unsteadiness of earth's atmosphere, was found to be greatly lessened by the use of photography. On the other hand, it has been proved at the 'Lick' that eye-observations of this type are equal in accuracy to photographic observations, *when* —and only when—the light given out by the object observed is sufficiently strong. When the light is dim, then the eye has to yield precedence to photography.

During the years 1888, 1889 and 1890 extraordinary results followed upon Dr Vogel's systematic and persevering use of this method at Potsdam, with the help of photography and with immensely improved instruments.

Those results were briefly epitomised by Dr Huggins himself in his Presidential Address to the British Association at Cardiff in 1891. 'The spectroscope, . . .' he said, 'enables us to measure directly, and under favourable circumstances, to *within a mile per second*, or even less, the speed of approach or of recession of a heavenly body!'

For the said method is absolutely independent of distance. The motions of the spectroscopic lines are the same in amount, whether the star under examination happens to be one of our nearer neighbours, or one of those farther off; whether it be a sun only

THE LICK OBSERVATORY.

twenty billions of miles away, or whether it be a sun a hundred billions of miles away; provided only that we receive from the sun in question light enough for efficient examination. In other measurements of heavenly bodies—such as measurement by parallax, for instance—the difficulties rapidly increase with increasing distance; but here it is merely a question of light. Given, sufficient light!—and more or less distance becomes a question of small moment. This at once shows the enormous value of the method, when it has to do with the vast distances of our Stellar Universe.

A list of fifty-one stars, all belonging to the two chief Classes—the White and the Solar—has been published by Dr Vogel, giving the speed of each, either straight towards us, or straight away from us, in so many miles per second. Here are a few examples, culled from the list:—

Among White Stars,—Regulus journeys at a rate of over five miles each second; Spica, at a rate of more than nine miles each second; Vega, at a rate of more than nine miles each second; Castor, at a rate of more than eighteen miles each second; Altair, at a rate of more than twenty-two miles each second.

Among Solar Stars,—Procyon, at a rate of over five miles each second; Pollux, at a rate of less than one mile each second; Rigel, at a rate of over ten miles each second; Capella, at a rate of over fifteen miles each second; Polaris, at a rate of over sixteen miles each second; Aldebaran, at a rate of over thirty miles each second.

When star-speeds are given as above, in reference merely to their motions directly towards or directly away from our earth, no account is taken of their possible sideway motions.

A star may be rushing in a sideway direction, as seen from earth, with great speed, and yet may be slanting away from us so slightly as to increase the distance very gradually indeed,—or it may be slanting towards us so slightly as to decrease the distance very gradually. In such a case, the spectroscopic method of reading would give a low rate of motion, while in another direction the star might really be moving with extreme rapidity. We have to join together the two kinds of observations,—the eye-observations, which tell only of sideway motions; and the spectroscopic observations, which tell only of line-of-sight motions,—if we would learn the true movements of a star.

For instance, the line-of-sight motion of Arcturus, as given in Vogel's list of fifty-one stars, is less than five miles per second; and yet from eye-observations it seems probable that Arcturus is travelling at an enormous rate of speed, over three hundred miles per second. But this great speed is in a direction *sideways* to Earth, and so it is not manifest in the spectroscopic measurements.

The above figures show something of the great variety in degrees of motion among the stars.

Some of the Nebulæ, as well as many of the Stars, are found by means of the spectroscope to be on the move. The Great Nebula in Orion appears to be steadily journeying away from our earth, at a rate of about ten miles each second. But as the whole Solar System is believed to be drifting through the Stellar System at about that same speed, it may be that this only means our motion away from the Great Nebula, and not the Great Nebula's motion away from us.

Other nebulæ are found to possess much more decided movements, even when the drift of our System is allowed for. Of ten, examined by Mr Keeler, the rates of journeying varied from about two miles to twenty-seven miles per second. Among all that have been thus far looked into, the Great Nebula in Orion seems to be the most nearly at rest—perhaps not only the most nearly so among nebulæ but among all heavenly bodies known to us. Yet probably even that vast nebula has some degree of movement of its own, although not in our line-of-sight.

Amid all these new observations, none are of greater interest than those which belong to Double-Stars or Binaries.

By the delicate observations of the spectroscope, many stars hitherto supposed to be single are now found to be double; and not only this, but the movements of the separate stars of a 'double,' can be noted and carefully measured. Our knowledge of such far-off systems is thus greatly increased.

In an earlier chapter we heard of certain 'whispers' from double-stars, first heard and understood by Herschel, as speaking across the abyss to man of the governing laws of the Universe. And now, in these later days of science, the whispers of binary stars are heard anew, telling us of fresh marvels in the same vast Universe. Those whispers the spectroscope translates for us, as from some foreign language.

The double-star, Mizar, is one of which the 'components'—that is, the two separate stars which together look to us like one—are in reality widely apart, though through distance they seem so near together. A gap of about one hundred and forty-three millions of miles lies between the two; a much wider gap than that which separates our Sun from the Earth. Each of the two stars travels at a rate of about fifty miles per second,—both revolving around one common centre of gravity. The two stars are about equal in brightness; and together they weigh forty times as much as our sun weighs. Their 'period'—the time they each take to journey once around their centre—is about one hundred and five days, or, roughly, some three earthly months.

When we come to the double-star, β Aurigæ, a very different state of things is shown by the spectroscope.

Here again we have two stars, not so heavy as the last; yet the two together weigh nearly five times as much as our sun. But instead of being separated by one hundred and forty-three millions of miles, these two suns are only about seven and a half millions of miles asunder; a very small rift in the heavens! So near together are they, that the mightiest telescope ever yet made, or at present likely to be made, could not possibly separate the two for our inspection. Seen through the giant Lick telescope, those two great suns are still only as one; the whole of their radiance coming to Earth as a single slender ray of light. An object-glass *eighty* feet in diameter would be necessary to divide the binary star, β Aurigae, into its two components.

The spectroscope, however, that marvellous modern instrument, before which distance becomes as nothing, is able to do what the telescope cannot do. It can divide the one star into two separate stars; and it can examine and measure with accuracy the motions of the two, from which measurements the weight and probable size of each can be calculated.

These two suns are again much the same in weight. They whirl around their common centre, at a rate of nearly seventy miles each second; and the period of revolution for each is only about *four of our days!* In addition to this, the β Aurigæ system is travelling towards our earth at a rate of sixteen miles per second.

Imagine what it all means. Two radiant Suns, each much heavier and no doubt much larger than our Sun, less than eight millions of miles apart, whirling around their centre in four days, at a rate of nearly seventy miles each second ; while both together advance in our direction at a rate of sixteen miles per second. The mental picture produced is astounding. Whether those two Suns have worlds travelling with them we cannot tell. It may be so. There is no reason known to us why such worlds should not exist.

Two other stars of very great interest have undergone careful examination ; and those are Algol and Spica.

Algol is a double-star ; and Spica probably is the same. Algol is a variable star ; and Spica is not a variable star.

Algol, in the constellation Perseus, has long been well known as a most remarkable specimen of Variable Stars. It is commonly a second-magnitude star ; but at regular and short intervals its radiance lessens and then again increases. Once in about every three days this variation occurs. The brightness becomes rapidly less, until in the course of less than four hours the second-magnitude star has become a star of only the fourth magnitude. But this state of things does not last much longer than a quarter of an hour. Then it begins to brighten again, and in less than four hours it is once more a second-magnitude star; so to continue for another two days and a half, when exactly the same process is gone through afresh.

The reason for these changes, now known, is very simple. Algol is really two stars; but in this case the 'double' does not consist of two equally radiant stars. One of the two is very bright; the other is comparatively dim. The pathway of the dim companion brings it from time to time—regularly once in every two days and nearly twenty-one hours—between the bright star, Algol, and ourselves. Then by the passing of the large dark body, the light of the bright Algol is for a little while dimmed. It is, in fact, just the same as when the body of our moon passes between the sun and the earth, and so causes an eclipse. The dark companion of Algol partially eclipses Algol.

So far back as 1783 the existence of this dark companion was suggested by Goodricke, in consequence of observations which had clearly shown the presence of such a body.

The two Algol Suns are not equal in size any more than in brightness. Algol, the bright star, is believed to be a sun perhaps over 1,000,000 miles in diameter; and the dim companion is believed to be another sun perhaps about 830,000 miles in diameter. These figures are not exact; but it is known that the bright Algol is not so heavy as our Sun;

and that the dark companion is a good deal less heavy still.

It must not be supposed that the dark companion is really dark. No doubt, if we were near at hand, we should see it to be shining very brightly indeed; only with nothing like the exceeding radiance of the bright companion. At this enormous distance its light seems to us to be very faint.

The motions of the two can be spoken of with more certainty than the sizes. They are only about three and a half millions of miles apart; and they whirl around their common centre in less than three earthly days,—the bright one at a rate of some twenty-six miles per second, and the dim companion at a rate of some fifty-five miles per second. The lighter in weight of the two has of course to go much the faster. Algol and his companion together are approaching us at a rate of between two and three miles per second.

Spica, a first-magnitude star in the constellation Virgo, is in all probability another 'double.' Not even by means of spectroscopy or of photography has any dim gleam of a companion as yet been found; but the movements of Spica, as shown in photographs by displacements of the spectroscopic lines, are so singular, that no other explanation will meet the case.

If this be as supposed, the bright star, Spica, is most likely about the size of our Sun; and the dim companion would probably be also much the same.

The two bodies are reckoned to be some six millions of miles apart, and to revolve around one centre in the course of about four days. Lastly, the Spica System is found to be drawing nearer to us at a rate of more than nine miles each second.

But Spica, although it is believed like Algol to have a large dim companion, is not, like Algol, a Variable Star. How is this? If Algol is a variable, because of the dark companion, why not Spica also?

For a very simple reason, which even a child might understand. The pathway of the dark companion of Algol brings it from time to time regularly between Algol and Earth. The pathway of the supposed companion of Spica does *not* bring it from time to time between Spica and Earth. It is, as before said, really neither more nor less than the question of an eclipse. Algol's companion partially eclipses Algol at intervals from earthly observers. Spica's companion does not eclipse Spica from earthly observers. It all depends upon the position in which the pathway of the companion is placed with respect to our Earth.

CHAPTER XXVI

PROOFS OF MODERN ASTRONOMY

But how can we know with any manner of certainty the truth of all these wonderful and extraordinary things in Astronomy?—asks some impatient listener. Suppose some of it is a mistake! Suppose some of the spectroscopic readings are wrong! How can we know? How can we be sure?

You cannot always know; and very often indeed you cannot be sure. That is a point which ought to be understood early in the study of science, whether of Astronomy or any other science.

Children like to be invariably quite sure; and people with minds of the same *calibre* as a child's mind must always settle everything to their own satisfaction, careless whether or no that which they maintain is absolute truth. In science, however, a very different spirit ought to prevail; and among really great scientists it does prevail. Many and many a question has to be left for years, perhaps for centuries, unsettled; and many a seeming conclusion must be held tentatively, in view of possible fresh discoveries. Further light on a subject must never be refused, even though it run straight in the face of our former beliefs.

For no voice direct from Heaven tells us of these things. We are left to search out scientific truths for ourselves, by dint of hard toil and patient waiting; and the road to many a longed-for goal lies through many a slough of blunders.

Some things at present are impossible to see through; impossible to fathom. Some things are so far proved, that they are accepted by competent judges as all but certain truth; and you may accept them also on that score. Some things are as absolutely sure as that the Sun and Moon are in our sky; and yet it may be impossible to explain to ordinary minds the full reasons for such absolute certainty. Scientific truths, as well as scientific probabilities, you will often have to receive on the testimony of others; a testimony worth far more in these cases than your own untrained judgment could be worth.

To make yourself a competent judge on such questions, years of scientific training and of hard persistent toil would be necessary; not to speak of the natural scientific gifts, which all do not possess, and without which even the hardest work, the most arduous training, would not lift you into the position of a reliable judge.

For your comfort, however, remember this. Many of the foremost intellects of our age have given themselves to the study of the heavens; not as a mere pastime, but as the absorbing business of their lives; and they are in the main men who do not speak hastily, men who do not decide lightly. No doubt there are scientists of a lower order, who are perpetually flinging half-fledged theories before the public; theories untested and unproved, and often not likely to be ever proved. But these are not the truly great men of our age.

And even the greater men do and must occasionally make mistakes. In time such mistakes are rectified by further observations. They are but the output of feelers in new directions. The broad outlines of the science of Astronomy rest, meanwhile, upon a firm and solid foundation of well-proved truths; not only the older Astronomy of the last two or three hundred years, but also the newer branches. Spectroscopy has felt its way with care; and inch by inch, as it has advanced, it has proved its way. Photography, not new to us as practised upon earth, is a comparatively new aid among the stars; but we do not need to be persuaded of the dependableness of light-pictures. As for the calculations which are founded on those pictures, the deductions which are made from them and from spectroscopic observations, the ordinary student must trust to wiser and more learned brains than his own.

Have you ever seen and examined a Nautical Almanack?

There, years beforehand, are carefully detailed for sailors' use the positions of the leading heavenly bodies in the sky, at any and every given date. And upon these particulars the sailor may entirely rely. He steers his way through the wastes of earthly waters by the guidance of those heavenly bodies, as pointed out and specified in his nautical almanack.

Pointed out and specified *beforehand*, remember! The paths of the planets in the heavens are foretold and precisely described. This is no matter of guess-work. If it were, mistakes would be incessant; and one single mistake in the nautical almanack might mean the destruction of many ships, the loss of countless lives.

Yet the planet-paths are no simple matter. To be able to point out the precise position of each world in the sky at any given moment, years ahead, means an extraordinary amount of knowledge.

It is not only an affair of past observation, but of complicated calculation. The weight of the planet itself; the attraction of the Sun at a particular distance, which distance varies at every point in the planet's annual pathway ; the weight and pull of the planet's own moons, if he has any; the disturbing influences of any other planets near at hand, if any chance to be near at hand at that particular date, and this also has to be known; the movements of our Earth in her journey round the Sun, causing apparent changes in the positions of companion worlds;—all these and many other matters have to be reckoned in and allowed for, in the preparation of such an almanack.

And yet we do not hear of mistakes. The papers do not tell us of ships lost through the false calculations and mistaken deductions of astronomers.

If such mistakes were made, we should hear of them fast enough; and if the Captain of a ship in the midst of the Pacific knew that he could not depend upon his nautical almanack, he would indeed be at a loss. Nay, all the Captains of the thousands of ships which belong to our seafaring nation would be in an utterly vague and bewildered condition, if once it became known that the calculations of astronomers were a failure, and that the nautical almanack was a mere humbug.

One thing is certain. If Modern Astronomy did *not* rest upon a firm foundation; if the accepted theory of the Solar System and of the paths of earth and planets in the sky were a delusion; then that almanack could not by any possibility continue year after year to be correct. It must, in such a case, have speedily proved a mere tissue of hopeless blunders. The close and exact foretellings, of which it is largely made up, must long before this have turned out entirely useless, because never to be relied upon.

It would, in fact, be worth no more than certain popular magazines, much patronised by nursemaids, which profess to foretell the weather, months beforehand. A few lucky hits are found to be broadly correct; these are remembered, and countless failures are forgotten—by the nursemaids. But a scientific man would not forget the failures, in his delight at the few lucky hits. Neither would they be forgotten by a Captain who had lost his good ship at sea, through trusting to the almanack or serial.

Eclipses of the Sun and of the Moon are known any number of years beforehand.

How are they known? How can the date of such an event be so precisely fixed, that we on Earth may be quietly looking out of our windows, just at the very moment when the dark rim of the moon's body first seems to touch the bright edge of the sun; or when earth's grey shadow first begins to creep across the moon's fair face?

This can be no matter of guesswork.

Think of the wide extent of the skies,—of the millions upon millions of miles which divide earth from sun,—of the bewildering intricacies of the moon's path and of the earth's path; and picture to yourself the utter unlikeness that any mere conjecture, as to the time of one heavenly body happening to pass exactly between two other heavenly bodies, should ever chance for once to prove correct.

Yet the foretelling is always correct. There are no uncertainties, no blunders. When we hear that the

Earth will pass between Sun and Moon at a particular minute on some particular day, she does so. When we hear that the Moon will pass between Sun and Earth at a particular minute on some particular day, she, too, does as is expected of her.

Such exactitude can only spring—not from guessing, not from any mere clever 'hit,'—but from the perfect knowledge possessed by Astronomers, of the Earth's path and of the Moon's path together around the Sun.

In neither case is the pathway a smooth and simple curve, easy to imagine and to follow, but a complicated swaying to and fro, as each world is affected by the other.

The earth travels round the sun; and at every point in her pathway she is slightly swayed by the moon's pull. The moon also travels round the sun, and at every point in her pathway she is very greatly swayed by the earth's pull.

Nor is this all. The movements of both earth and moon are affected by passing planets. As Venus draws near behind, overtaking the earth and moon, she pulls them back; then, when she passes us, and gets ahead, going faster, she draws both earth and moon on. Or, again, as earth and moon begin to overtake Mars, he hurries them on; and, when they have overtaken him, he drags them back.

A dozen different influences come into play, influences varying in kind and degree at every stage of the pathway. Every one of these has to be accurately understood, and carefully allowed for.

Sometimes also the Moon's path takes her a little higher or a little lower than the precise spot in the heavens, which lies in a straight line between earth and sun ; and then no eclipse is possible. It is only once in a while that she comes just between. To foretell beforehand exactly when that once in a while shall be, involves a most intimate understanding of the lunar motions.

All these things are known, however, and all are taken into full consideration. If the slightest mistake were made, then, when the almanacks announce 'an eclipse,' and thousands of people are on the look-out, no eclipse would occur. But such a *fiasco* is never heard of. The eclipse, whether of sun or of moon, always comes when announced ; and we have grown so used to the precision of knowledge shown, that it has ceased to impress us. We do not realise half that is implied. We are no more amazed, than when an opening of Parliament has been foretold as about to take place on a certain day, and comes about just as foretold.

More of this in the next chapter.

CHAPTER XXVII

ADDITIONAL PROOFS

To continue the argument of the last chapter, in proof of the sound and firm position of Modern Astronomy.

The same thing that we see in the foretelling of Eclipses, is also seen on a more delicate and complex scale with the Transit of Venus.

This is comparatively a rare occurrence. Twice only, in the course of about one hundred and twelve years, Venus passes exactly between the Sun and our Earth, neither higher nor lower, so that we may see the small dark body creep across the brilliant photosphere. If the event were not known beforehand, and definitely expected, it would seldom be noticed, —in fact, through ages it never *was* noticed.

But here again the calculations of Astronomers are found to be entirely reliable; calculations founded on their knowledge of the path of Venus, the path of our Earth, and the various disturbing influences which each bright world encounters in its annual journey round the Sun. The transit is foretold; and at the moment named hundreds of telescopes are pointed sunward,—there to find invariably the tiny black spot.

In a like manner the transits of Mercury are known, and are foretold beforehand.

A certain comet, now named after 'Halley,' had paid our celestial neighbourhood a visit in 1682. Halley observed it, and watched its course. He then made careful calculations from so much of the path as could be noted, reckoning how soon that particular comet might be expected to return from the farthest point of its journey, and to be seen by us again.

It was no easy sum to work out. The comet would travel near different planets, and each planet in turn would hurry it on or draw it back. These and many other 'perturbations,' as they are called, had to be allowed for; and Halley, having gone into the whole question, came to the conclusion that the comet might be expected to reappear somewhere about the year 1758.

Halley passed away, not living to see his prediction fulfilled. But it was fulfilled! On the Christmas Day of 1758, the comet which had been so carefully considered by Halley, was again seen returning to the neighbourhood of the sun.

The discovery of the first-known Planetoids, the discovery of Neptune, and the discovery of the companion to Sirius, are all marked and manifest proofs of the truth of Modern Astronomy.

Before a single Planetoid had ever been seen, Herschel announced that, arguing from certain known laws which were found to hold sway in the entire Solar System, it appeared to be exceedingly probable that some planet or planets did exist in the wide empty belt between Mars and Jupiter.

A great many astronomers set themselves to work, towards the close of the eighteenth century, hunting for the missing world. And in the very beginning of the present century, in the year 1801, a little world was actually found, exactly as had been foretold. Within seven years three more had been discovered, and now, in the end of the century, the planetoids are numbered by hundreds.

Herschel, you see, was strictly in the right as to the fact of a missing world, and as to the fact of its position; only instead of one large world, as he expected, there are a great many very tiny worlds.

Again, Uranus was counted to be the outer world of our Solar System; quite far enough, too, from the central light-giver and heat-giver, some were disposed to think. But a disturbing force was found on the outskirts of the System; something which prevented Uranus from keeping to the path laid down for him.

What that path would be, and what in fact it had to be, according to certain definite laws of gravitation and of motion,—by which laws the whole Solar System, nay, the whole Universe, is governed,—astronomers could confidently say. They knew the distance of Uranus from the sun; they knew the sun's power of attraction at that distance; they knew the speed of Uranus; they knew the disturbing influences of Saturn and Jupiter, when Uranus happened to draw near to either; and they knew exactly when Uranus *would* draw near to either. All these matters being understood, the exact path of Uranus in the sky was merely an affair of mathematical calculation. And when Uranus, without apparent rhyme or reason, quitted that pathway, they knew with a certain knowledge that some definite cause, as yet undiscovered, lay behind.

Two astronomers, an Englishman and a Frenchman, grappled independently with the problem.

They reckoned the amount of disturbance; they calculated the degree of attraction which would be required to bring about just that amount of disturbance; they decided on the spot in the heavens from which the attraction probably proceeded; they conjectured that some heavenly body—doubtless another planet—must be there. And when a telescope was turned to the spot indicated, there, truly enough, it was!—another Planet of our System, till then unknown and unsuspected.

The new planet was named Neptune; the path of Uranus ceased to be a puzzle; and another strong proof of the truth of Modern Astronomy was added to the list.

Once more, the bright star Sirius was a source of much perplexity. His movements, however tiny in amount, through vastness of distance, were found to be irregular.

I am speaking now of the *real* motion of Sirius through Space; not of any mere seeming motions, caused by our earth's journeyings; not of the apparent motions, due to aberration of light, or to parallax, or to aught else; but of the real actual onward travelling of that great and distant Sun.

It may seem extraordinary to talk of irregular motions in a star tens of billions of miles away—a star whose light takes many years to reach us. But Astronomy, as you have by this time learnt, deals with very minute measurements, and with motions very tiny in appearance.

Well, this irregularity was noticed, and it had to be accounted for. In science, everything has sooner or later to be accounted for. One may have to wait patiently for years, or mankind may have to wait through ages, for the true cause; but a cause there always is.

Here, again, a definite idea was formed that some disturbing body, near at hand to Sirius—comparatively near, that is—might make the great Sun swerve in his path, when otherwise he would have travelled straight forward.

No 'companion' was then known as belonging to Sirius; nothing of the kind had ever been detected. But astronomers, studying the ways of Sirius, offered this theory as a most probable clue to the mystery. They even reckoned that the disturbing body, which nobody yet knew to exist, must travel round Sirius in the course of about fifty years.

There, for nearly twenty years, the matter rested. Then, quite suddenly, quite unexpectedly, a glimpse was caught of a dim companion-star, a smaller fainter star, belonging to the System of Sirius, close beside him in the sky. Close, that is to say, as seen by man from earth; not really close in the heavens; yet still belonging to Sirius, and swaying by his attraction the radiant 'king of stars.'

This companion-star was found to move just as Astronomers had foretold years before that such a disturbing body would move; and also he was found to journey round Sirius only a little faster than had been expected.

All these and many more like feats have extraordinary weight in the history of Modern Astronomy. If the science were not in the main absolutely true, if its reasonings were not founded upon reliable facts, such discoveries, taking place through definite calculation and expectation, could never have come about.

In the still more modern spectroscopic researches, a system of the most careful *proving* goes on, side by side with discovery.

The deciphering of some dim and distant Star, through the unravelling of its slender light-gleam, and the delicate measurement of its speed, through that same means, do not stand alone. The truth of those results is carefully tested by the use of a precisely similar mode of light-reading, as applied to planet-light and to sunlight.

If the method is found to be absolutely correct, in those cases where an answer to the same question can be obtained by other and entirely dependable means; then we know that it may also be relied upon, in those cases where we have to trust to it alone, as in the matter of the stars. And not only with the stars, but also with the yet more dim and mysterious nebulæ.

Is this argument clear? Let it be stated differently.

Think for a moment about the measurement of distant objects by parallax, as described in an earlier chapter. Suppose star-distances *alone* had been measured in that way; and suppose the same mode of measuring distances had never been tried upon any other far-off bodies whatsoever! Then men might well and reasonably doubt whether the results of such calculations were at all to be relied upon.

But the same mode of measurement has been used, and is constantly used, for objects far nearer at hand than the nearest star. Not only for the sun, for the planets, for the moon, but for objects actually upon our earth; and not only for very distant objects on earth, but for nearer objects. You may measure, if you choose, the distance of a tree in your garden, by precisely the same mode as that by which the distance of Sirius has been measured; and afterwards you may prove the truth of the method by tape-measurement of the dividing space.

Having once proved that the *mode* is to be relied upon, we can confidently trust to results from that same mode, in cases where no second kind of measurement is practicable.

The same is true of Spectroscopic matters.

Some of the new discoveries and freshly-learnt facts, related in recent chapters, connected with the new method of deciphering light-gleams, must strike the uninitiated as extraordinary, and as almost past belief. To an outsider, unacquainted with the methods of observation and the modes of reasoning and calculation which are employed, many of the statements made can hardly fail to sound wild and baseless. Involuntarily the question will spring up: 'Is all this—can all this be true? May not these things be a mere delusion?'

Yet in the minds of those who are most fully competent to judge, no doubts whatever exist as to the great value, the complete accuracy, of the results achieved. The exceeding minuteness, the excessive delicacy, of the measurements undertaken, can hardly be so much as imagined by those who have never gone closely into the question. One instance of this minuteness may be given.

Repeated mention has been made in past pages of the two fine sodium-lines constantly seen, so close together that to the naked eye they are but one, and even when magnified they were long mistaken for one. Now, the spectroscope can make distinctly apparent a change of position in a line on the spectrum *equal to the two-hundredth part of the distance* which separates those two fine lines.

The 'make' of a star can be examined only in the one way; only through spectroscopic analysis of its slender ray. But that method of light-reading can be proved to be absolutely reliable by being tested on nearer objects; on the sun, for instance; on earthly metals in a state of vapour; on the moon and on clouds, both of which show, as was to be expected, a reflected solar spectrum. All this has been extensively done. The mode has been tried and tested often and severely one way and another way; and the general results of such testing have combined together to assure us of its truth. Mistakes, of course, are made; and such mistakes have in time to be corrected; but the broad outlines of the spectroscopic method of research into the nature and the motions of the stars may now be regarded as proved and trustworthy.

Yes; their motions as well as their nature or make,—

though this is the newer branch. Even here, astronomers are not simply feeling their way in the dark. The light of knowledge may be dim, but it is real.

In the last chapter a few particulars were given as to the marvellous mode in which 'line of sight' star motions—that is, motions straight towards or straight away from our earth—can be now read by means of a very tiny and delicate shifting of the dark lines on a star-spectrum. The mode has been most carefully tested in various ways, before reliance was plaeed on its results.

The same star is examined, and its movements are reckoned from the displaced lines, in different observatories; and the results are found to be in agreement. This again is like 'proving one's sum.'

Also, the same spectroscopic mode of measuring line-of-sight motions has been applied to Venus. Now the rate of travelling of that bright world, at any particular time, is known with exactness, quite apart from the said calculation. Venus at one part of the year is journeying towards Earth; and at another part of the year she is journeying away from Earth; and between whiles she is moving sideways to Earth. The different modes and speeds of Venus were measured by the spectroscopic mode, as she moved towards Earth and as she moved away from Earth. And the results of such measurements were found to be in agreement with the knowledge already possessed of the movements of Venus. So here was another proof.

One more may be mentioned. As the Sun whirls round upon his axis in about twenty-six days, one side of his vast body is always coming towards earth, and the other side is always going away from earth. The spectroscopic method of measuring distant motions was tried upon the two sides of the sun by Young, Vogel, Dunér, Langley, and others; and it was tried with complete success. Here again the results agreed with what was already known. The spectroscope was found, by means of the delicately-shifted lines, to speak with perfect truth of the two movements,—telling correctly about the side which was whirling away, and about the side which was whirling towards us, both as to direction and as to speed.

It is not difficult to understand that a mode of measurement, which is found to be entirely reliable in those cases where other modes exist of measuring and of proving or disproving, may be confidently looked upon as dependable in those cases when it alone has to be trusted.

PART III

THE STELLAR UNIVERSE

CHAPTER XXVIII

HOW MANY STARS?

HOW many stars are there in the sky?

This question makes another needful, before an answer can be so much as attempted. What do we mean by 'The Sky?'

Do we mean merely the visible firmament, blue by day, and blue-black by night, in which a certain limited number of stars are seen, more or less, by all of us, to shine and twinkle?

Or do we mean the whole vast extent of SPACE, which includes our earth and all the planets, our sun and all the stars, our Starry System and all other Starry Universes,—which may reach away and away to inconceivable distances, more remote than the most powerful telescope can grasp, farther than the most vivid imagination can compass? For whatever the human imagination is capable of, it cannot picture one thing, and that is the end or boundary of Space. It cannot realise Nothingness. Therefore, Space must extend outside the boundary-lines of imagination.

If the first meaning be that which is intended, then an answer is not difficult. If the second then to the question of, How many stars? no reply, no conjecture even, worth anything, is possible.

If, however, the question is put with respect to any and all such stars as may come, no matter how dimly, within the reach of man's powers, then some manner of answer may be obtained. Within the reach of man's *powers;* not merely within the range of his sight.

Unaided, we do not see any great number of stars. Although to our sight those twinkling points may seem to be uncountable, this is to some extent a delusion. The stars of the Universe are uncountable, but the stars visible to ordinary sight have been counted; and it is said that, in a general way, not more than perhaps two or three thousand are ever actually perceived at one time; seldom so many.

This statement has to be accepted with reservation. Eyesight differs very greatly in different people; and the conditions of our earth's atmosphere vary enormously at different periods of the year; still more in different countries of the world. In the clear skies of southern Europe many more stars are visible than can usually be seen in England, even under favourable conditions. Yet in England cases of exceptional vision are found. To perceive the moons of Jupiter with the naked eye is not an unique experience; and any man who should be capable of this, would, of course, see also a large number of stars, commonly counted telescopic, and quite beyond the range of ordinary sight.

Putting aside extraordinary instances, the number of stars visible to unaided vision is, as above said, by no means so large as one would imagine. But get an opera-glass or a small telescope, and a rapid spring is at once made to higher numbers, which numbers increase with each successive increase of telescopic power. A telescope, having a glass not more than two inches and a half in diameter, opens out a vast field of no less than about 650,000 stars all round the world.

Six hundred and fifty thousand; and of this multitude only some five or six thousand commonly visible!

But the remaining six hundred and forty odd thousand send to us through space their infinitesimal gleams of light. Although the naked eye cannot perceive the faintest glimmer of one of those stars, yet it is reckoned that the collected shining of them all together actually sheds *three times* as much light into our sky as the light given all together by stars of the higher magnitudes, which we are able to see.

So when we look on a bright star-lit sky, not all the light there flows from the twinkling points visible to us; but a large proportion of it comes from an unseen host of radiant suns, too far distant for human eyes, unaided, to make them out. Only, all the time there they are; and all the time there shines their light,—a soft wide-spread sphere of star-gleams, extending away from each, through millions upon millions of miles of space.

The amount of light which reaches us, as a whole, from any particular class of stars, depends on two things. It depends partly on their individual brilliance; and partly on their numbers.

Individually, any one star of the first magnitude very greatly outshines any one star of the second magnitude. Yet the second class contains so many more stars than the first, that their *collective* brightness is actually more, actually greater, than the collective brightness of all the first magnitude stars put together, including the radiant Sirius.

In the same manner, the whole collected light of the more dim third-class stars exceeds the whole light of the second-class stars; the fourth magnitude stars outshine in their aggregate the third class; the fifth outshine the fourth; and so on continuously, till, as we have just seen, the whole mass of over 600,000 telescopic stars of succeeding magnitudes absolutely outshines the whole mass of stars visible to the naked eye.

Therefore, dim as our star-lit midnight sky is at its best, for practical purposes, when sun and moon are absent, it would be yet more dim, but for the invisible light-givers of the Universe.

Not that we can for a moment suppose those myriads of distant suns to have been made, simply for the purpose of sending that faint glimmer earthward! If this alone were the object of their existence, one might naturally ask, 'Why not have had another moon or two near at hand, to accomplish the same work so much more effectually?'

A telescope of only two-and-a-half inches diameter is small compared with the vast tubes which of late years have been pointed to the skies, to search out mysteries in Space.

Wider and wider fields are ever opening before the human gaze. Vaster and vaster Universe depths are ever being sought into. And still, boundless fields beyond, unfathomable depths below, reward the utmost efforts of which man is capable.

Many different computations have been made, from time to time, as to the probable number of stars, bright and dim, near and distant, which may lie within the grasp of the most powerful telescope yet made. The sum of some sixty or seventy millions seems at present to be a moderate reckoning.

Only, this is not a full answer to the question with which we started. For it was not simply—'How many stars lie within reach of man's *sight?*'—but 'How many stars lie within reach of man's *powers?*'

His powers of stellar research extend beyond all limits of mere vision. There are stars in the sky, so distant that the most huge object-glass ever constructed cannot catch enough of their feeble glimmer, to impress their image on the human eye. No man has seen those stars from this world; perhaps no man, looking from this world, ever will see a great many of them. And yet those very stars are known to astronomers; and the positions of many of them are marked upon the celestial map.

You do not need to ask how this can be. You already know that the weak shining, which cannot make itself felt by the retina of a man's eye, *can* slowly impress its image on the photographic plate. Hundreds of stars, thousands of stars, utterly invisible to man, have had their photographs taken, as truly as you have had your photograph taken; only, it has been a longer business.

To realise, in some degree, what the immensity of the Universe must be, one has but to look at a photograph of some portion of the sky, more especially of the Milky Way, after long exposure; and to compare it with what can be seen by the unaided eye. Such a photograph may be found on the opposite page of a space in the sky, where the naked eye can detect perhaps some six or seven stars. See what an enormous mass of distant suns, and of hazy matter, is disclosed after eleven hours' exposure of the photographic plate,—all this utterly invisible to man, without the assistance of photography.

If the stars which are known and which can be known through photography alone, are added to the list of those known through telescopy, the num-

FROM A PHOTOGRAPH OF A PART OF THE SKY WHERE ONLY SIX OR SEVEN STARS CAN BE SEEN BY THE NAKED EYE.

bers again rise fast. According to one supposition, the total of one hundred millions may be fairly given; according to another, two hundred millions may be well within the mark.

And even this vast mass may still be, for aught that we know to the contrary, as a mere corner in the Universe.

When we shrink from the thought of such immensity, with a sense that our concerns must surely be too infinitesimal by comparison to claim the smallest share of DIVINE attention and care, we may turn for comfort to familiar words,—

'*The very hairs of your head are all numbered!*' and,—

> 'Thou art as much HIS care, as if beside
> Nor man nor angel lived in heaven or earth;
> Thus sunbeams pour alike their glorious tide,
> To light up worlds, or wake an insect's mirth.'

CHAPTER XXIX

ABOUT THE NEBULÆ

OUR view of the Universe by this time has extraordinarily widened since the days of Hipparchus, of Ptolemy, of Copernicus, of Galileo, even of Newton.

At least sixty million Stars, scattered over the length and breadth of our heavens, all around the whole earth, scattered singly and in pairs, in triplets and quartettes, in clusters, streams, and spirals! And among that multitudinous host of radiant suns some eleven or twelve thousand Nebulæ.

To this has Modern Astronomy brought us. Those unseen millions constitute the more distant scenery of the skies, outspread night by night for our inspection. And each star-group, each star-cluster, each individual star, each particular nebula, of all the vast array, has its own characteristics, its own spectrum, its own separate claims on our attention.

One may generalise with the stars of heaven, as one may generalise with the flowers of earth. But no two stars, no two nebulæ, are ever alike, any more than on earth two blades of grass or two leaves are ever exactly similar.

Also, one may classify the stars, as one may classify plants on earth. But just as plants refuse strict classification, and glide by gentle stages from one kind into another, so the stars and the nebulæ refuse to conform to hard and fast rules, and glide from one class into the next by imperceptible gradations.

Although one or two of the nebulæ can be faintly seen as a hazy spot, by the naked eye, with very good sight, yet as a whole they are a discovery of modern times. For a long while they remained a complete mystery to astronomers.

They are all so dim and vague, they are all so very far away, that mere eye-observations, however careful, were sorely at fault.

Larger telescopes did, indeed, open out some faint nebulæ, little white patches of cloudiness, into patches of minute collected star-points, or, more often, into only a more distinct patch of whiteness, dotted with star-points. But many others refused entirely to be so 'resolved.' Whether this were due to the nature of the nebulæ themselves, or due only to their exceeding distance, nobody could say.

Exceedingly distant no doubt they are; far too distant, it appears, to fall within reach of the measuring-line, parallax, through which the distances of a good many stars have been, more or less roughly, found out. Thus far, the nebulæ elude all such attempts, though made with the most delicate of instruments.

The Nebula in Andromeda is faintly visible, without telescopic aid, on a clear night; and some people are also able to make out the Great Nebula in Orion, when they know where to look for it But the dimness of even these two brightest nebulæ may be judged from the fact that, through early ages of Astronomy, they were never detected at all. Or if seen, they were doubtless supposed to be merely a shadowy cluster of stars, hardly deserving particular attention.

It may be that the whole Milky Way, to us a broad band of light encircling the sky, might appear as just such another small nebula, if viewed by a watcher, with eyesight like ours, at a distance of one of those nebulæ.

The Nebulæ have been described as 'faint cloudy spots or stains of light, on the dark background of the sky;'* and again as 'faintly-shining bodies,—shreds and balls of cloudy stuff;'† They shine as stars shine, by their own intrinsic light; not as planets shine, by light borrowed from another source. We know the nebulæ, as we know the stars, simply and

* Sir R. Ball. † Professor Young.

solely through the tiny glimmer of light, which has travelled to us, pulsating and quivering, through millions upon millions of miles of space.

Among the few thousands known to astronomers are found nebulæ of every imaginable shape—ring-shaped, fan-shaped, planet-shaped, comet-shaped, spiral-shaped; almost any kind of shape that you like to picture to yourself.

But it must be always remembered that these shapes are only *as they seem to us*, seen from this immense distance.

If we could halve that distance, or if we could approach one of the nebulæ from a different side, its shape would very likely in many cases be quite different. You know how different a large building looks—a castle, or a palace—if seen from ten miles off, and from two miles off; still more, if seen first from the north and then from the south.

Thus the peculiar whirlpool-like appearance of many nebulæ *might* not outlast a nearer inspection, or an inspection from some other direction; while, on the other hand, it *may* as truly show the whirling movement of that huge distant mass, as the very same appearance in a river shows a little circling whirlpool of water.

Though the nebulæ as seen by us are so small, some of them are known to reach through vast distances. For example, the one in Andromeda, which is just visible without a telescope, is believed to fill a space in the heavens, many thousands of times larger than the whole orbit of Neptune.

Neptune is the outermost planet of the Solar System; and so far as we know, not a single member of the sun's family has a wider orbit than Neptune, if we except some of the comets. Therefore, the great pathway of Neptune encloses almost the entire Solar System. Yet that pathway and all that it includes is believed to be as nothing, in point of size, compared with the much vaster size of this Nebula in Andromeda.

Another enormous object of the same description is the Nebula in Orion. To the naked eye, when seen at all, it is a mere dim spot; but when seen through telescopes it grows and widens marvellously. Still more are its complicated details brought out by photography.

For a long while, in pre-spectroscopic times, it was known as only a dim ghost-like apparition; soft and vague in its outlines.

Then the great Rosse telescope was turned upon it, and countless minute starry points became visible, never detected before. This surely proved that the immense nebula was, after all, merely a huge star-cluster, at an immeasurable distance, needing only stronger magnifying power to resolve the whole into a congeries of suns.

So said and so thought many observers. But they reasoned still in the dark. The spectroscope had not yet stepped in, to declare the true nature of the distant nebula.

In 1864 Dr Huggins brought various nebulæ, including that of Orion, under the test of the spectroscope. Their slender rays, when analysed—that is, broken up or disintegrated, through the action of the prism—cast each *three bright lines*, sharp and clear, upon a relatively dark background.

This discovery may be reckoned as an epoch in the history of Astronomy.

They were not *dark* lines upon a spectrum of many-hued colour-bands—commonly called 'a banded spectrum'—like the spectrum of the sun, and the spectra of many stars. They were *bright* lines, with no distinct underlying colour-bands. There was one unmistakable line of hydrogen; and there were two others, not yet identified, but certainly of some kind of glowing gases. These bright lines clearly did not come from a body even so nearly in the solid condition as our sun and as most of our stars.

In brief, the nebula in Orion, and several other nebulæ which were examined at the same time, most plainly declared themselves to be of thin diffuse gases, shining with the intensity of their own heat.

'These nebulæ are shown by the prism to be enormous gaseous systems,' wrote Dr Huggins. The sentence is pregnant with meaning, if we trouble ourselves to think what is wrapped up in that expression 'shown by the prism.'

That a small piece of glass, cut into a particular shape, should be able to speak to us, with unerring certainty, of the make of heavenly bodies countless billions of miles away, is one of the greatest marvels of our age. Wonderful in itself,—more wonderful still in the fact that man can have searched out such a mode of translating light-glimmers into speech and knowledge.

Picture to yourself the actual condition of things. Here are we upon earth—our earth being one of the smaller worlds in our sub-system of the vast Starry Universe,—we, like little ants creeping on their ant-hill, or, more strictly, like tiny insects at the bottom of their pond, creep below a profound Ocean of Air, bound fast prisoners there by ties of gravity, having only one single sense or outlet, by means of which we can be aware of the existence of other worlds and stars. Yet though so small, so limited, so hampered,—that, by the force of God-given intellect, we should have pierced the secrets of the distances of Space, so far as to be able to say what this star or that nebula is actually made of,—surely it is very wonderful, very extraordinary!

Certainly, there is an opposite side to the same question. Much as we know, the unknown 'beyond' reduces that 'much' to almost nothing by comparison. Things are still as in the days of Newton, still as that great intellect felt and humbly acknowledged. We are but as little children beside a boundless ocean, picking up a pebble here and there. For us to dogmatise one-tenth of an inch beyond what we know is worse than folly. We know a little ; we are in blank ignorance of the immeasurable depths extending in all directions outward from the small limits of our learning.

The tiny insect, creeping along the pond bottom, might quite as sensibly try to explain, by the light of his puny wisdom, the whole plan, control, and management of the British Empire, as a man, at the bottom of his little ocean, attempt to grasp with his puny intellect the Divine mystery of Creation—the whole plan and control of even one Universe such as ours.

Not that he cannot gain some glimmering idea of that plan,—some faint light through the dimness of mystery. This is possible to him, because of the 'likeness' in which he was 'made.'

Absolute comprehension is another matter. Yet, despite the very much that we do not know, the comparatively very little that we do know, that little, as found out by man himself, is in its kind and in its amount very marvellous.

CHAPTER XXX

MANY UNIVERSES

DR HUGGINS found a good deal of difference in the tale which was whispered by the prism concerning various Nebulæ. All were by no means exactly alike in their make.

Some, as already stated, showed only three bright gaseous lines on a relatively dark background. Others gave a continuous spectrum of bright bands, crossed by brighter parts. Not a continous spectrum, crossed by dark lines, like the sun and many of the stars, and not bright lines alone, like some of the nebulæ, but a kind of mixture of the two, partly like the one and partly like the other,—a sort of half-way stage between the two extremes. Of this description, the Nebula in Andromeda may be taken as a good specimen.

The nature of such nebulæ has still to be worked out. It may be that they are actually in a half-way stage of development, actually half-way between gaseous nebulæ and fully-formed stars. It certainly would appear that they are in a more advanced stage of growth—if one may use that word—than those which give a spectrum of bright lines mainly ; and in a less advanced stage of growth than the stars which give a banded spectrum, crossed by dark lines.

In other words, it may be that such nebulæ are simply on the high road from being a nebula to becoming a star.

For, indeed, it appears to us that growth and development are at work in the far distances of Space, no less than on our little earth. Just as here the acorn grows into the oak, so there, if we rightly judge, the nebula grows into the star. Only the one growth is small and rapid and near at hand, the other is vast and slow and enormously far away.

Enormously far from our Solar System,—that is certain, speaking of the nebulæ. One may say positively that none of those with which we are acquainted is near, even in the sense in which some few stars may be termed comparatively near. If any do lie nearer in the heavens, they are too small or too dim to be perceived from earth.

Whether the majority of nebulæ belong to our Stellar System, or whether they—some or any of them—lie altogether outside of and apart from our Stellar System, has been a question much debated. To some extent it is a question which must remain unanswered. Probabilities may be stated; certainty is not possible.

The question is, perhaps, in itself not a very important one. That other starry systems—other

Universes—do exist outside of and away from our own particular Universe, is a matter hardly to be doubted by any who at all realise the immensity of Space. How far our Stellar System reaches, and how much it includes, we have no power to determine. Even conjecture is at fault here. We only know that the distances which it embraces are enormous, past calculation. Yet we cannot believe the system to be infinite in extent; and if it is not infinite, it has limits, it has boundaries, it is surrounded by a Beyond.

Every glimmer of star or of nebula which comes to us, whether seen by the eye or impressed upon the photographic plate, *may* arrive from within the bounds of this particular System; every single glimmer, without exception. This is the view taken by some astronomers. Or, on the other hand, while the great majority of light-gleams thus belong to our Starry System, one feeble gleam here and there *may* reach us from untold distances, from far beyond its outermost bounds. This, again, is the view held by other astronomers.

In either case, whichever be the truth, it is equally marvellous,—whether our Stellar System extends as far as the very uttermost limits of human powers to discern, or whether its boundary is less, and we do really get occasional dim glimpses of outer Systems, perhaps equally enormous and inconceivably remote.

The matter hinges upon two questions,—First, Whether the limits of our Universe are more or less extensive?—Second, Whether light could by any possibility reach us from outer Universes, at their probably immense distances from ours?

Certain general rules of proportion, more or less understandable by us, are frequently seen in the Universe. If we reason outward, from what we know to what we do not know, some idea may be occasionally formed of things which we cannot yet discover. As you have seen in earlier chapters, many a great truth has been stumbled on thus, grasped dimly by some thoughtful mind, having then to wait long for actual proof and establishment.

Some reasoning outward is possible here. We know the proportions of our own Solar System; and we know the distances of the nearer stars, together with the breadth of the vast gap between. If we take as a model the Solar System and its surrounding void, it is possible to reckon roughly, allowing for the enormously greater size of the Stellar System, what should be the *proportionate* gap of emptiness between it and other kindred Universes scattered through the stupendous distances of Space.

Can you imagine it yourself? Can you picture our little Solar System as a mere speck, with a broad band of emptiness around; and then the mighty Stellar System, itself only one among countless Stellar Systems, each divided from the rest by gaps unutterable in depth and reach?

There is nothing about this impossible or inconceivable. He Who made one world could make any number of worlds; He Who formed one sun could form a billion suns; He Who created one universe could with equal ease create ten thousand universes.

But whether we on our little earth can ever catch the faintest glimpse of those outer Universes depends on two or three different things. It depends partly on the strength of our own eyesight. It depends on whether light, travelling to enormous distances, does or does not suffer extinction. It depends also on one crucial question,—whether the luminiferous ether which we believe to fill our Universe does or does not fill all outside Space?

It might do so; but why should it? Quite conceivably it may thin out and gradually cease, in the tremendous abyss which encircles our Starry System, even as the atmosphere around our earth gradually thins out and ceases.

If this be the case, then no light-gleams from any outer universe, from any outer star or nebula, could by any possibility reach our eyes or impress itself upon a photographic plate; for there would then be no medium to carry the light-gleams. There would be no ether, and consequently no ether-waves, in the profound dividing gaps. And then, *all* heavenly bodies perceived from earth would inevitably belong to our own Stellar Universe.

Light-rays cannot cross an absolute vacuum, a perfect emptiness. The very essence of light, so far as we know it, is that it consists of tiny waves or undulations of ether,—just as the essence of sound is that it consists of waves or undulations of air. Where no air is, sound cannot travel, cannot exist. Where no subtle ether is, light cannot travel, cannot exist.

Mr Gore, after coming to the conclusion that, even if ether does exist throughout the vast dividing spaces between our Universe and other probable Universes, their light would still be unseen by us, because of immensity of distance, continues thus :—

'We are not, however, precluded by this hypothesis from supposing that numerous similar systems exist in external space ; and although we must consider the number of *visible* stars as strictly finite, the number of stars and systems really existing, but invisible to us, may be practically infinite. Could we speed our flight through space on angel wings beyond the confines of our limited Universe to a distance so great that the interval which separates us from the remotest fixed star visible in our largest telescopes might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision? Systems of a higher order might there be unfolded to our view, compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore,—Systems, perhaps, stretching out to infinity before us, and reaching at last the glorious "mansions" of the Almighty, the Throne of the Eternal.' *

Things may be as above suggested. It may be that our whole Stellar System is isolated in the midst of unlighted Space, divided utterly from all other Universes by the absence of light-conveying ether; and that, consequently, we never see the faintest gleam of light from anywhere outside our Universe. It *may* be so; but here I speak of possibilities only, not of known and proved truths. The limits of certainties have greatly widened; still there is always a broad border-land of uncertainty beyond; and these questions lie in the dim light of that uncertain border-land. We can say what is possible, what is even probable; but we cannot say that we *know*.

However, you can be quite sure of, at least, this—that some of the nebulæ, most likely by far the greater number of them, are undoubtedly within the confines of our Universe, and as much a part of it as the stars are part of it. In fact, we believe that the nebulæ are only stars or star-clusters at an earlier period of their existence.

Conjecture, again, you will say. Perfectly true. But, as you heard in earlier chapters, conjecture is the mode by which most frequently advance is made. We have to feel our way onward in an unknown and unfamiliar country. To treat conjecture as reality is

* *Visible Universe*, by J. E. Gore, F.R.A.S.

wrong; but to fling aside all conjectures as worthless is also wrong. We should take each one for what it may be worth; weigh it well; consider it; hold our judgment in abeyance; and wait patiently for fuller proof or disproof. One or the other is sure in time to come. No need to be in a hurry to make up our minds.

CHAPTER XXXI

THE GARDEN OF THE SKIES

THE theory of Development among heavenly bodies, now held by the great majority of Astronomers, is not new. Nor, indeed, was it first suggested by Astronomers. It seems to have occurred to several different minds independently. The keen intellect of William Herschel caught clear glimpses of it through his observations, in days when the wonderful revelations of the spectroscope lay beyond men's wildest dreams.

In Herschel's view, the heavens were as a piece of ground, wherein might be found all stages of growth from the seed just sown to the aged and dying plant or tree. He saw that nebulæ might probably be unformed suns or sun-systems; gradually as ages passed to take shape, and grow, and alter.

The theory has much advanced since his days, being worked out and elaborated, and receiving a very large amount of support from newer observations and discoveries. Yet a 'theory' it may still be called; since ages must pass before the changes among heavenly bodies can be actually verified through watching.

We are much in the same position with regard to the heavens, that an ephemeris or mayfly would be in, with respect to a fair summer garden.

The mayfly, a creature of a day, comes into the garden and sees plants at various stages of growth—seeds just sprouting, tiny plantlets just growing, older plants full of flower, young saplings, vigorous trees, and aged dying trunks.

If the mayfly had such powers of thought and observation as man possesses, he too might reason from the seen to the unseen. He too might note plants and trees in their divers stages of growth; might compare the young with the old; might even, with close watching, detect the minute change which takes place in a single summer's day, the opening wider of a leaf, the bursting of a bud into bloom. And from these things he might draw wise deductions as to the growing and developing of the whole garden; as to the manner in which each young plantlet would in time become full-sized, then would grow old and die. Or, in the reverse fashion, looking at some aged tree, he might conjecture how it had once, in all probability, been a young sapling, and even a tiny plantlet. No doubt, in his conjecturing, he would make some odd blunders, and imagine certain processes, certain changes, wide of the truth. Yet on the whole, one can fancy his arriving at a fairly just notion of the general state of the case.

The mayfly could not *see* all this—could not test and prove for himself the worth of his conjectures. He could only note a few minute alterations in the plants around; alterations suggestive of the possibility of others. Then his little life would end, leaving the theory or hypothesis unproved.

We are in a like condition in the great Garden of the Skies. We see there suns in apparently every variety of growth; incipient suns, half-formed suns, radiant suns, fading suns; but the actual process of change and development, which we believe to take place, we cannot possibly see. And the reason is, that our lives are too short, too 'ephemeral.' Changes visible in the course of the longest life of a man on earth are so very slight, so very small, that they can scarcely be detected, and can hardly be reckoned on. We think we just manage to see one or two, perhaps; and then we conjecture a cause or an explanation; and then our little lives end, and the theory is not proved.

But we are able to do what a mayfly could not do. We are able to hand on our knowledge from generation to generation; and what one man has not time to observe, many successive men *can* observe; and so, in the course of generations, each conjecture or explanation is tested.

This theory too will be fully tested; but, necessarily, it will take a long time.

In an earlier chapter mention was made of different classes of suns—White Stars, Yellow Stars, Red Stars, and so on.

It seems exceedingly probable that these varying colours show different stages in the life of a star; representing youth, middle age, and old age. The white stars may be the younger and the least developed; the yellow or solar stars may be considerably more developed; the red stars may be older still, and nearer to becoming dark suns or cooled worlds.

When 'age' among stars is spoken of, it is more a matter of condition than of length of existence.

For example, our world is not counted so *old* a heavenly body as the moon. The two might actually have come into existence at the same period; but this would not affect the question. The moon, being the smaller, has cooled and shrunk and solidified more quickly, and therefore is practically more aged, than the much larger earth. Our sun is very young compared with both earth and moon; yet he must have existed quite as long as they have. He is only at an earlier *stage* of star-life. This is what we mean, commonly, when we talk of the different ages of different stars.

Sirius, apparently, is a good deal younger than our sun; not much heavier, but very much brighter, which probably means immensely larger, and that, with comparatively light weight, means that he must be very much more diffuse in weight, very much less cooled than even our blazing sun. The case of Sirius, therefore, tells strongly in favour of the view that white stars are younger than yellow or red stars.

Evidence in the same direction is given by the nature of the ultra-violet series of hydrogen lines, discovered by Dr Huggins in the spectra of various stars; and also by the varying behaviour of two magnesium lines in different star-spectra, as observed by Dr Sheiner at Potsdam in photographs taken by him. But any complete statement of the arguments in favour of white stars being younger than red stars is too complex for these pages.

If the above theory be right, we should expect to find white stars generally more light and diffuse in make than yellow stars; and also it would not surprise us to find most of the red stars comparatively small in size,—small, because greater age means greater coolness, and a cooler body is always a smaller body than it would be when heated.

Some astronomers, indeed, are inclined to take an opposite view, supposing that the red stars are the youngest, and that they become white as they grow older. It has also been suggested that stars start in their career as red suns, become yellow and then white, and then again return to yellow and to red, going through a double cycle of changes.

In any case, it must not be imagined that the same rule is strictly followed out by all stars. Whatever theory may be adopted as most probable, countless exceptions will be found.

Also, when 'classes' are spoken of, we have not to think of all stars as divided sharply into separate classes, like the children in a school. The gradations between class and class are very gentle. One class seems to slide softly into the next. They are separated by indefinite belts of grass, not by hard stone walls. So it is often difficult to say exactly where one ends and where another begins.

The same thing is found on earth. There are animals, and there are vegetables; but when men try to classify the two, a puzzling borderland is reached, where creatures are discovered which may be either animal or vegetable, seeming to partake of the nature of both. Here, again, the one class slides gradually into the other, instead of being sharply cut off from it, as by stone walls.

As in the Animal and Vegetable Kingdoms, so is it also in the universe of heavenly bodies. Class glides gently into class. From an absolute nebula to an absolute sun, the gradations are everywhere continuous, never abrupt.

The mayfly must have found this in his summer garden. Suppose he had tried to classify the various stages of vegetable life, ranking them as Seeds, Young Plants, Fully-grown Plants, Flowering Plants, Aged Plants, and so on; he would soon have found his attempts at classification baffled by the difficulty of deciding to which of the said classes certain specimens should belong.

In the Garden of the Skies we are confronted by the same difficulty. Nebulæ and Stars, Half-nebulæ and Half-stars, are there in every imaginable variety, in apparently every imaginable stage of development, from the vaguest of nebulæ up to the most decisive of suns, the most highly-developed of solar systems or of star-clusters.

Though we cannot yet absolutely declare that the one kind is a perfected specimen of the other kind, it seems, to say the least, more than probable.

Let us try to picture to ourselves the manner of development through which a Nebula may grow into a Sun.

For this you must put aside the thought of a nebula as it is seen from earth,—a mere dim hazy patch in the sky. Think of it, instead, as an enormous mass of thin radiant gas, heated to brightness; whirling steadily about its centre; doubtless, also, travelling steadily onward through Space, as the stars travel, though whence coming and whither going no one on earth can say.

Two forces govern the whirling mass of gas, which spreads far and wide, perhaps filling a space in the heavens large enough to contain hundreds or even thousands of Solar Systems, each one as extensive as our own.

First, there is the force of gravity, by which every single atom of the gas attracts every other atom, and which, if the total mass is great enough, keeps the whole from flying off into distant space. Gravity, in fact, binds the mass into a single body, though it be a very light and hazy body.

Why should it be light and hazy—not solid? Why do not all the particles of gas fly into a closer and closer embrace?

Because there is, secondly, the force of resistance to gravity, due to the rapid motion of the molecules of gas; which rapid motion is due to heat. Each hurrying particle of hot gas is perpetually striving to rush onward and outward, away from the mass of its fellows.

It is, in fact, a conflict between gravitation and heat; and the question in such a case is, Which of the two forces will prove victorious? The pull together of gravity?—or the repulsive rush apart of the colliding molecules? The greater the heat the quicker the motion, and the stronger in consequence is this disruptive rush apart of the gas-molecules—each rebounding after impact. We see the same even in a little body of heated steam on earth, when it is confined in a vessel. With increasing heat the particles of steam move more furiously, cannonade the walls of the confining vessel more fiercely, and at length, if not able to escape otherwise, they burst those walls asunder.

A mass of gas out in Space has no confining vessel-walls; but the same part is performed for it—if the mass be large enough—by the pull of gravity, drawing all particles toward the centre. But for the rapid molecular motion, caused by heat and increased by greater heat, the particles would all rush speedily into a close and fixed embrace.

An analogy may be seen in the Solar System. If all the planets were not attracted by the sun and by one another, they would wander far away, each one apart, into the cold and darkness of outer space. If, by the outward drag of their steady rush, they did not effectually resist the inward drag of that attraction, they would all fall down upon the sun; and the Solar System as such would exist no longer.

So we find a similar set of forces or laws governing the Universe, throughout its measureless expanse. In earlier chapters we saw how men gradually felt their way upward to this knowledge.

Worlds appear to be subject to the same manner of control as the tiny particles of a mass of gas; and the Suns of the enormous Stellar System appear to bow to the same manner of control as the little worlds of the comparatively small Solar System. The Divine government of material things seems to be similar in kind, at all events through the length and breadth of our Universe, and probably so far as Matter reaches.

In the history of a nebula, gravitation proves the stronger force, becoming in the end victorious. Certainly it has been so in all such nebulæ as we see to be nebulæ. If in any mass of gas the outward-flying force, induced by intensity of heat and consequent rapidity of motion, were stronger than the inward-drawing force of gravity, the whole would be gradually dissipated into space; and the nebula would exist no longer. Should this ever occur, we have no means of knowing the fact. Perhaps with large gas-masses it never does occur; for gravity is a constant force, unvarying in strength, while heat slowly pays itself away and loses power; therefore, gravity seems, in the long run, and under suitable conditions, likely to prove conqueror, however lengthy the contest may be.

With the particular nebula which we are picturing, you—should shut your eyes and get away into Space and *see* it!—gravitation has the best of the matter. Slowly the central parts draw closer together, either into only one vast mass, or into more masses than one. As it contracts, lesser masses may perhaps from time to time be thrown off from the central mass as whirling rings, or more probably as lumps of matter; and these rings or lumps, gradually concentrating into closer masses, travel round and round the central mass.

In each separate mass, whether large or small, the heavier materials will naturally, though very slowly, find their way first to the centre; and lighter materials, notably hydrogen, will tend rather to remain outside.

Through ages, this gradual drawing together may continue, until at length a Sun begins to take definite form. Only a gaseous sun at first; a nebulous star; partly sun, partly nebula. The spectroscope tells us of many such half stars, apparently on the road between a nebula and a star.

Very gradually still, as one force becomes feebler through loss of heat, the nebulous star grows more and more dense; and, in time, the formation of a photosphere comes about. If astronomers judge rightly, the photosphere of sun or star is a mass of molten dazzling clouds, or of molten descending rain, in an atmosphere of fiery gases.

No star, which has not a radiant photosphere, is classed as a true Sun. But when at last the photosphere is formed, then a real Sun, a fully-developed Star, is there, blazing in the heavens, and sending through the little earthly prism, no longer bright gas lines on a relatively dark background, but dark lines on a spectrum of many-coloured bands.

Or, it may be, as already suggested, that the nebula does not shrink into one star alone, but into several bodies; the largest in the centre, the smaller ones revolving around it.

At first, they are all suns large or small; all bright; all hot; each having its own photosphere of radiant clouds.

Then, in time, those fiercely-glowing clouds begin to cool; and through long ages of parting with their heat, it may be that some of those *suns* are on their way to becoming *worlds*.

How long a star remains a star, no man can say. It depends mainly on the size of the star in question. A large body is always much slower in cooling than a small body. We see this, even on earth, with a large and a small lump of metal.

Many guesses have been made, and some calculations have been attempted, as to how many millions of years our sun can be expected to keep up his heat and brightness. But all we can venture to say with any confidence is that, sooner or later, in the course of ages, the sun will surely cool down, as his planets have cooled and are still cooling.

Slowly, very slowly, yet surely, his radiance must become dim, and he will subside into the semi-liquid but no longer fiery condition of Jupiter and Saturn. Later still, he will cool, as they also must cool, to a solid state, like that of our earth at the present moment.

CHAPTER XXXII

GROWTH IN THAT GARDEN

THUS the order of growth in the Garden of the Skies would appear to be very much as follows :—

First, the nebula stage; a mass of glowing and rotating gases held together by gravity. This, of course, is not really the first stage; and science has imagined an earlier period, when thin gases were perhaps diffused everywhere through Space, drawing later together, under the influence of gravity, into distinct masses. But this only puts the mystery a step farther back. How the gas came to be there at all; above all, how its particles were first imbued with their wonderful properties of gravity and momentum,—these are questions at present beyond our depth. We only know that GOD 'spake, and it was done.'

Secondly, the stage of nebulous sun, of gaseous star, of half-nebula, half-sun. Or, it may be, the stage of a partly-formed System or Cluster; many star-points appearing in a nebulous mass.

Thirdly, the stage of a fully-formed sun with radiant photosphere. Or, it may be, the stage of several suns which have been developed out of one nebula. This long-lasting stage includes divers sub-divisions of varying changes, of different cloud and atmosphere conditions.

Fourthly, another half-way stage of greatly-heated bodies; no longer suns, because they no longer glow with intrinsic heat; yet still too hot to deserve properly the name of 'worlds,' and in a state of acute atmospheric turmoil; all oceans floating as hot steam in the atmosphere.

Fifthly, a warm world still, but cooled down from the boiling and tumultuous stage. The oceans at last lie as water in their beds, though as warm water. This would be a stage of great geological change and development.

Sixthly, a cooled world, such as ours; perhaps in time prepared for being inhabited by some kinds of living creatures.

To certain minds this idea of the gradual development of heavenly bodies is somewhat startling. Yet why should it be so?

Everywhere in our world we see the Divine power working gradually, step by step. It does not startle us that the wheat-ear springs from seed, the oak from an acorn; instead of both appearing in one moment ready-made. We do not expect to find ready-made fields of corn, waiting to be cut, without ever having been sown.

First the seed-sowing, then the harvest; first the blade, then the ear, after that the full corn in the ear; —this is the order to which we are accustomed. Why not in the Universe as on Earth? The same laws govern the two. Why are we to expect a harvest of Suns ready-made, with no previous time for growth and preparation, any more than a harvest of corn or a forest of oak trees? Why is not orderly development to be looked for there, even as here? The same Divine Mind has created both, and rules over both.

True, the cycles of time involved are enormous in the one case and in the other are minute. But this does not touch the gist of the question. To us there is a terrific difference between one year and a million years. With the Eternal Father a thousand years are but as one 'day'; and a million years may be to Him as a very little thing.

If He wills to form His stars and worlds slowly, by degrees and stages, as He certainly wills to make an elm tree or a water-lily,—why not? What is there in the notion to startle us?

Nay, surely, there is something more grand, more regal, more DIVINE, in the calm and steady development of an Universe, such as modern science tells us of, than in a sudden and swift creation of everything in half-a-dozen short earthly 'days,' of only twenty-four hours each, after the manner of our great-grandfathers' belief. That would have shown infinite power. This shows infinite power, no less, and an august calm of Divine patience and waiting as well.

And if the whole history of man sinks to a point by comparison with these countless ages of preparation —what then? God does not measure great and small as we measure. Our little world, which He 'so loves,' *may* be more to Him, *may* be dearer to His Heart, than all those hundred million stars and all the thousands of nebulæ.

The very words 'development' and 'evolution' have a sound of terror for many minds, as if they must of necessity mean an attack upon revealed religion. No doubt there are scientific men, here or there, as there are also non-scientific men, who would use that or aught else if they could to shake the foundations of the faith. But in itself, intrinsically, development or evolution, call it which one may, is simply a scientific theory, designed to explain provisionally certain phenomena seen in nature, whether on our little world or in the wide regions of the skies. While some eager devotees of the theory may undoubtedly push it too far, it contains, no less undoubtedly, a very large amount of truth, so far as it is founded upon actual observation. Facts seen may be accepted. Deductions drawn from those facts should be held tentatively, as possible but not yet certain truth.

It would be well if men could divest their minds of the idea that this theory, or, indeed, any other scientific theory of importance, is essentially an attack upon the fortifications of our religion. Divine Truth is strong enough to stand; and our earnest desire should be to find what is actually true in Nature as well as to possess it in Revelation.

The real question is *not*,—Did God create the stars, or did evolution produce them? That is an utterly wrong statement of the problem. The question simply is,—Did God create the stars instantaneously by the mere fiat of His Word, or did He create them, by His Word no less, but through the processes of evolution and development?

If, as time passes, the latter explanation is found to be without question true, it will not shake 'the faith once delivered.' Some of our private and pet notions on religious questions, as well as a good many private and pet notions on scientific questions, may have in time to be given up. But the TRUTH of GOD must and will remain ever untouched. If we have misunderstood aught that He may have said, the sooner we find out our mistakes the better.

It need not be supposed that the Development Theory is as yet a proved and unquestionable fact in Astronomy; such as, for instance, the precession of the equinoxes or the pathway of the moon. In the very nature of things, direct proof of its

THE NEBULA IN ANDROMEDA.

FROM A PHOTOGRAPH BY DR. ISAAC ROBERTS, F R.A.S.

truth is at present impossible. But this is the case with many matters, which, nevertheless, we have abundant reasons for believing to be true. The theory, apart from its beauty and grandeur, certainly serves to explain much that is otherwise unexplainable; and as a whole it is accepted by those who are scientifically best fitted to judge, although they may differ as to probable details.

Among other evidences in favour of it is that afforded by Dr Roberts' marvellous photograph of the great nebula in Andromeda, of which he kindly allows us to give an engraving. There development in the very act appears to lie, magnificently pictured, before our eyes; or, as Dr Huggins' expresses it, 'We seem to have presented to us some stage of cosmical evolution on a gigantic scale.' The position of this nebula has not been measured by parallax; but it is believed to lie at an immense distance, and to be of vast size. It has in the photograph a whirlpool-like aspect, suggesting a rotatory motion; and around the larger central mass are distinct rings of shining matter, separated from the main body by dark rifts or spaces. Although one may not venture to dogmatise as to what precisely may be implied by such an appearance, it certainly would seem, so far as we can decipher its probable meaning, to lend no little support to the theory of development.

We can, of course, no more *see* the changes which take place in the heavenly bodies than, as stated in the last chapter, an ephemeris can see in its tiny day the growth of trees or plants in forest or garden. To put the matter differently — we can no more see the development of a nebula into a star, or of a star into a world, in the course of a human lifetime, than we could perceive the growth of an acorn into a sapling, or of a sapling into a tree in the course of one morning's walk through a wood.

The original Nebular Hypothesis, as first definitely started by Swedenborg, Kant, Herschel, and Laplace, each having the idea separately, and as mathematically worked out by Laplace, bore reference only or chiefly to the Solar System. In the next chapter we will consider the question rather more exclusively from that point of view.

CHAPTER XXXIII

THE SHRINKING OF OUR SUN

SUPPOSE that our Solar System grew and took shape, after the mode pictured in the last chapter. Here perhaps would have been the fashion of its development.

Once upon a time the Sun must have been a mighty and far-spreading mass of glowing gases. Later, this mass would have become more dense towards the centre, through the action of gravity,—gradually taking form as an incipient sun, with still a wide-spreading nebulous atmosphere. At that time, one imagines, the sun would have appeared, if seen by a watcher in the very far distance, as a nebulous star, to which it had slowly grown from the yet earlier phase of simple nebula.

The said atmosphere would have extended at least as far as the present orbit of Neptune, perhaps very much farther; and the central body, with the whole surrounding atmosphere of gases, no doubt steadily revolved, ever turning round and round, as the sun and the planets still continue to turn.

In the huge rotating mass, as we have seen, gravitation and the outward pull of motion were both at work, and gravity had the mastery. If not, the whole mass as such must in time have ceased to exist, first growing larger and larger, as the particles separated more widely; and then being completely dissipated into space. But, on the contrary, the mass grew gradually smaller, gradually shrank in size, as its innumerable particles drew more and more closely together, under the perpetual pull of gravitation. And *this* means, through certain laws, too complicated to be explained here, that the very act of shrinking would cause quickened rotation.

This quickened rotation might have another result. It would probably mean an occasional throwing off, or breaking off, of outer rings or masses of the nebula; first one, then after awhile another, then it might be yet another, and so on, at different distances from the main body.

Each hazy nebulous ring would continue to revolve around the sun, in the *same direction* as before. But after a while the nebulous ring, in one case or another, might lose its equilibrium, and break up; and the mutual attraction of its various parts might draw the whole together into a little outer nebula, travelling still round and round the central body. This little outer nebula, cooling a great deal faster than the huge central mass, would probably develop earlier into a tiny bright sun, and then would cool further down into a world.

And still the central sun, the main part of the mass, would go on steadily shrinking, gradually growing smaller.

One writer says of this theory, that it is,—'A famous hypothesis . . . emphatically a speculation; it cannot be demonstrated by observation, or established by mathematical calculation. Yet the boldness and the splendour of the nebular theory have always given it a dignity not usually attached to a doctrine which has so little direct evidence in its favour.' *

Arguments in its favour exist in abundance; and arguments also of course in its disfavour. Two of the former may be here mentioned.

One is, that all the planets of the Solar System, and nearly all the moons, revolve in the same direction, and travel round the sun in the same direction. This seems to point to some such possible origin as the one proposed above. The same result *might* have come about in some other way, but at least it appears that such a result *could* have come about in this way.

In opposition to this argument, it should be remembered that comets do not travel in the same direction as the planets.

A second argument in favour of the theory, is that all the principal bodies of the System travel very nearly on the same plane. Here, again, we find

* *Encyclopædia Britannica.*

exceptions in the comets, and also in the smaller planets,—the ring of planetoids.

One further argument, of a different type, is with reference to the conjectured shrinking of the whole original nebula first, and the continued shrinking, later, of the sun. We believe that *the sun is still shrinking!*

It has been reckoned that in the course of each century the sun probably grows four miles less in diameter.

Four miles during one hundred years, in a body of such stupendous size, does not sound much; but in the course of ages it would mount up very considerably. Four miles in one century means forty miles in one thousand years; and four hundred miles in ten thousand years. A few millions of years would show at that rate a marked difference in the bulk of the sun.

This question of sun-shrinking, besides giving a certain amount of support to the nebular theory, is very interesting in another respect also. You may perhaps say that one theory can hardly give efficient support to another theory; but to some extent this is more than a theory. We know that the sun is parting with his heat; and we know that a cooling body does and must lessen in size as it cools. Particular calculations may be wrong in detail; but about the main fact we can perhaps hardly be mistaken.

Did you ever wonder what it is that causes sun-heat,—what it can be that keeps up that tremendous heat perpetually, century after century, thousand years after thousand years, million years after million years? We talk of 'fires' in the sun, and of 'burning' and of 'furnace glow' and so on. But these words are very inadequate to explain the reality. There is no such thing as the burning away of materials there, as we know it on earth; but there is perpetual parting with heat. The sun is incessantly pouring out enormous supplies of heat on all sides, into space; and unless there were some means whereby fresh heat is caused, he would before long cease to glow. Heat must have something to feed it, or it cannot be sustained.

It has been reckoned what amount of earthly coal would be required to support the present degree of sun-heat, supposing that coal were used by being burnt away as on earth. How much do you think? No less than twenty tons of coal every single day upon every single square foot of the whole enormous surface of the sun.

Evidently that cannot be the plan!

Others have suggested meteors. No doubt enormous quantities of meteors are ever circling round about the sun, especially in his nearer neighbourhood, and are ever falling down in countless multitudes upon his surface. But here again it has been reckoned that the largest amount conceivable would be insufficient. The meteors may have some share in the matter, but they can hardly form the main source of sun-heat.

The most satisfactory suggestion yet made seems to be that of the sun's gradual shrinkage. In other words, we believe that he still keeps up the slow lessening of size, which he has in all likelihood kept up from early stages of his existence. We believe that, as he shrank from a hazy nebula into a star, so he continues to diminish from a larger to a smaller star, and so he will continue to diminish from a heated to a cooled body, more like a world. And it is thought that such shrinking is, or may be, sufficient to account for the enormous length of time during which the sun's heat lasts.

The laws which are held to govern this contraction of the sun are singular.

First, he shrinks in size because he is cooling; and a cooler body necessarily takes up less room than a more heated body.

The act of shrinking means that all the tiny particles in the body of the sun draw just a little closer together than they were before. And this means,—what do you think? It means that the *energy* or *working-power* which has thus far held the particles farther apart must be used in some other way. It cannot die or be destroyed. Energy does not cease to exist. Under present conditions of the Universe, if energy disappears in one form it reappears in another form. If a horse does but strike his shoe against a stone, you see a spark. Why? Because the moving leg is suddenly arrested; and the energy of motion is converted into the energy of heat. Still more, the same thing is seen if a rushing cannon-ball is suddenly checked, great heat being then evolved.

Well, the energy which has served to hold the particles or molecules of gas apart disappears; at least, some of it does. It disappears in that particular form; allowing the sun-particles to creep a tiny space nearer together; and then it reappears in quite another form. It reappears as heat.

So the sun shrinks and becomes a little smaller through becoming colder; and that very act of shrinking produces more heat, whereby our little earth is warmed and kept in life.

Things might be very different without some such compensating process as described above. The sun then would doubtless cool very much faster than he does now. He does cool steadily all through the ages—so we suppose,—but it is with exceeding deliberation. For the work of cooling is constantly retarded by the very act of shrinkage causing fresh heat.

Yet, however slow the cooling may be, and however long it may last in coming ages, sooner or later the sun must become a dark globe, no longer fiery and radiant, no longer the source of heat and light to his family of worlds. The dazzling photosphere must lose its glowing brightness; and at length our sun will be a sun no longer.

How soon? That question no man can answer with the slightest certainty, or even with anything approaching to probability.

Calculations have been made allowing so much heat, so much loss of heat yearly, so much retardation of the heat, with a view of finding out about how long our sun may perhaps have been in somewhat of his present condition, and also how long his radiance may be expected still to continue. Lord Kelvin decided that about twelve millions of years was the outside which could be allowed for the past history of our sun as a sun. Thereby, his opinion was at issue with the geologists, who require a very much longer period for the working out of some of their theories. The fact is worth noting, as an instance of how little is or can be really known on such questions.

Certainly, the length of the sun's existence, if once known, would speedily settle other matters. It must, however, be understood that this theory of Sun-shrinkage, proposed by Helmholtz as a possible explanation of the continued outpour of sun-heat, is no more than a theory. We do not even know with absolute certainty whether at this particular moment the sun is growing colder or becoming hotter.

It is believed to be with the stars as with the sun. They too are suns. They too are incessantly pouring out their heat. They too are probably cooling. It may be that they too, as they have shrunk in the past from nebulæ into stars, are now still shrinking from larger to smaller stars; and that in them, too, the very act of shrinkage retards the cooling process by producing fresh heat.

However this may be, one fact seems clear, past the possibility of mistake,—that not only our little earth, not only the Solar System, but the whole vast Stellar System, the Universe of Stars, so far as we can know anything about it, is a changing fleeting dying Universe. Nothing there can in its present condition last for ever. All is evanescent; all is passing away. Heated bodies are losing their heat; young suns are becoming old; bright bodies are growing dark; and on all sides is found a steady onward progression towards an inevitable end.

> 'I marked those ancient clusters one by one,
> The same that blessed our old forefathers' sight.
> For God alone is older,—none but He
> Can charge the stars with mutability.'

So writes the poet.* But man in these days—man on his little earth, out of his ephemeral earthly life, can venture so to charge the very stars, in the light of modern science, with mutability. Read the following remarkable words:—

'One lesson seems to stand out clearly,—that the present system of stars and worlds is not an eternal

* Jean Inglelow.

one! We have before us irrefragable evidence of continuous uncompensated progress, inexorable in one direction. The hot bodies are losing their heat, and distributing it to the cold ones, so that there is a steady unremitting tendency towards an uniform (and therefore useless) temperature throughout the Universe. . . . To use the technical language now usually employed, energy is unceasingly "dissipated" by the processes which maintain the present life of the Universe; and this dissipation of energy can have but one ultimate result,—that of absolute stagnation when a uniform temperature has been everywhere attained. If we carry our imagination backwards, we reach at last a 'beginning of things,' which has no intelligible antecedent; if forwards, an end of things in stagnation. That by some process or other, this end of things will result in 'new heavens and a new earth' we can hardly doubt; but science has as yet no word of explanation.' *

* *General Astronomy*, by Professor Young.

CHAPTER XXXIV

KINGDOMS AND REPUBLICS IN THE SKY

COMPARED with the Stellar System, our Solar System is a simple arrangement. There is the great central controlling power; and there are the many small obedient worlds. Each lesser body is held firmly in by bonds of gravity; and each world, travelling at a certain rate of speed, resists that inward-drawing power sufficiently to remain at a particular distance from the sun.

True, the solar attraction is not the only attraction. Mutual gravity exists throughout the entire system. As the sun attracts the planets, so the planets attract the sun; each one with a strength proportioned to its mass or weight, and also to its distance from the sun. The united pull of all the planets together is, however, so weak by comparison with the sun's attraction for them, that he is scarcely affected by it.

True, also, each world attracts each other world; every planet has some power over every other planet. One world passing near another world is always hastened or retarded by the other's pull. But all these lesser attractions, again, are as nothing beside the great overmastering control of the sun.

We talk popularly of the moon going round the earth, as the earth journeys round the sun. In reality, earth and moon together journey round the sun; each as much as the other; both alike controlled by him; both alike held in firm leash by his power; while each to some extent sways the other out of a direct path. The earth being far the heavier is swayed very little; the moon being far the lighter is swayed very much. But both are alike planets; both alike are entirely subordinate to the sun.

For the sun is supreme ruler over his kingdom; a vast kingdom compared with earth; a little kingdom compared with the Universe. He is a despotic monarch in the Solar System; a very absolute sovereign over his subjects.

In the Stellar System, of which our whole Solar System is but as one tiny corner, we find a different state of things.

Our sun belongs to that Universe; he is one of its innumerable stars; but among those millions and tens of millions he is no longer supreme, no longer head and king. He ranks only as one among many; not even as one of the greater or more radiant suns. Such power of attraction as he has over other stars in the Universe, they have equally over him.

We find in that Universe no central sun of extraordinary size, controlling all the other suns. Stars of extraordinary size there are; but they do not appear to hold any such position of supreme power and lordship.

The movements of each star in the Universe may be said to be governed by the attractions of all other stars in that Universe. As a matter of fact—and this must not be forgotten—any motions which can be detected in the stars are probably due mainly to original motion in one direction, derived from the matter out of which they were formed. But such motion would, of course, be affected by the attractions of other bodies, either connected with them or only accidentally near.

It may seem a little puzzling, at first sight, how the movements of a star can be affected by other stars; since around each particular star there are stars in every possible direction, above and below, before and behind. Why should not the pull be all ways at once?

So, no doubt, it is. Every star in the Universe, except those on the very outskirts, has stars on all sides of him, pulling at the same time in every direction. But the pull is not *equal* in all directions. It is most improbable that any one star should ever, in the past history of the ages, have been so placed as to be subjected to a precisely equal and balanced pull from all sides at once, from tens of millions of suns lying irregularly around. If such a state of things ever were,—and if by any means that star had been brought to a state of repose in that spot,—then for a time it might perhaps be expected to remain in repose. But the condition of balance could not last. Every star, as we believe, is rushing through space, at varying rates of at least thousands of miles each hour. So exact and delicate an equilibrium, if once attended to, would speedily be again upset.

Each star, therefore, moves in whichever direction the united pull of many suns is stronger than in any other. He may be attracted—rather, he must be attacted—to right and to left, as well as straight forward. Other pulls retard his speed; the most powerful combination of them in any one direction helps to decide his course.

These thoughts may be kept in mind. But the actual motions of Stars or of Systems of Stars through space are doubtless due, for the most part, to original motion. That is to say, they do not journey because other stars attract them, but, as they journey, the attractions of other stars assist in deciding the path which they pursue.

The Stellar System is held in existence by the balance of those same forces, through which the balance of the Solar System is maintained.

There is, first, the force of gravity; not, as in the Solar System, and as in a great mass of nebulous gas, a drawing inward towards the centre of all outer parts;

but rather a mutual drawing, however feeble in amount, of all the multitudinous suns exerted by each upon all the rest, according to the mass of each, and according to their distance one from another.

So far as we yet know, gravity does not take time to travel, like light. If it does, the travelling is so inconceivably rapid that we have no power to measure it. But with widening distance the strength of gravity diminishes fast. This is at once apparent in the Solar System. The pull exerted by the sun over Mercury is far greater than his pull over Mars; and the still weaker pull over Jupiter is much stronger than the pull over Uranus.

There is in the Stellar System, secondly, the persistence in direction which is due to speed of motion; this, again, as with the worlds of the Solar System. Each sun, by the impetus of his own quick rush, resists the continual drawing of his companion-stars, which otherwise would tend to drag them all close together.

What the form may be of the starry pathways it is impossible yet to say. Some may be ellipses. Some may be, at least for a while, straight forward. Stellar Astronomy has not yet lived long enough for sufficient observations, however partial, of the pathways of the suns.

A little is known as to orbits of double-stars. The pathway of Sirius a good while ago was so far grasped that tiny inequalities could be detected; and thereby his companion-star was conjectured to exist. But all this was only in reference to a minute slice of the pathway of that bright sun. About the whole vast journey in the heavens which he has taken, which he is taking, and which he probably will take through coming ages, we do not know any particulars.

Nay, we do not know the particulars of our own voyage through the skies. We understand fairly well how our earth travels round the sun; and we believe that our sun, like other suns, has a vast journey to perform through some part of the Universe, carrying his worlds with him. But what may be the shape of his pathway, and which may be the stars which most strongly influence him, and whence he has come, and whither he will ultimately go—these questions we cannot fully answer.

It has been suggested that, if our Solar System is a kingdom, with a despotic monarch at its head, the Stellar System is rather to be likened to a republic in its nature. Or, perhaps one might say, not so much like either a despotic monarchy or a simple republic, as like a huge confederation of nations, bound together into one great brotherhood,—despotic kingdoms such as the Solar System, and republics such as Star-clusters, all combined together, and each helping to control the rest.

Probably the Universe contains many another system like ours, governed by one supreme monarch; and there are doubtless many over which two or three or several suns preside; and again worlds may move amid multitudes of small suns, no one of which is distinctly ruler over the rest.

Theoretically, at least, a republic means something of equality; and certainly equality is not found in the Stellar Universe. True, there is reason to believe that the extreme inequality in size which we find between sun and planets is not the rule among the stars. Mr See has shown, in harmony with the previous researches of others, that the masses of two or more suns in closely-connected systems, such as 'doubles,' are commonly more equal in size. Still, looking upon the Stellar System as a whole, the suns of which it is mainly composed are anything rather than equal in size, in radiance, in power.

Magnificent kingly suns are found there; far transcending in beauty and in glory the ordinary run of stars; and they, as a matter of course, have far mightier influence than more insignificant stars.

Moreover, in picturing to ourselves the guidance of stars upon their heavenly pathways, we must not forget the unknown attractions of unseen suns.

What of DARK BODIES in the Universe?—bodies either entirely cooled, like our earth; or bodies so far dimmed in their lustre that the faint shining cannot be perceived at our great distance.

Such bodies may be scattered through the Universe on all sides, in all directions, in numbers past computing. What else do we mean, when we talk of possible 'worlds' revolving around distant suns? If such cooled worlds are there, they may be of any size. If suns exist, as we believe, enormously larger than our sun, the planets revolving around such suns may be perhaps proportionately larger than the worlds in our Solar System. Nay, what else do we mean, when we talk of millions of cooling stars,—suns huge as Sirius, vast as Arcturus? If stars, which once were the peers of Arcturus in his present majestic proportions, have faded into darkness, they must be bodies of no mean size floating in the skies.

All these would add immensely to the sum-total of attractive power, exercised by the Suns of the Stellar System, each upon the rest.

We do not in the least know how long the Stellar System has existed. Calculations have been attempted, with a view to discover how many millions or tens of millions of years our sun may have been a sun; and the reckoning baffles human powers. The answers arrived at amount to hardly more than guesses. How much more is the effort vain, if we speak of the entire Universe, and try to picture *its* probable duration.

We seem to see it in young suns, half-formed suns, fully-grown suns, to any extent. Why not also suns like the dim companions of Sirius and Algol, elderly suns, fading suns, dying suns,—suns too old, too used-up, for even the photograph plate to capture their beams,—yet all of them just as potent as ever in the exercise of their attractive power; all of them just as useful as in their blazing youth to control other heavenly bodies?

For the attractions of these decrepid suns, which may lie through the Universe in numbers incalculable, we can make no definite allowance.

Not that any body of this description, very large in size, can well be revolving anywhere near to our Solar System! Astronomers would soon become aware of the fact, through the perturbations of the outer planets, caused by the pull of such a neighbour. But away in the distant reaches of the Universe, dark bodies may exist in every direction, without the least token of their presence being perceived by us. And though they could not lie close to our system undiscovered, there may be any number of them very much nearer than the nearest known star.

How numerous and how huge in bulk such bodies may be, we can form no conception. For aught that we know to the contrary, the united mass of them all together may equal, may even outweigh, the combined mass of all those shining suns which constitute the visible Universe.

The longer the present state of things lasts, the greater must be the number of dark and cooled bodies in the skies.

It is a marvellous fact that in the Universe we appear to have the old and the young side by side,—unformed nebulæ and aged suns,—as in a wood are found saplings and decaying trunks together. But the saplings and the trunks did not spring into life in one day. They belong to successive generations.

When we speak of 'age' in the heavens, we mean rather the stage of growth than the actual length of existence. This has been already explained. Still, we cannot for a moment assert that all stars and nebulæ have existed during the same length of time. In the great Garden of the Skies, as in some little earthly garden or wood, there may be successive generations; there may be longer-lived and shorter-lived stars, side by side.

What if collisions should sometimes occur, among these dark suns,—and if, through such collisions, fresh heat and glowing life were set up in the old effete suns, making them young again? It might perhaps even be that young unformed nebulæ should spring from such collisions; and so a fresh generation of star-life should be begun? Things *may* be thus. We cannot speak here with any manner of certainty. If things were so, the existence of youthful and of aged heavenly bodies together in the Universe would be explained.

In the case of those mysterious apparitions, New Stars, seen from time to time, it may be that their sudden and temporary brightness is due—at least sometimes—to the breaking up of the cooled crust, and the setting free of heated matter within. A 'new star' may be only an old half-cooled sun, made young again,—a sun so far cooled as to give out little or no light, while still exceedingly hot beneath the crust. And while such outbursts may occur in the natural process of cooling, they may also be brought about by the tidal disturbances caused by the near approach of another body,—perhaps of another dark body.

But in these matters, occupying the dubious borderland beyond scientific certainties, we have to be cautious; we must be willing to wait, willing not to be sure. At the best, our outlook is very partial and very dim. The connecting link between us and each far-off glimmering point consists of only a few rays of light. We can watch those rays; we can sub-divide them; we can analyse them; we can decipher a little of the make and of the movements of the star of nebulæ from which they come,—and yet how small is the sum-total of our information!

That very star upon which you and I now gaze, may no longer be in existence. What we see is not the star itself, as that star now is. We are aware only of the effects of the waves of ether which were set vibrating in the vast distance, five years ago, ten years ago, twenty years ago, one hundred years ago, two hundred years ago,—who can say how much longer ago? Since your birth, since the middle of the last century, since the days of Copernicus since the times of Hipparchus, the swift impulses have been speeding onward; and now at last they impinge upon the retina of your eye or mine.

The famous New Star in Auriga, about which we have all heard so much, tells doubtless of some mighty outburst in the heavens, but not of an outburst which has only now taken place. It may have been in the reign of Queen Anne—amid the throes of the great plague—during English civil wars! The New Star lies beyond reach of parallax measurement. We can only conjecture its probable distance.

Who can say what may have happened meanwhile to the orb which sent those messages of light? From them, in each instance, we learn in what state the star *was*, such and such a length of time ago; not at all what is the condition of the star now. She may even since then have ceased to shine!

If so, what matter? As Jean Ingelow has beautifully said—

> 'Though she ministers
> No longer with her lamp to me and thee,
> She has fulfilled her mission. God transfers,
> Or dims her ray; yet was she blessed as bright,
> For all her life was spent in giving light.'

INDEX

THE END

COLSTON AND COMPANY, PRINTERS, EDINBURGH.

PICTURESQUE PLACES.

A Series of Illustrated Books.

THE INNS OF COURT AND CHANCERY. By W. J. LOFTIE. With upwards of Sixty Illustrations, chiefly by HERBERT RAILTON. New Edition. Large crown 8vo, cloth, 6s.

'A charming monograph on a topic of manifold interest, historical, literary, architectural, topographical and archæological.'—*Times.*

THE BRITISH SEAS. By W. CLARK RUSSELL, and other Writers. With Sixty Illustrations, after HENRY MOORE, R.A.; J. C. HOOK, R.A.; COLIN HUNTER, A.R.A.; HAMILTON MACALLUM and other Artists. Price 6s., cloth.

LANCASHIRE. Brief Historical and Descriptive Notes. By LEO GRINDON. With many Illustrations, by A. BRUNET-DEBAINES, H. TOUSSAINT, R. KENT THOMAS and others. 6s., cloth.

PARIS. In Past and Present Times. By P. G. HAMERTON. With many Illustrations, by A. BRUNET-DEBAINES, H. TOUSSAINT, JACOMB HOOD and others. 6s., cloth.

THE RUINED ABBEYS OF YORKSHIRE. By W. CHAMBERS LEFROY. With many Illustrations, by A. BRUNET-DEBAINES and H. TOUSSAINT. 6s., cloth.

OXFORD. Chapters by A. LANG. With many Illustrations, by A. BRUNET-DEBAINES, H. TOUSSAINT and R. KENT THOMAS. 6s., cloth.

CAMBRIDGE. By J. W. CLARK, M.A. With many Illustrations, by A. BRUNET-DEBAINES and H. TOUSSAINT. 6s., cloth.

WINDSOR. By W. J. LOFTIE, dedicated by permission to Her Majesty the Queen. With many Illustrations, by HERBERT RAILTON. 6s.

STRATFORD-ON-AVON. In the Middle Ages and the Time of the Shakespeares. By S. L. LEE. With many Illustrations, by E. HULL. 6s., cloth.

EDINBURGH. Picturesque Notes. By ROBERT LOUIS STEVENSON. With many Illustrations, by W. E. LOCKHART, R.S.A. 3s. 6d., cloth; 5s., Roxburghe.

CHARING CROSS TO ST PAUL'S. By JUSTIN M'CARTHY. With Illustrations, by JOSEPH PENNELL. 6s., cloth.

LONDON: SEELEY & CO., LIMITED, ESSEX ST., STRAND.

EVENTS OF OUR OWN TIME.

A Series of Volumes on the most Important Events of the last Half Century, each containing 300 *pages or more, in large 8vo, with Plans, Portraits, or other Illustrations, to be issued at intervals, cloth, price* 5*s.*

Large paper copies (250 *only*) *with Proofs of the Plates, cloth,* 10*s.* 6*d.*

---

*THE LIBERATION OF ITALY. By the Countess MARTINENGO CESARESCO. With Four Portraits on Copper. Crown 8vo. Price 5s., cloth.

THE WAR IN THE CRIMEA. By General Sir EDWARD HAMLEY, K.C.B. With Five Maps and Plans, and Four Portraits on Copper. Fifth Edition. Crown 8vo. Price 5s., cloth.

THE INDIAN MUTINY OF 1857. By Colonel MALLESON, C.S.I. With Three Plans, and Four Portraits on Copper. Sixth Edition. Crown 8vo. Price 5s., cloth.

THE AFGHAN WARS OF 1839-1842 AND 1878-80. By ARCHIBALD FORBES. With Five Maps and Plans, and Four Portraits on Copper. Second Edition. Crown 8vo. Price 5s., cloth.

THE REFOUNDING OF THE GERMAN EMPIRE. By Colonel MALLESON, C.S.I. With Five Maps and Plans, and Four Portraits on Copper. Crown 8vo. Price 5s., cloth.

*ACHIEVEMENTS IN ENGINEERING DURING THE LAST HALF-CENTURY. By Professor VERNON HARCOURT. With many Illustrations. Crown 8vo. Price 5s., cloth.

*THE DEVELOPMENT OF NAVIES DURING THE LAST HALF-CENTURY. By Captain EARDLEY WILMOT, R.N. With Illustrations and Plans. Crown 8vo. Price 5s., cloth.

Of Volumes so * marked there are no Large Paper Editions.

LONDON: SEELEY & CO., LIMITED, ESSEX ST., STRAND.