ASTRONOMY

THE PLANET SATURN. (S. Bolton)

December 18, 1910

ASTRONOMY

BY

GEORGE F. CHAMBERS, F.R.A.S.

Of the Inner Temple, Barrister-at-Law

AUTHOR OF "A HANDBOOK OF ASTRONOMY," "THE STORY OF THE COMETS," AND OTHER WORKS

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PREFACE.

THIS volume is not a formal treatise on Astronomy, nor is it a mere educational text-book; but the idea which underlies it may be realised from the following considerations. An extended experience as an astronomical writer, and likewise lecturer on the science, coupled with much intercommunication with many of its votaries in divers walks of life and places, including colonies and foreign countries, has led me to notice the remarkable spread of late years all over the world of a taste for Astronomy. Some recent eclipses of the Sun, and especially some recent comets, have had a good deal to do with this, especially Halley's Comet of 1910. I have often been struck by the frequent requests for information on astronomical topics from all sorts of people, the majority of whom, I fancy, would have resented a suggestion that they should sit down and seriously study text-books on the subject. These are the people whom I want to get hold of through this volume.

There is nothing profound or inconveniently deep in it, but it just gives a popular outline of leading facts, which may be easily grasped by any fairly educated person who is only able, or disposed, to give a limited amount of time or thought to the matter, but who may happen to possess a small telescope of, say, two or three inches aperture, or even a good opera-glass. My endeavour has been to deal descriptively with some of the more ordinary sights of the Heavens, the examination of many of which can be carried out with the class of instrument just mentioned. Mathematical and theoretical matters and speculations have been kept entirely in the background.

It will appear, I hope, from the foregoing statement that my idea has been to direct the reader's attention to what may be called every-day topics, and to give in a handy form information on such phenomena as are constantly brought under the notice of people in general without exactly being sought for by them. I want the reader to be able to answer such questions as, "What is the meaning of the term Sun-spot?" "What is the name of that bright star, or is it a planet, which I see in the west every evening?" "Is there any difference between an eclipse of the Sun and an eclipse of the Moon?" "Was Sir George Cornwall Lewis right when he stigmatised Astronomy as a science of 'pure curiosity'?"

Such questions as these, and others much more shallow, have often been addressed to me, and I want to provide people who possess only a smattering of scientific knowledge with the means of answering some of these questions which frequently crop up when some noteworthy astronomical event or discovery gets mentioned in the newspapers or is talked about. It will be seen, I think, that whilst my aims are modest, I have endeavoured to provide materials for sensible and exact knowledge, truly scientific and correct, yet not needing too severe a demand on the time or mental powers of those who patronise the book.

The illustrations have been obtained from many sources, and, whilst it may be said of some of them that they are not new, or only reproduce old ideas in new form, yet I have endeavoured as far as possible to be chary in the insertion of such, being desirous of providing my readers with pictures which are not in general circulation or accessible to the reading public. This really means that I have ransacked the publications of various scientific societies, European and American, for illustrations. America has been a rich field for this purpose.

I have to thank Mr. H. F. Bushell, of the Gresham School, Holt, Norfolk, for kindly reading the proof-sheets, but my special thanks are due to friends too numerous to mention all by name, who have provided me with drawings and photographs, without which it would have been impossible to produce this, the most copiously illustrated book on Astronomy which, I should suppose, has ever been published. There are, however, a few names which stand out more conspicuously than others, and which must receive special mention. In such a list I must include the following: Professor E. E. Barnard, of the Yerkes Observatory, Williamstown; Professor W. H. Pickering, of the Harvard College Observatory, an institution to which Astronomy owes more than can be expressed; the Councils of the Royal Astronomical Society and of the British Astronomical Association; and several private friends, under which head there must be included Mr. E. M. Antoniadi, Mr. E. H. Barlow, Mr. S. Bolton, Rev. A. L. Cortie, S.J., Mr. W. F. Denning, Mr. W. B. Gibbs, Mr. F. W. Longbottom, Admiral Moore, Rev. T. E. R. Phillips, Mr. W. E. Wilson, Mr. H. E. Wood, together with Messrs. Cooke & Sons and Sir H. Grubb.

AN attentive, or even a cursory, perusal of this book will give the go-by to the idea that astronomy is a science of "pure curiosity." On the contrary, it has a great deal to recommend it even in this utilitarian age, for the navigation of the high waters of the world, and the daily disposal of our time by all of us by the agency of clocks and watches, depend upon the practical application of astronomy to the concerns of daily life. But over and above all this it is a science which points unmistakeably to the Universe having been created, and being still maintained, by a Divine Hand which controls everybody and everything around us. It was no poetical fancy which inspired Young in his *Night Thoughts* to write the significant words "An undevout astronomer is mad."

G. F. C.

Lethen Grange,
Sydenham.

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THE GREEK ALPHABET

*** The small letters of this alphabet are so frequently employed in Astronomy that a tabular view of them, together with their pronunciation, will be useful to many unacquainted with the Greek language.

α Alpha.	ν Nu.
β Beta.	ξ Xi.
γ Gamma.	ο O-mīcron.
δ Delta.	π Pi.
ε Epsīlon.	ρ Rho.
ζ Zēta.	σ Sigma.
η Eta.	τ Tau.
θ Theta.	υ Upsīlon.
ι Iota.	φ Phi.
κ Kappa.	χ Chi.
λ Lambda.	ψ Psi.
μ Mu.	ω O-mega

ASTRONOMY.

CHAPTER I.

INTRODUCTION.

The scope of the Science of Astronomy.—Its modern developement.—The other sciences which come in contact with it.—The resulting necessity of keeping the treatment of the science within defined limits.—The different divisions of pure astronomy.—Mathematical Astronomy.—Lord Grimthorpe's book, "Astronomy without Mathematics."—Theoretical Astronomy.—Descriptive, or Visual Astronomy.—Practical Astronomy.—Amateurs may dispense with knowledge of mathematics altogether and of the theory of telescopes and optics in part.—The modern application of the spectroscope.

THE word "astronomy," coming as it does from two Greek words which, in combination, represent the idea of "the Laws of the Stars," fails altogether to indicate especially the modern scope of the science with which it professes to deal. The fact is that the discoveries of modern times, which supplement the astronomy known to the people who lived a century or two ago, have extended it into so many other fields of knowledge that it is not altogether easy always to say where astronomy, pure and simple, ends and something else begins. The chemist, the photographer, the optician, and to some extent the geologist, are all concerned, or consider themselves concerned, in the sphere which formerly was limited to pure astronomy, being the Sun, Moon, Planets, Comets, and Stars, and the phenomena strictly connected with and arising out of the study of these various celestial objects.

It will be my endeavour in the following pages to keep as closely as I reasonably can to astronomy in its older and more limited sense, because were I to attempt to draw into the astronomer's net everything which, by modern custom or practice, comes over the border-line, this book might be open to the objection that it comprised too much of everything and not enough of anything.

The Science of Astronomy, taken as a whole, itself embodies several distinct lines of thought and treatment. One of these may be termed Mathematical Astronomy, and perhaps it may be said that it is this subdivision which is most generally assumed by people who have not looked into details to be the cardinal feature of the science, and therefore the one which comes first into the mind of the general reader as the dominant character of the science. This explains the fact that often when I have recommended the study of astronomy to persons who have never thought much about the matter, I have been met with remarks couched more or less as follows : "Yes, I dare say it is an interesting subject, but it is too mathematical for me, and I know nothing of mathematics." All this is, in a sense, fallacious. Whilst it is perfectly true that a professed student who wishes to get up the subject to the fullest extent must be of a mathematical turn of mind, and be prepared to go through to the highest mathematics, it is a very great mistake to suppose that unless this is done it is no good taking up the subject at all. The view which I am now presenting is not novel, for a great many years ago the late Lord Grimthorpe, when he was plain Mr. Beckett-Denison, Q.C., published a very useful little book with the pointed title of "Astronomy without Mathematics." Perhaps in some general sense the reader will find that I have trodden in the footsteps of my departed friend, but nobody could possibly assimilate Lord Grimthorpe's style and language, which was completely *sui generis* in every sense of those useful words.

Mathematical Astronomy may otherwise be spoken of as

Theoretical Astronomy, because it covers the theories of the movements of such of the heavenly bodies as move, and the laws which govern their movements, and so enables the advanced students and professors to predict with precision and detail the motions of the planets and other moving bodies whose positions in the sky from day to day and month to month and year to year are set out in our almanacs.

In a measure independent of this, we have what may be called Descriptive, or Visual Astronomy. This represents, with respect to the heavens, the work done by the newspaper reporter and the illustrated newspaper with regard to things mundane. In other words, the student of astronomy who concentrates his attention on the descriptive side spends his time in using his eyes to see what he can see, and to draw with his pencil or record with his camera what he has seen, and perhaps to commit to writing his observations for the use either of himself or of somebody else. It is obvious that this is the popular, everyday side of the subject, and that people with fairly good eyes and a certain amount of common sense and intelligence can study the celestial bodies with pleasure and profit, even although they know little or nothing of mathematical astronomy, and have no great acquaintance with the third leading subdivision of the science which is called Practical Astronomy.

Practical Astronomy deals with instruments, processes, and methods—with the principles, the construction, and the use of telescopes, the construction and use of star-maps, the instrumental measurement of angles and distances, and the tabulation of observations and the drawing of conclusions from them.

As in the former case a student may do a good deal of useful work with his eyes without troubling himself much or at all with mathematics, so also he can do useful work, and derive pleasure from it, in connection with descriptive astronomy, using th telescope to help him. And this, though he knows little or nothing about the theory and construction of telescopes, or how they are put together, or the names of the different sorts of lenses which he uses each time that he handles his telescope. In mentioning the range of astronomy it must not be forgotten how important to us all (at times) is that branch or subdivision of the subject which goes by the name of Nautical Astronomy—the application of the science to the navigation of ships; but that, of course, is entirely beyond the scope of this work.

I hope that the foregoing ideas will be realised by those people who read this book, and that accordingly they will also realise the fact that they can obtain a great deal of pleasure and profit from a study of such departments of astronomy as may be readily reached without great exertions of the mind, and without any large expenditure in the way of apparatus.

There is only one more subject which must in brief form find a place in this volume, and that is Spectroscopy. It is only within 50 years or so that the spectroscope has been brought into general use as an accessory to the study of astronomy; and it has come, almost with a rush, to occupy a prominent place in the minds and work of those who, going beyond the modest aims of this volume, desire to dive into hidden things which do not in the first instance appeal to the eyes of the casual student of nature who takes up astronomy.

In order not to burden the pages of the book with uninviting masses of figures, statistics involving numerical quantities will to a certain extent be excluded from the text and relegated to an Appendix, where they will be more accessible for consultation and comparison.

CHAPTER II.

THE SUN.

Important position occupied by the Sun.—Its general appearance.—Its mottled surface.—"Granulations" probably the best word to describe it.—Spots on the Sun.—Their periodicity.—General description of them.—Peculiarities of spots.—Period of the Sun's rotation.—The Photosphere.—Distribution of the spots in latitude.—Discovery of the periodicity of the spots.—Auroræ.—Terrestrial Magnetism.—Sun-spots and terrestrial weather.—Possible influence of some of the Planets on Sun-spots.—Wilson's theory respecting them.—Vortex movements on the Sun.—Faculæ.—Apparent movements of spots at different seasons of the year.—Notable large spots.—Light- and heat-giving powers of the Sun.—The Krakatoa sunsets.

WE are so accustomed to see the Sun and feel its heat-giving effects that we are apt to lose sight of the important position which it occupies in the Universe—or perhaps I ought rather to say in our Solar System, because the Universe, in the proper sense of the term, extends far beyond our Solar System, which is probably only one of many systems, and perhaps even not the most important. The late R. A. Proctor entitled one of his many books, "The Sun: Ruler, Fire, Light, and Life of the Planetary System." The phrase was a comprehensive one, but did not go beyond the legitimate expression of the facts.

Everybody, I suppose, knows—at any rate, in a general way—that the Sun is the centre of our Solar System, not only in the sense in which the nave is the centre of a carriage-wheel, but as the immediate and the prime source (humanly speaking) of all light and life on the Earth; moreover, it is also the central force which keeps everything going. To pursue this thought further would lead me into a disquisition on the Law of Gravitation and the laws generally of Celestial Motions, which, it will be understood from the previous chapter, would be foreign to the aims of this volume.

If we look at the Sun soon after sunrise or towards sunset, or through a fog, or through a smoked or dark-coloured glass, what do we see? Apparently a luminous disc, which for our present purpose may be regarded as a true circle, though, when it is viewed near sunrise or sunset, the circular outline is slightly distorted. To the naked eye this disc appears as a flat patch of yellowish light, possessed of great inherent brightness and powerful heat-distributing properties.

But this is a very poor description of what the Sun really is. The astronomer, by means of his instruments and calculations, determines it to be very large and not flat, but globular or spherical—a ball, in fact. To the naked eye the Sun seems to have the same smooth surface and yellowish tint all over; in a telescope, however, matters are far otherwise. The surface appears speckled or stippled, and near the limbs or edge of the circle streaked, whilst every now and again and here and there blackish spots are sometimes visible, the centre of the Sun being always brighter than the edges. This latter fact is a very obvious result of its globular form, but the mottling and streaks and spots depend on certain physical causes which are not in every respect capable of full explanation.

A great many words and phrases have been brought into use with the object of conveying an intelligible idea of the appearance of the surface of the Sun. "Willow-leaves," "rice-grains," "shingle beach," "mottling," "stippling," "granulations," and "photospheric network" are amongst the terms which have been employed, first by one and then by another observer. The last-named term is decidedly objectionable, because it conveys too much the idea of an artificial formation. On the whole, because of its vagueness, I am inclined to prefer the word "granulations" as being most expressive of the ordinary appearance of the Sun in telescopes of sufficient size to show anything.

A great controversy raged over several of these phrases half a century or less ago. The term "willow-leaf" was put forward by Mr. James Nasmyth, the inventor of the steam-hammer, who in his later years became a great observer, being also very skilful with his pencil. His idea was that the whole surface of the Sun exhibited the appearance which would be presented by a large mass of willow-leaves if flattened out and lying promiscuously one on the top of another at all possible angles. Though the term "willow-leaf" did not meet with general acceptance, it set astronomers thinking how they could best describe the general appearance of the Sun's surface, which all agreed was not smooth and uniform, as a planed slab of wood covered with a coating of oil-paint appears smooth and uniform. Langley's well-known picture of what he called a "Typical Sun-spot" brings out the "willow-leaf" idea, though I do not think he used the words. [Plate II.]

Sir W. Huggins, one of our greatest and most experienced English observers, took up the subject very carefully at the time, and summarised his conclusions by giving the preference to the word "granule," because no positive form is implied by its use. He thought "rice-grain" was a suitable expression to represent what was seen in small telescopes, but that there was thereby implied a definiteness of shape which to some extent disappeared when large telescopes and high powers were resorted to. He thought, however, that it might safely be said that these objects, whatever their nature, did affect an elongated, oval, or lenticular form.

These opinions have not been seriously disturbed by later discoveries, and, on the whole, it may be said that the general surface of the Sun presents a granulated appearance to which some apply the word "network," though, as I have said before, I think the word is too precise. Another word in use is "pore"; and this has something to recommend it, because when the spots (presently to be described) break out, they often start from a pore as a place of origin.

Other similes have been suggested for the granulations on the surface of the Sun. An American astronomer has likened them to the snow-white ends of coral. He says that the picture

Fig. 2.—Madrepora Specifera.
An East Indian Variety of Coral.

here given (Fig. 2) of a specimen of East Indian coral in the Natural History Museum at Williams College, Massachusetts, "held at arm's length, and viewed with eyes partially closed, gives a tolerable idea, though on an enlarged scale, of the appearance of the solar mottling as seen in the largest telescopes."

The spots on the Sun are a very notable feature, and now and again become a very striking feature visually, and the whole history of their observation is one of intense interest. Before the invention of the telescope little or nothing was thought or known of them, because it was only at long intervals that a spot sufficiently large to be seen with the naked eye became visible. And even when telescopes did come into use, and spots were much more often noticed, it was a long time—more than 200 years—before observation of them came to be made systematically, and some 250 years before it was realised that their visibility from time to time depended upon a recognisable law of periodicity.

Before dealing with this law let us consider for a while something about a spot on the Sun *quâ* spot. We will suppose that on a certain day an observer turns his telescope, armed with a suitable dark glass, on to the Sun, and that he notices nothing but the uniform granulated surface of which I have already spoken, and that on the following day he detects a little blackish point. If he watches this point during several days he will notice that it increases in size, and very likely develops into two blackish points. In such case the two will separate from one another more and more, become larger in size and probably more irregular in shape, whilst, when they have become considerably separated, other outbursts will take place in between the two original spots, so that a very broken but somewhat regular irregular group or chain of spots will have sprung up. The forward spot of the original pair will become as it were the leader of the group, the word "forward" being used to indicate the spot which is at the end of the group reckoning in the direction in which it will have been noticed that the group is moving over the Sun's disc, which will be from E. to W.

It is necessary to give an explanation here. Whether a spot is endowed with an absolute motion of its own is an independent question which may, or perhaps may not, have to be answered in the affirmative in any given case; but, inasmuch as the Sun is endued with a motion of rotation on its axis, every spot, whatever its inherent permanency may be, will be visually noticed to be constantly in motion across the Sun's disc.

As the Sun rotates on its axis from E. to W. in about $25\frac{1}{4}$ days, no spot can remain continuously on view for more than about half of this period—actually about 13 days—for a reason to be presently given.

If, as often happens, a spot has a lifetime of several weeks, it will, after disappearing on one edge of the Sun, reappear a fortnight later on the other edge, and so on and so on, it may be for two or three months or more.

Let us now go back to the chain or group of spots with the consideration of which we started. This will be seen to undergo incessant changes—the constituent spots increasing in size and number or decreasing as the case may be. Sooner or later they will all disappear, being smothered or blotted out by the onward rush of the waves of luminous matter which constitute the ordinary surface of the Sun as seen by us, and to which the name of Photosphere (or shell of light) has been given.

Spots on the Sun do not always appear in groups or with a gregarious tendency, for sometimes we may see a single spot which apparently has no neighbours or belongings. Near such a spot sometimes small neighbours may spring up, or, on the other hand, it may retain its individuality for some time, increasing in size or diminishing, but retaining during its whole existence a compact and somewhat symmetrical form which more or less approximates to a circle, like a hole bored in a piece of wood by a gimlet, which, when removed, shows the edges to be rough and frayed.

So much for the personal appearance of an average Sun-spot, but a good deal remains to be said on the subject. When a spot is beginning to disappear it does not always do so by a uniform contraction all round its circumference. Not unfrequently the final closing up will be preceded by a bridge of luminous matter darting over the dark area, and forming for the time it endures a bridge over the dark area, making indeed the whole appearance to be that of two small spots side by side instead of one large spot.

The mass of material which is available for an account of

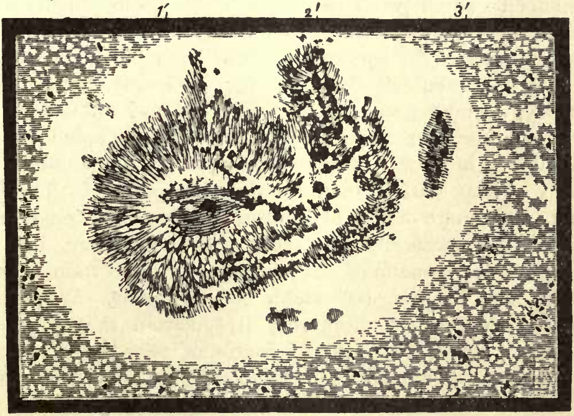


Fig. 3.—Spot on the Sun, Aug. 14, 1868.

the Sun, even if only limited to the standpoint of visual observation, is so great that it is very difficult to know how much to include and what to exclude in writing an account of the Sun. Something more, however, needs to be said as to the physical appearance of the Sun's surface and of individual spots.

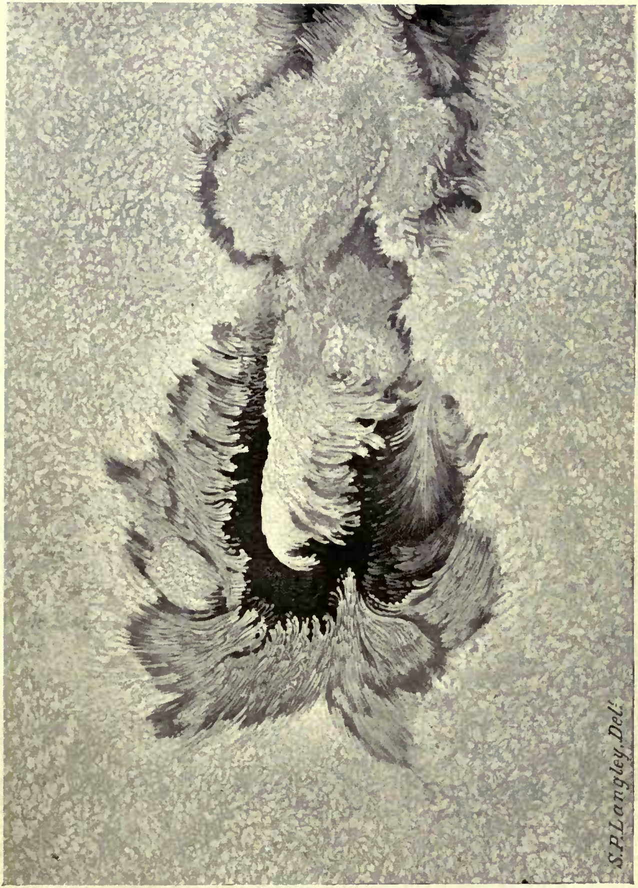
We talk about spots on the Sun, and colloquially call them dark spots; but that adjective is really only a relative term, and must not be pushed too far. The ordinary dark central part of a spot is commonly called the *Umbra* (Lat. "shadow"). This is surrounded usually by a fringe of a lighter shade to which the name of Penumbra is applied (Lat. *pene*, almost; *umbra*, a shadow).

These two portions of an ordinary spot are generally very distinctly defined, and the umbra does not usually pass into the penumbra by a gradual change of intensity. It occasionally happens that, within the limits of the Umbra, there may be noticed a small patch of deeper blackness to which Dawes applied the term *Nucleus*. But Dawes's description of an ordinary nucleus as "intensely black" is again a misnomer, for it is only relatively dark, showing in reality, according to Langley, a violet purple hue. One spot may either have its own penumbra, or several spots may be included in one penumbra. Moreover, the outer edges of a penumbra will usually appear darker than the interior portions. This, no doubt, is a mere effect of contrast. The outer edge of a penumbra is generally of a very irregular outline, but not always so, for sometimes the outline bears a certain general resemblance to the spot which it surrounds. Whilst the spots themselves are often very irregular in shape, yet, on the other hand, they are sometimes very compact and symmetrical—a remark still more true of nuclei where a nucleus exists.

The duration of the existence of a spot is a matter of extreme uncertainty. Sometimes a spot may be seen to appear and disappear in the course of a few hours; or it may remain visible, disappearing and reappearing several times by virtue of the Sun's axial rotation, as already pointed out. It cannot be said that every spot remains absolutely fixed in its position during the period of its visibility. Some spots certainly have a motion of translation of their own which makes it impossible to rely upon their disappearance and reappearance as a means of deducing the exact period of the Sun's rotation.

FIG. 4

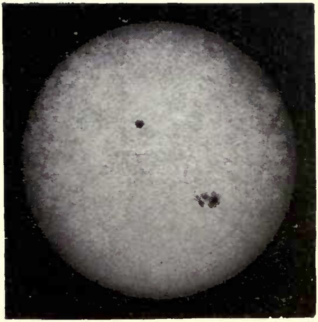
PLATE II.



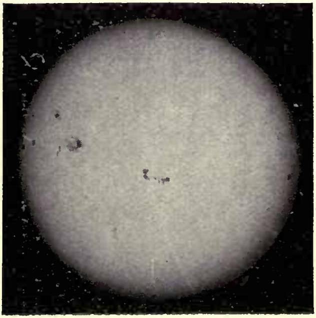
A **Typical Sun-spot** (*S. P. Langley*).

FIGS. 5–8 PLATE III.

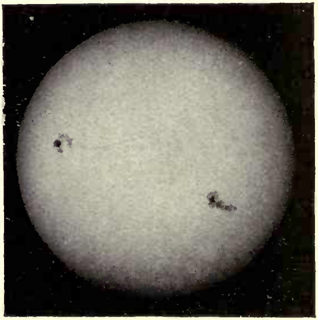
Oct. 22, 1905.



July 31, 1906.



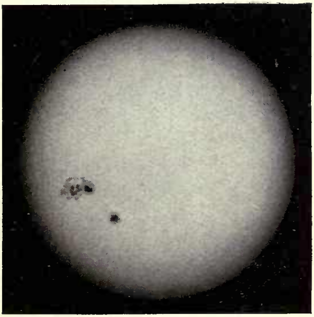
Feb. 7, 1907.



May 6, 1907.

Disc of the Sun, showing Spots (*E. W. Barlow*).

FIGS. 9–12 PLATE IV.



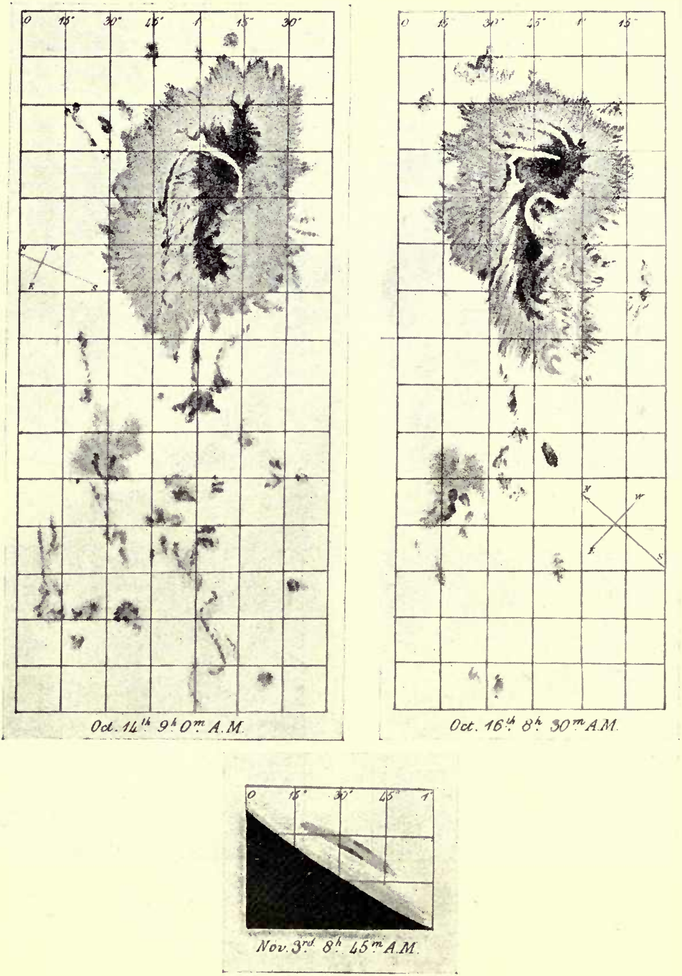
July 15, 1907.

May 4, 1908.

Aug. 3, 1908.

Sept. 2, 1908.

Disc of the Sun, showing Spots (*E. W. Barlow*).



Oct. 14th 9h 0m A.M.

Oct. 16th 8h 30m A.M.

Nov. 3rd 8h 45m A.M.

The Great Sun-spot of 1865 (*Howlett*).

However, as the result of multitudes of observations by various observers, we shall probably be not far wrong in putting this at 25 days 8 hours. It must be noted, however, that these figures are not a measure of the time which a spot takes to disappear and reappear and disappear again. This occupies 27 days 7 hours, being longer than the true rotation once, on its axis, of the Sun itself, because between the commencement of an observation dating from the disappearance of a spot at the eastern limb and its arrival at the same point again, the Earth has moved forwards, and the Sun has, so to speak, to turn a little farther than one revolution in order to be again abreast of the Earth.

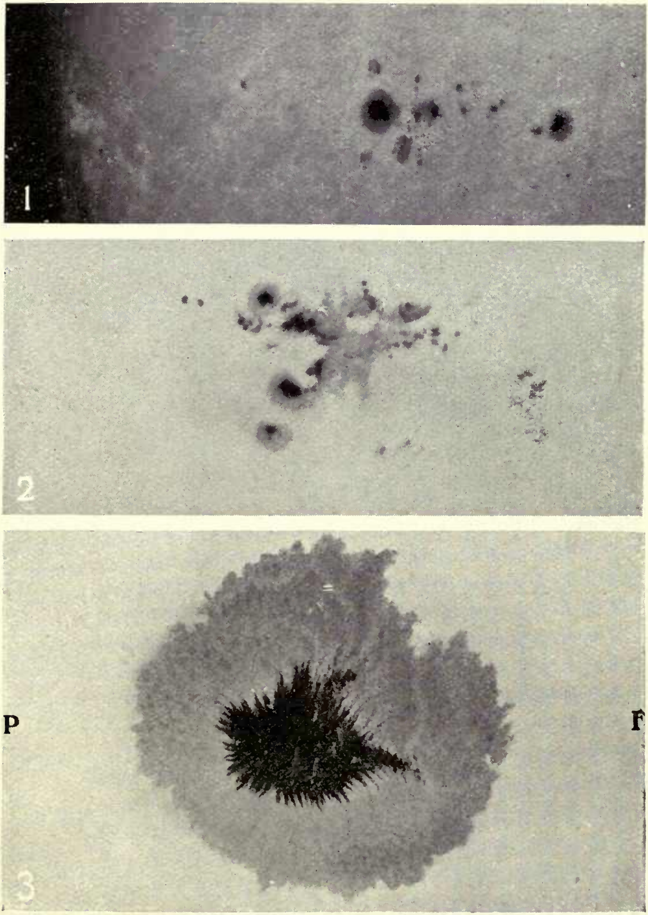
We have not yet exhausted the special features of the Solar Orb as made manifest even to the casual observer. In the first place, the intensity of the solar light is greater in the centre than at the exterior limits of the disc. This is a natural consequence of the obvious fact that, in looking at the edges, we are looking through a thicker layer of the outer coating of the Sun than when we look straight at it in the middle of the disc. It remains now to answer, or to try and answer, the questions, "What is the Sun?" and "How is it put together?" These questions are difficult, and are very much mixed up.

To say that the Sun is not a solid body as the Earth is, and with a luminous atmosphere surrounding it, is a statement altogether inadequate, and beside the mark. The general opinion now is that there is probably nothing solid in the Sun, but that it is an enormous mass of gaseous matter of various kinds, surrounding which are two or more shells or strata of matter of different chemical constitution, including hydrogen gas, and divers metallic vapours. To the innermost of these layers the name of Photosphere has been given, and this is the visible source of the ordinary solar light which reaches the Earth. Next outwards comes the Chromosphere, a thin casing of luminous matter, chiefly hydrogen gas, and the seat of the Red Flames seen in total eclipses of the Sun; whilst, still reckoning outwards, there is a third shell to which the name of "Corona" has been given. We shall have to consider further some of these matters in the chapter (*post*) which treats of eclipses of the Sun.

The spots do not appear promiscuously all over the Sun. They are never seen at either of the poles or anywhere near them. They seldom reach a greater latitude, N. or S., of the Solar Equator than about 30° to 37°; but, even within these equatorial regions, they are not promiscuously distributed—that is to say, they are rare at or near the Solar Equator, and perhaps may be said to be most usually seen in latitudes between 10° and 20° N. or S., being as a rule more numerous and of greater general size in the northern hemisphere, especially between the latitudes of 11° to 15°. I shall have to recur to this question of the distribution of the spots in latitude after I have spoken of their periodicity.

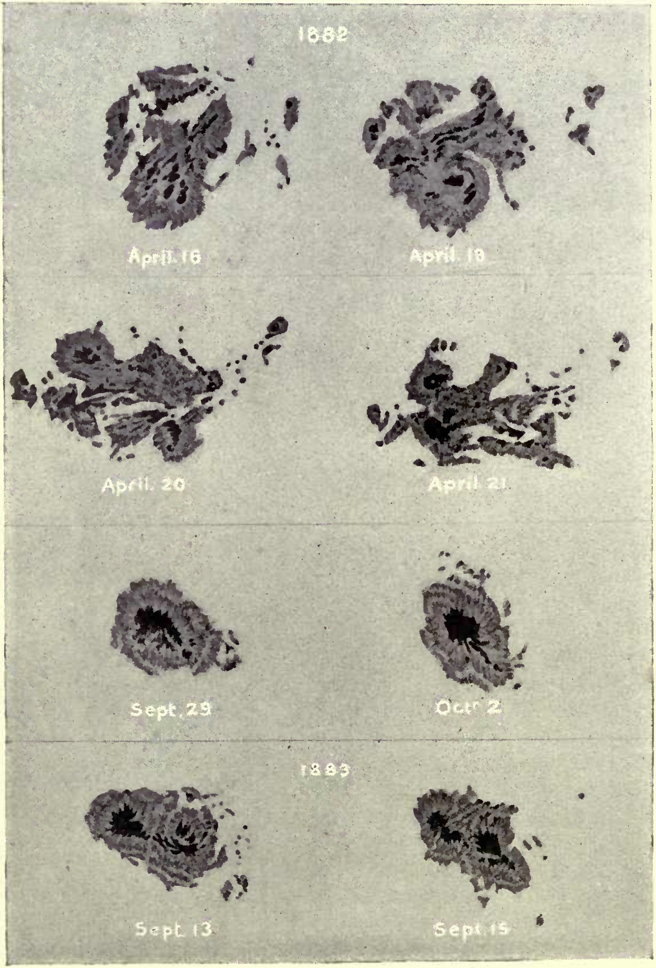
This is a very interesting and important detail. For more than two hundred years after the invention of the telescope and of its employment in the observation of Sun-spots, they were regarded as haphazard manifestations of some kind of outbursts on the Sun's surface, the causes of which were quite unknown, and least of all were imagined to be subject to any laws.

In 1826 a German amateur named Schwabe, who lived at Dessau, commenced a systematic observation of the Sun day after day. He appears to have been able to see it, on an average, about 300 days in every year, and he carried on such observations for about 30 years, when he reached a remarkable stage in his career. He seems to have begun by suspecting that, if he observed the Sun through a sufficiently long number of years, he would find that the spots were subject to a law or laws of some sort. Twelve years enabled him to satisfy himself that there was a periodicity about them: he then spent another 6 years in trying to



Sun-spots.

(1) Oct. 20, 1905. (2) Nov. 16, 1905, showing granulations and faculæ (*Barlow*). (3) June 22, 1889 (*McK.*).



Sun-spots in 1882 at Various Dates (*Cortie*).

impress astronomers with the truth of his opinion, and in the course of another period of 12 years or more he was able to convince mankind that the periodicity of the Sun-spots was absolutely assured; and, to cut a long and very interesting story short, it will suffice for me now to say that, as regards their numbers, the spots are subject to a period of slightly over 11 years. Or, to put it in another way, 1911 having been a year of practically no spots at all, 1912 has seen a few; they will now go on increasing every year until about 1916, when they will be very abundant, reaching their period of maximum; they will then diminish until 1922 or 1923, when very few, and during many months none at all, will be visible.

This question of periodicity and its amount of 11·1 years is now established to a dead certainty. It must be stated, however, that a minimum does not occur midway between two maxima, but that 6½ years elapse between a maximum and the next minimum, leaving 4½ years as the interval between a minimum and the next maximum. These precise figures for the intervals are not, however, quite assured.

We are not yet able to put a very explicit interpretation upon this 11-year period, though there are some incidental coincidences connected with it which are striking and unmistakable. These include the diurnal variation of the magnetic needle and manifestations of the Aurora Borealis. It is beyond the scope of this volume to discuss in detail terrestrial magnetism and the Aurora. It must suffice, therefore, for me to state that the magnetic needle is subject to a minute change of an oscillatory character in the nature of an effort on the part of the needle to turn towards the Sun. These diurnal vibrations are not uniform, but vary in extent during a period of years now recognised as being about 11 years. Manifestations of the Aurora also vary from year to year during 11 years; and now comes the singular coincidence that maxima of terrestrial magnetic displays and of auroral manifestations are synchronous with maxima of Sun-spots, and minima with minima.

The coincidences which have just been pointed out will be far more easily realised by an inspection of the annexed diagram than by the fullest verbal description. The rise and fall of the curves in the diagram indicate in each case both the extent of the changes and the dates thereof; and the most cursory inspection of the three divisions of the diagram will show at once the coincidences of maxima and of minima and of dates.

With these facts before us it is not permissible to doubt that there is some intimate connection between certain events which happen on the Sun and certain events which happen on the Earth. What the nature of the connection may be cannot quite definitely be stated, but that electricity is concerned in the matter in some way or other seems perfectly certain. There is, indeed, more evidence on record than I have yet stated. For instance, on September 1, 1859, two English observers in different places were examining a fine group of Sun-spots, and suddenly, at 11.18 a.m., two patches of bright light burst forth in front of the spots. They were at first thought to be due to a fracture in the screen attached to the object-glass of the telescope; but such was not the case. The patches of light were distinctly on, or connected with, the Sun itself. They remained visible for about five minutes, during which time they moved a short distance.

A remarkable fact has now to be added. Simultaneously there happened a great disturbance of the magnetic instruments at the Kew Observatory, followed 16 hours afterwards by a violent magnetic storm, during which the telegraphs were interrupted and Auroræ appeared. This incident does not stand alone, for on several more recent occasions large Sun-spots and marked disturbance of instruments recording terrestrial magnetism have been noticed as contemporaneous events. Probably the truth is enshrined in the following words of Mr. H. C. Lewis, an assistant at the Greenwich Observatory :—

"The theory is not improbable that Sun-spots are the result of solar electrical or magnetic storms, and that Auroras are the result of a disturbed electrical condition of the Earth caused by induction from the Sun. The common cause for both phenomena is probably cosmical."

Maunder has summed up the situation, as regards the question of solar magnetism, thus :—

"It is evident that, besides sending to us light and heat, the Sun sends us some kind of influence which comes only from certain portions of its surface. We find that there is a tendency for magnetic disturbances to take place when a Sun-spot is on a definite portion of the Sun's disc."

The question is often mooted as to whether any connection can be traced between the prevalence or absence of spots and the character of the weather on the Earth. The evidence as to this is exceedingly contradictory, and great names are to be found ranged on both sides of the controversy, and it is really impossible to present any trustworthy definite conclusions.

The matter has been approached from two somewhat independent standpoints, namely, terrestrial temperatures as distinguished from terrestrial rainfall. Perhaps it is in respect of temperatures that the evidence is more contradictory than in the matter of rainfall. For instance, Wolf, a well-known Swiss observer, considered that he had found decisive evidence "that years rich in solar spots are in general drier and more fruitful than those of an opposite character, while the latter are wetter and stormier than the former." Another Swiss observer, Gautier, discussing 62 sets of observations, extending over 11 years and taken at various places in Europe and America, arrived at exactly the opposite conclusion. Professor C. P. Smyth considered that a great wave of heat passes over the

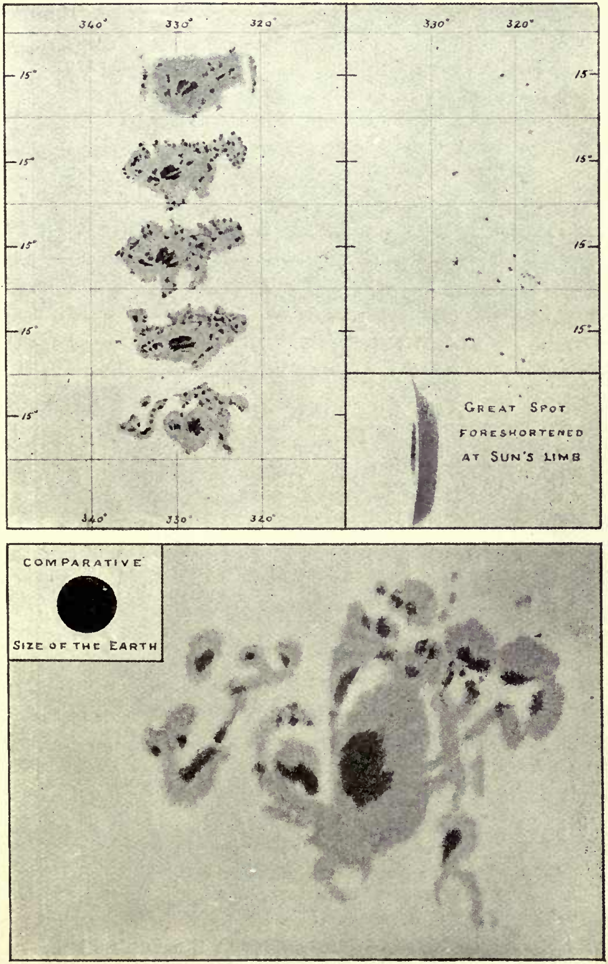
Earth every 11 years and a fraction, and nearly coincident with the beginning of the increase of each Sun-spot cycle. A German observer, Steen, collecting materials obtained during 30 years ending with 1903, considered that there was evidence that the maxima and minima of thunderstorms occur at about the periods when Sun-spots are at their maxima and minima respectively.

Perhaps it may be added with safety, though I shrink from dogmatising on the matter, that a year of high temperature is coincident with an absence of Sun-spots. This idea, which was put forth by E. J. Stone about 1870, as the result of 30 years' observations at the Cape, and by Abbé as the result of 60 years' observations at Munich, certainly found a confirmation in the long prevalence of intense heat in 1911, which was a year of unusual deficiency in Sun-spots.

The question has been seriously mooted as to whether spots on the Sun are subject to any further cycle than the 11·1 year cycle, and whether planetary influences come into the question. It seems that an affirmative answer must be given on both these points. Wolf considered that the activity of the Sun, as indicated by spots, has two further periods of 55½ years and 166 years respectively; the former period being made up of 5 normal cycles and the latter of 15 normal cycles. This is a matter which needs and deserves further investigation.

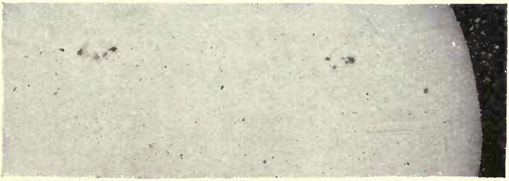
The following table of dates of recent Sun-spot maxima and minima will be useful for reference:—

Maxima.	Minima.
1860·1	
	1867·2
1870·6	
	1878·9
1884·0	
	1890·2
1894·0	
	1901·9
1906·4	
	1911

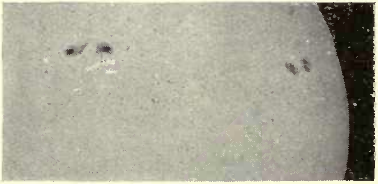


The Great Sun-spot of February 1905.

1


2


3


4


5


Changes in Spots as they approach the Sun's Limb.
(*E. W. Barlow.*)

1906. (1) May 13; (2) May 14; (3) May 15; (4) May 16; (5) May 18.

As regards planetary influences, there is a considerable amount of testimony to show that the prevalence of Sun-spots depends in some way on the position of certain of the Planets with respect to the Sun. Wolf thought he found traces of an influence exerted by Venus in the course of its annual revolution round the Sun, and Balfour Stewart thought that Mercury and Jupiter might also be brought in as exercising some effect. The influence of Venus, assuming it to be real, implies that the planet causes spots to break out in longitudes of the Sun which are opposite to the planet, though, supposing a spot to have been started by Venus, its maximum developement does not take place till, by the Sun's rotation on its axis, the place of origin has been carried farthest away from Venus.

In spite of the distinguished names which are attached to some of these surmises as regards planetary influence, I do not feel inclined to rely very much upon them because of the obvious liability to mistakes being made in the inferences, owing to the general complexity of the whole subject and the difficulty of proving connections of cause and effect.

A large amount of attention has been bestowed on the Sun of late years by astronomers generally throughout the world, with the especial object of determining, if possible, what are the causes of Sun-spots, and what are the physical circumstances which may be supposed to govern them. Much progress has been made, but, nevertheless, more information than we at present possess is needed. The oldest and most attractive theory of the spots is that associated with the name of a certain Professor Wilson, of Glasgow, as modified by Sir W. Herschel. This assumed that the Sun is surrounded by two atmospheres, arranged somewhat as the skins of an onion, the outer one being luminous (thence termed the Photosphere, as already mentioned) and the inner one non-luminous, and that the spots are rents or apertures in these two skins through which we see revealed the solid body of the Sun itself.

Bearing in mind that it is now the received opinion that the

Sun is not a solid body, it must, nevertheless, be confessed that the Wilson theory has something very attractive about it, in view of what one sees when a Sun-spot is scrutinised with a telescope. Suppose we find a spot somewhat symmetrical in shape, and in the middle of the Sun's disc, and watch its gradual change of place towards the edge by reason of the Sun's axial rotation. It will be seen that such a spot, whilst it of course undergoes foreshortening, in accordance with the natural law of foreshortening when a globe is turning on its axis, undergoes foreshortening on the side nearest the limb which the spot is approaching; so much so that the penumbra on that side will have ceased to be visible whilst a certain amount of penumbra exactly opposite still remains in view. A person carefully studying the career of a particular spot can hardly fail to be impressed with the feeling that his eye is resting on a cavity with sunken walls, so to speak, all round it, not necessarily perpendicular, but rather in the form of a funnel.

This theory of the nature of a Sun-spot finds confirmation in the fact that now and again a large spot, when it is passing out of view and turning the corner of the disc, so to speak, generally appears as a notch in the outline of the disc—a fact which distinctly favours the idea that the spots are depressions, and condemns the idea (held by some) that the spots are elevations above the general surface of the Sun. Spots as notches have not infrequently been recorded by observers; a notable case occurs in a photograph taken at Dehra-Dun, in India, in 1884.

The newest idea[1] respecting the condition of the Sun is that put forth in America by Professor Hale (a highly skilled observer) that he has detected signs of Vortices, or cyclonic action of a magnetic nature, in connection with the visible surface of the Sun. Hale has investigated the subject in

[1] I am not at all sure that this idea ought to be considered "new," because I have in my possession a drawing by Howlett dated May 11, 1863, which is actually labelled what it shows, "Interesting Vorticose Group."

a very exhaustive fashion, and his conclusions have met with much acceptance; but it is only fair to add that signs of cyclonic action on the Sun, and of a disposition for the granulations to take up sometimes a spiral form, were obtained and noted many years before Hale went to work by observers as early as Huggins and Secchi in the 'sixties and 'seventies of the last century. This branch of solar study is a highly delicate and intricate one, requiring skilled observers and large and special instruments, and therefore is a subject somewhat beyond the scope of this volume.

Before passing away from the Sun from a sight-seeing standpoint, I must not omit a few words about solar *faculæ*.[1] These are streaks of light frequently to be noticed in the equatorial regions of the Sun, and near either limb, and often running somewhat in a N. and S. direction. They are generally of no particular form, though perhaps a policeman's truncheon is not a very far-fetched simile to convey an idea of their shape. Without exactly pretending to say what they are in constitution, it seems at least certain that they are elevations or ridges in the Photosphere, possibly even detached masses of luminous matter floating in or on the Photosphere. It would seem that they have some sort of association with spots, in so far that they are often to be found just outside the penumbra of a disappearing spot, or even occupying the place where a spot has actually disappeared. [Figs. 36–37, Plate X.]

The fact that the position of the Earth with reference to the Sun at different seasons of the year varies, and that the Sun's axis is inclined to the plane of the Ecliptic, has this result, namely, that a spot on the Sun, if attentively followed during the fortnight it occupies in crossing the Sun's disc, will be found to pursue a path which differs with the season of the year. In June and December a spot will seem to follow a straight path diagonally upwards in the former case, and diagonally downwards in the latter case; whilst in March

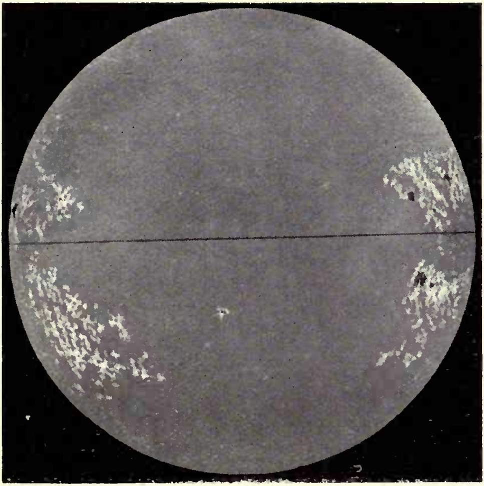
[1] Latin *facula*, a torch.

and September the apparent path will be curved—with the convexity in the former case towards the North Pole and with the convexity in the latter case towards the South Pole.

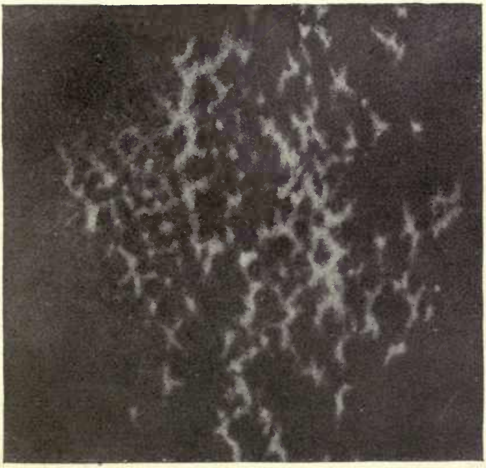
Astronomical writers of popular books generally try to excite their readers by giving a wonderful array of figures supposed to represent the dimensions of remarkable Sun-spots. I am not convinced of the usefulness of such statistics, and I shall give but a very few. It may be taken for granted that no Sun-spots are fairly visible to the naked eye unless they have a breadth of at least 50,000 miles, but many spots of greater size than this are on record. For instance, on March 15, 1858, a spot was visible having an angular breadth of 4′, or about 108,000 miles.

This chapter may be brought to a close with a few statistics. The distance of the Sun from the Earth, or, to put it more consistently, of the Earth from the Sun, may be taken as averaging 92,000,000 miles, which varies slightly in the months of January and July, when, owing to the ellipticity of the Earth's orbit the Earth is nearest the Sun and farthest from the Sun respectively. Why we in England (and in the Northern Hemisphere generally) experience colder weather in January than we do in July, though we are nearer the Sun in January than we are in July, perhaps needs a word of explanation.

The explanation is exceedingly simple. The meridian altitude of the Sun in January is low, and its rays reach us through a certain thickness of atmosphere, and much of the heat is therefore lost; but in July the meridian altitude of the Sun is very considerably higher, and its rays descend upon England and the Northern Hemisphere more nearly perpendicularly, and therefore more directly, and through a thinner depth of atmosphere to absorb them. The diameter of the Sun is about 32′ of arc (say just over $\frac{1}{2}°$), or about 860,000 miles. The Sun's mass, or attractive power, is 332,000 times that of the Earth, and about 750 times that of all the



June 28, 1884.



Nov. 28 1884.

Faculæ on the Sun (*Cortie*).

FIG. 38

PLATE XI.

The Red Sunsets in 1883.

planets put together. The density of the Sun is about $1\frac{1}{2}$ times that of water.

These figures are an indication of the comparative lightness of the Sun as a matter of weight. Many experiments have been made to arrive at an idea both of the heat-giving and of the light-giving power of the Sun. The conclusions as to this are very apocryphal, and do not deserve much weight. For instance, it has been stated that our annual share of the heat would melt a layer of ice all over the Earth 100 ft. in thickness, or heat an ocean of fresh water 60 ft. deep from freezing-point to boiling-point; whilst the direct light of the Sun has been supposed to be equal to that of 5563 wax candles of moderate size at a distance of one foot from the observer. Such figures as these seem rather to savour of "Alice in Wonderland."

Though attempts have been made to calculate and state by figures the heat-giving power of the Sun, it must be obvious that all such calculations can only be, if not quite imaginary, yet very wild and indeterminate. It is, however, worth while to record a few practical consequences of the power of the Sun's rays being what they are. For instance, in constructing the Breakwater at Plymouth, the men working in diving-bells at a distance of 30 ft. below the surface had their clothes burnt by coming under the focus of the convex lenses fixed at the top of the bell to let in the light.

Some years ago the bedroom curtains in the house of a friend of mine at Bromley, in Kent, were set on fire by the concentrated Sun's rays; and I once read in a book of military history relating to Sir R. Abercrombie's expedition to Egypt in 1801 that the Turks captured from the French a brass gun which had been fitted up so that every day at 12 noon the gun was fired by the sun igniting a charge of powder by means of a burning-glass (*i.e.* a double-convex lens), which focussed the Sun's rays on the touch-hole, and so ignited some powder.

It would not be possible, nor indeed desirable, in my limited space to describe in any detail the various pictures of Sun-spots given in this chapter, but the one dated August 11, 1868, will really serve to describe a good many Sun-spot pictures. The wisp-like structure of the penumbra will be readily realised, whilst on the southern side of the vast depression (for the penumbra is a depression thousands of miles deep) there will be noticed, closely packed, a vast crowd of rice-shaped grains which appear to be flowing up to and over the edge of the centre. The picture also shows a long straggling line and small spots trailing after the principal spot, which, as has already been mentioned, is often a feature of a prolonged and extended group of spots. It may help to convey an idea of the magnitude of these spot apertures in the Sun's outer atmosphere if I say that the one under consideration is sufficiently spacious for the Earth to be dropped into it without touching the penumbra on either side.

Figs. 19–26 represent various Sun-spots at various dates as observed at the Stonyhurst College Observatory, and have been kindly placed at my disposal for reproduction in this volume by the Rev. A. L. Cortie, S.J. The 4 pictures dated April 1882 show the day-by-day changes in a spot in the course of a week or less. The spot dated Nov. 17, 1882, was accompanied by a great magnetic storm and a magnificent display of Aurora. The spots dated Sept. 29 and Oct. 2 and Sept. 13 and Sept. 15, 1883, are examples of spots with double penumbræ. Fig. 37, dated June 28, 1884, gives the whole disc of the Sun with certain spots and a remarkable manifestation of faculæ. The picture dated Nov. 28, 1884, shows a very fine group of faculæ on the E. limb of the Sun. The whole-page plate [VIII.] dated February 1905 gives the life-history of what became a great spot from its developement from a few small spots.

Fig. 38 is a representation, taken from a photograph, of the red sunsets (or "Red Light") which created so much sensation in the autumn and winter of 1883, and which were regarded as one of the most remarkable solar-terrestrial effects of modern times. The strange feature of the Red Light was the peculiar halo which it caused around the Sun by day, and its long duration after sunset. At that time, and during the early evening, the colour was usually orange-red, or even rose, and it stretched far up towards the zenith with a bright spot at the highest point. There was also a bright spot and coloured arch in the E., opposite the point of sunset, as if due to a reflection of the western display. The phenomenon changed rapidly, arch succeeding arch with changing colours as the sun sank lower and lower. It will be remembered that the phenomenon was by common consent ascribed to volcanic dust sent forth from an active volcano on the island of Krakatoa, near Java and it was supposed that the dust was belched forth in such enormous quantities that it was carried round and round the World by the Earth's axial rotation.

CHAPTER III.

THE MOON.

Next after the Sun in popular interest.—How soon visible after being new.—Its phases.—Its movement through the heavens.—General physical aspects.—Its mountains.—The walled plains.—The rills.—Mountain chains.—Isolated peaks.—Signs of volcanic action.—Resemblance between lunar and terrestrial volcanoes.—Names applied to the principal mountains.—The so-called seas on the Moon.—General appearance of a crater.—Changes in their appearance owing to the Moon's axial rotation.—The motions of the Moon very complex.—The Librations.—The Harvest Moon.—The Hunter's Moon.—Brightness of the Moon compared with the Sun.—Supposed influence of the Moon on the weather.—Other influences ascribed to the Moon.—The "New Moon in the Old Moon's Arms."—Influence of the Moon on clouds.—Influence of Moonlight on human beings, a fallacy.—Some statistics.

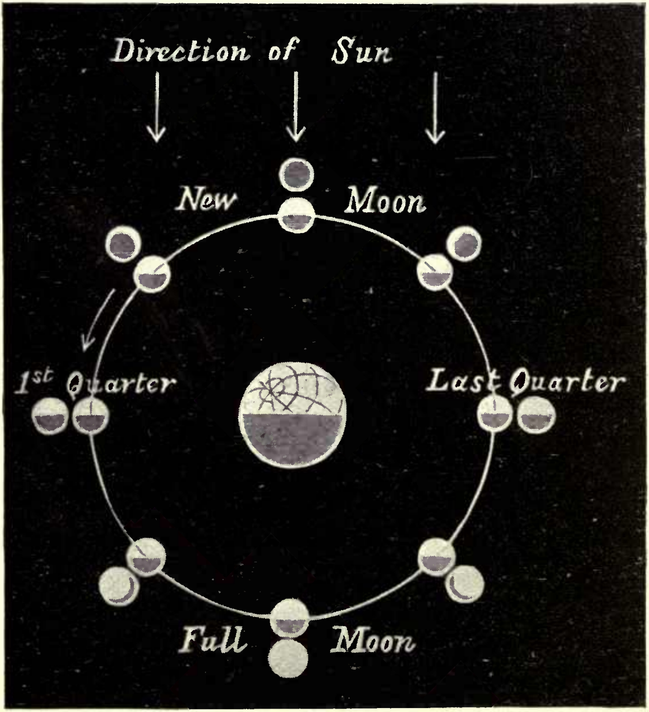
NEXT after the Sun the Moon ranks as the celestial object best known to the inhabitants of the Earth, though we do not, under ordinary circumstances, see it every day. This is owing to the fact that, during the third quarter of the Moon's monthly circuit of the heavens, it only shines when most of us are in bed. Still, it is there for those who choose to rise early, or take rest very late, in order to see it. Indeed, except for a certain number of hours, usually considered for good eyes to be about 30 before or after it is "new," the Moon is visible, weather permitting, throughout the whole of its monthly journey round the Earth as projected on the sky.

The phases of the Moon—that is to say, the ever-changing outline of its illuminated portion—are so well known that it

SEAS.
Sea of Tempests B 3 5
Showers D 2
Vapours F 5
Cold G 1
Serenity H 4
Tranquility I 6
Crises L 5
RING MOUNTAINS.
Plato D 1
Cassini F 2
Aristoteles G 1
Posidonius H 3
MOUNTAIN RANGES.
Appenines F 4
Caucasus G 2
Alps F 1
Taurus I 4
CRATERS.
Aristarchus B 4
Kepler b 6
Copernicus C 6
Linne G
Proclus K
A B C D E F G H I J K L
SEAS.
Sea of Humors b 9
Clouds C 8
Nectar I 8
Fecundity L 7
RING MOUNTAINS.
Grimaldi A 7
Gassendi b 8
Schickard b 10
Ptolemaeus E 7
MOUNTAIN RANGES.
Pyrenees J 8
CRATERS.
Tycho
Theophilus

The Moon.

FIG. 40 PLATE XIII.



The Phases of the Moon.

seems almost too commonplace to describe them in detail; but something must be said on the subject.

Let us start with what is called a "New" Moon, which means that, after the Moon has completed one revolution round the Earth ending with its being lost in the Sun's rays, then, after passing a particular point when Earth, Moon, and Sun are all in a straight line, it emerges from the Sun's rays in the western sky in the evening. Each night thenceforward it gets farther and farther away from the Sun, and day by day becomes more easily visible, until on or about the 7th day it reaches a position we designate as its "First Quarter" (*lucus a non lucendo*), which means that half of the whole circle of its disc is illuminated, and it is then on the meridian at about 6 p.m. On or about the 14th day, it is "Full Moon," when the whole disc is illuminated and we see a complete circular area of light. The Moon is then on the meridian at midnight. It still proceeds in its easterly course, and the next important stage brings it, at about the 21st day, to its Third, or, as it is more commonly called, its "Last Quarter." It is then on the meridian at about 6 a.m., and may be noticed in the W., shining brightly or dimly (dependent on whether the season of the year is winter or summer) at or near the time when it is the ordinary breakfast-hour of the ordinary Englishman. Still moving in the same easterly direction, it will again come into "conjunction" with the Sun on or about the 28th day from which we started; that is to say, it will again be "New" at or near the time of midday. During, however, speaking roughly, the 26th, 27th, and 28th days it will be shining in broad daylight, and therefore more or less invisible, except that a good eye with a good telescope should be able to see it up to within about 30 hours of actual conjunction, being the 30 hours' interval already mentioned in a previous paragraph. [Fig. 40, Plate XIII.]

The terms "New," "First Quarter," "Full," "Last Quarter," which have been made use of above are rather in the nature of fancy phrases, though everybody uses them, and they are fairly well understood ; but, when employed in connection with the weather, are altogether illusory and meaningless.

The special attractions of the Moon from the spectacular point of view are its mountains and the other physical features of its surface, including those to which the names of "seas" and "walled plains" have been given. There are also certain clefts or rifts, to which the name of "rills" has been attached, and perhaps we should not be far wrong in regarding these as cracks in the lunar surface. The mountains, however, are the special features of our satellite to deserve, as indeed they receive, the particular attention of the ordinary sightseer. It may be said that, as on the Earth, so on the Moon, the mountains are of two types : chains of mountains and isolated mountains. The character of the former is sufficiently obvious from the name, but the isolated mountains are of a twofold character—single peaks, and crater mountains, of which we have, on the Earth, few examples except certain volcanoes. Here we come upon a marked difference between the mountains of the Earth and the mountains of the Moon. Craters on the Earth are the exception, and very few in number ; craters on the Moon are the rule, and in overwhelming numbers. Indeed, this is hardly putting the matter strong enough, because nearly the whole surface of the Moon is made up of crater formations. This fact is especially interesting, because it makes it perfectly clear that, at some past time, the whole surface, as we now see it, took its ultimate shape as the result of volcanic action. If anybody has any doubt about this the doubt must assuredly be removed by comparing, say, a photograph of the Peak of Teneriffe with that of any number of lunar peaks selected promiscuously.

All the principal lunar mountains have received names, chiefly those of men eminent in science, both ancient and modern. This system of nomenclature dates from the 17th century having been instituted by an Italian astronomer named Riccioli.

The Moon's Surface Modelled.

By James Nasmyth, 1861.

The Lunar Mountain Copernicus (*W. H. Pickering, photo*).

In more recent times the greater number of the important mountains have been measured to ascertain their height above the general level of the Moon, above which some of them rise to an elevation of 20,000 ft. The work of measuring these heights was carried out on a large scale more than half a century ago by two German astronomers named Beer and Mädler, the value of whose labours has been universally recognised. The work is one of some difficulty owing to the lack of water on the Moon, but it is accomplished by taking observations under special circumstances of the angular dimensions of the shadows of the mountains whose height it is desired to ascertain.

The portions of the Moon's surface to which the name of "seas" has been applied were so called originally from their supposed nature; but it is now quite certain that there is no water on the Moon, and that these areas are in the nature of vast plains like the Steppes of Asia or the deserts of Africa.

The seas have received very fanciful names, but, as they are commonly referred to by the Latin form of their names, the result is not so irritating as when the English translation is employed. The following are some of the names: Mare Humorum, Mare Imbrium, Mare Nectaris, Mare Serenitatis, Mare Tranquillitatis, and so on. These names, if one does not think to translate them, may pass muster; but how vapid they sound in their English forms: the Sea of Liquids, the Sea of Showers, the Sea of the Drink of the Gods, the Sea of Serenity, the Sea of Tranquillity—unworthy of exact science!

A lunar crater usually consists of a sort of basin with a conical elevation rising from the centre, and a raised rim encompassing it. The cases of a crater mountain not having a circular contour are rare; sometimes, however, a crater may be thought to be elliptical, but this is probably in most cases a perspective effect due to the foreshortening of the crater, which will be one seen near the Moon's limb.

A verbal description of the appearance and structure of one crater would more or less serve to describe every crater, and in real truth no verbal description is worth much ; the craters must be seen either in photographs, or in drawings, or through a telescope for the features, which all of them have more or less in common, to be properly realised.

In examining the craters by means of a telescope it is important to bear in mind that it is only at the same period in each lunation—that is to say, at the same age of the Moon in days—that a crater always looks the same. The constant movement of the Moon round the Earth, and consequently the constant changes in the amount of sunshine falling on the Moon, makes the mountains present an incessantly varying appearance. In the case of mountains situated near, but just outside, the terminator (as the line dividing the illuminated from the unilluminated portion is called) the changes in question may often strike an observer, even from hour to hour. The tips, of course, of the mountains may be in sunshine, whilst the adjacent valleys are in shade ; and the size and appearance of the tips are things always changing. At one moment two tips, perhaps, may be visible as bright points, whilst after a short interval a third will become visible ; or, on the other hand, the two tips first seen may become invisible, whilst a new intermediate tip may come into view.

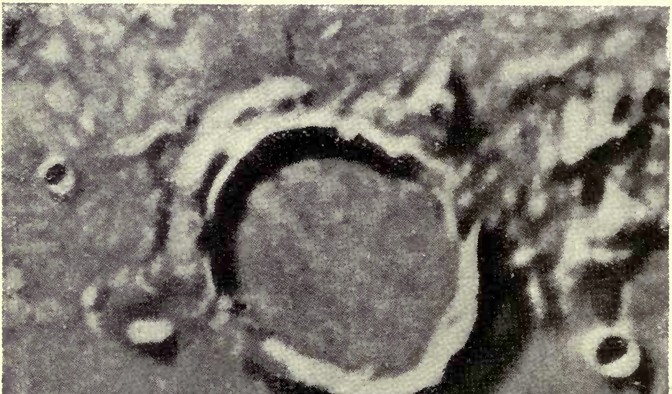
At or near the epoch of Full Moon it is not much worth while looking at the Moon, so far as a desire to examine its formation in detail is concerned, because, the Sun then shining straight on the full face of the Moon, there will be no shadows. On this account the Moon can best be studied at or near the Quarters, or when the Crescent Moon is sufficiently clear of the Sun. At such times the shadows cast by the mountains will fall to their maximum length on to the adjacent valleys and plains. Be it remembered, of course, that they will point in one direction when the Moon is waxing and in the contrary direction when it is waning.

From the point of view of the general reader who only

The Mare Crisium on the Moon.

From a Drawing by Professor L. Weinek from a negative taken at the Lick

Aug. 27.



Aug. 15.

Archimedes, 1888.

From Drawings by Prof. Weinek, enlarged ten times from negatives made at the Lick Observatory.

aspires to be a sightseer there is not very much more to say with respect to the Moon. To the mathematical astronomer the Moon has given a great deal of trouble from time to time because its motions are exceedingly complex, and it can hardly be said, even now, that the subject has been thoroughly mastered.

Speaking roughly, we may say that the same hemisphere of the Moon is always turned towards the Earth ; but this is not absolutely true, for, owing to certain physical causes connected with the position of the Moon's axis with respect to the plane of its orbit, and the inclination of that plane to the Ecliptic, the poles of the Moon's axis lean alternately to and from the Earth. Likewise, the Moon's angular velocity in its orbit is subject to a slight variation, in consequence of which a little more of its eastern or western edge is seen at one time than at another.

Moreover, on account of the diurnal rotation of the Earth, we view the Moon under somewhat different circumstances at its rising and at its setting according to the latitude of the place on the Earth at which we make our observation.

These three foregoing sets of circumstances give rise to three irregularities called Librations, respectively known as libration in latitude, libration in longitude, and diurnal libration. The general effect of these librations is that, comparing one epoch with another, we see a narrow strip at one time which we do not see at another time. In other words, though we never see more than a complete hemisphere at one time, yet in the course of time we see a whole hemisphere, and a little bit beyond, all the way round. We have, in fact, a sort of surreptitious look round the corner.

It is commonly stated that the Moon possesses no atmosphere, and this is in substance true ; but very refined observations of planets and stars when occulted by the Moon suggest the existence of an atmosphere so infinitesimally small that W. H. Pickering has put it at only $\frac{1}{8000}$th that of the Earth.

He says: "Although this value seems small, it is by no means insignificant, and would correspond to a pressure of hundreds of tons per square mile of the lunar surface."

Two expressions connected with the Moon may find a place here. The "Harvest Moon" and the "Hunter's Moon" are both of them well-known phrases—more familiar, however, to dwellers in the country than to dwellers in towns. The Harvest Moon is that Full Moon which occurs nearest to the autumnal equinox. As the Moon then rises nearly at the same hour on several successive evenings, and at a point of the horizon almost opposite to the Sun, the duration of its visibility at night is about the maximum possible. The protracted moonlight is often very acceptable to the farmer at that critical period in his agricultural occupations.

An old 18th-century writer on astronomy named Ferguson thus puts the matter:—

> "The farmers gratefully ascribe the early rising of the Full Moon at that time of the year to the goodness of God, not doubting that He had ordered it so on purpose to give them an immediate supply of moonlight after sunset for their greater conveniency in reaping the fruits of the Earth."

The near coincidence in several successive risings of the Moon takes place in every lunation whenever our satellite is in the signs Pisces and Aries; but the phenomenon is only prominently noticeable when the Moon is "full" in those signs, and this only occurs at or near the autumnal equinox with the Sun in Virgo or Libra. The Harvest Moon is most useful when it is Full Moon about September 23. The Moon may then rise for two or three nights in succession no more than 10 minutes later each night. Under different circumstances—that is, when the Moon is in Libra, and at or near the descending node of its orbit—it may rise as much as $1\frac{1}{4}$ hours later one night than on the preceding night.

The Full Moon next following the Harvest Moon is called the "Hunter's Moon," and will usually fall in October. There does not attach to it the same glamour that attaches to the Harvest Moon, and it is spoken of much less frequently. It is to be presumed that it implies that the operations of hunting will commence at much about the time that this particular Moon displays itself in the heavens.

There remains to be mentioned an interesting fact in connection with the light afforded by the Moon, namely, that we in the Northern Hemisphere get more of it in the winter (when it is most wanted) than we do in the summer (when we can most readily dispense with it). These differences in the availability of the moonlight are due to the fact that it is in the winter that the Moon is found in the most northern part of its orbit, because the Sun at the same time is exactly opposite to it in the most southern part of its (apparent) orbit. The nights of short Moon in winter are also the nights before and after the New Moon when there is the least possible amount of moonlight to lose.

In summer, for us in the Earth's Northern Hemisphere, the reverse of all this is the case: the Moon's elevation above the horizon is the minimum possible, and the northern hemisphere of the Earth therefore receives the minimum amount of moonlight.

The following quotation from a well-known book by a very well-known man brings under notice the Moon in quite a novel connection:—

"The evening was pleasant, and we dined in the open air. All the valley was very dark. The mountains showed a velvet black. Presently the moon rose. I repress the inclination to try to describe the beauty of the scene, as the valley was swiftly flooded with that mysterious light. All the suitable words have probably been employed many times by numerous writers and skipped by countless readers. Indeed, I am inclined to think that these elaborate descriptions convey little to those who have not seen, and are unnecessary to those who have. Nature will not be admired by proxy. In times of war, however, especially of frontier war, the importance of the moon is brought home to everybody. 'What time does it rise to-night?' is the question that recurs; for other things—attacks, 'sniping,' rushes—besides the tides, are influenced by its movements."[1]

What is the amount of the light sent to us by the Moon? We buy and sell electric lamps calculated to display so much candle-power. Can we make any analogous calculation with respect to the light of the Moon compared with that of the Sun? Such calculations have been made, but, as was to be expected, there is great discrepancy. More than a century ago Bouger calculated that the Moon's light was only $\frac{1}{300000}$th that of the Sun; several more modern estimations make it much less, and the only safe conclusion that one can submit is, that if the whole sky was covered with full moons we should still hardly get the amount of daylight which we owe to the Sun.

The question of the Moon influencing the weather on the Earth has already been alluded to, but something more must be said. People often remark in common conversation, "Ah! the Moon changes to-morrow, and we shall have a change of weather." Supposing that on the aforesaid to-morrow the Moon will be reaching its First Quarter, or Eastern Quadrature (to use the proper scientific term), the exclamation quoted is intended to mean that directly the Moon reaches a point in its orbit 90° away from the Sun, whatever has been the weather during the few days before the Moon reaches that point, that weather will be replaced by some other weather. It may as well be stated plainly and broadly that this is absolute nonsense. I will here quote the testimony of two experts on this subject. The late Astronomer Royal, Sir W. H. Christie, in 1896 said:—

"It seems doubtful whether the Moon has, or has not, any influence on the weather; but it is clear that, in any case, it can

[1] W. S. CHURCHILL, M.P., *The Malakand Field Force*, 1897, p. 174.

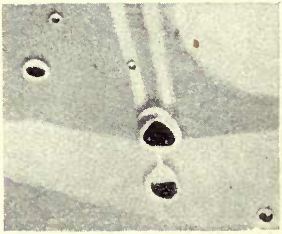
FIGS. 46–51 PLATE XVIII.

Hippalus.

Bernoulli.

Kies.

Ramsden.



Messier.

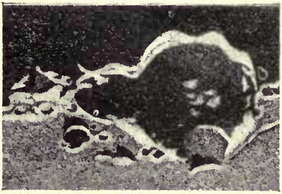
Condamine.

Mountains on the Moon (*Stuyvaert*).

FIGS. 52–57

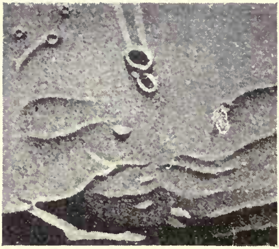
PLATE XIX.

Tirmicus.

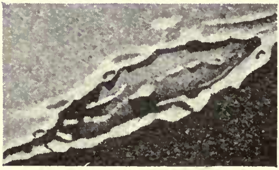


Guttenberg.

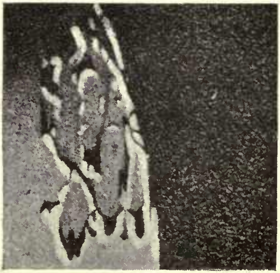
Jansen



Messier.



Gauss.



Meton.

Mountains on the Moon (*Stuyvaert*).

have but very little influence, as such an influence has never been detected with certainty. The Moon's place is always changing, and there is no warrant for the popular idea that the instants of change are 'new,' 'full,' and 'first' and 'last quarters.'"

If this pronouncement is not sufficiently emphatic, perhaps another somewhat similar one, taken from a letter from the Meteorological Office in London, may convince a Moon-believer:—

"No one in his senses can believe in the Moon's influence on the weather. The fact that storms move over the surface of the Earth is sufficient to show that, if the change of weather suits the Moon in Ireland, it must fail to suit it in England."

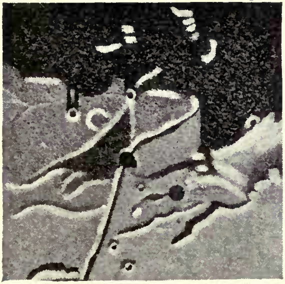
It is very remarkable how deeply ingrained in the minds of people is the idea that the Moon influences the weather, and that what are very inappropriately called "changes of the Moon" bring about, or are associated with changes in the weather. Most grotesque of all is the idea that it makes a difference in the consequential result whether a so-called "change of the Moon" occurs at one particular hour rather than at another. In real truth the word "change" in this connection is a curious misnomer, which has no astronomical basis; and neither literally nor even figuratively has the slightest foundation in fact. Perhaps the situation may be brought home to some by asking, Who would suggest that an express train travelling from London to Manchester without stopping at Rugby, and returning via Oxford without stopping at Birmingham, underwent a "change" when it passed through Rugby and Birmingham?

Notwithstanding what I have said above, there are a few genuine weather signs which, it may be admitted, are associated with the Moon, but have no physical connection with it. For instance, if the Moon looks pale and the horns blunt, or lack sharpness, rain is indicated; but if the Moon is clear and sharp and silvery bright, so to speak, it is a sign of fine weather which is likely to continue. An old adage which has come down to us in Latin from I know not what date runs thus:—"A pale moon indicates rain; a red moon wind; a clear moon fair weather."

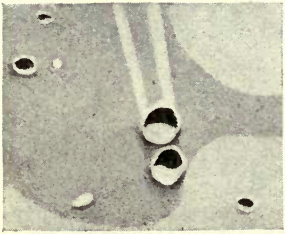
It often happens that when the Moon is two or three days old the dim outline of the portion not directly illuminated by the Sun can be seen, shining with a pale grey light. This appearance is popularly called "the New Moon in the Old Moon's arms," though it would be better to put it the other way about and call it "the Old Moon in the New Moon's arms." The appearance may be taken as a sign of rain, being the equivalent of the clearness of distant hills, which clearness is an almost invariable forerunner of rain. It is sometimes suggested that the question of the effective meaning of this sign depends upon the position of an imaginary line joining the horns relatively to a horizontal or an inclined position; but nothing depends on this, because the position as regards level of the line joining the horns is simply a matter which depends upon the season of the year as regards the place of the Moon in the heavens with respect to the Sun. [Plate XXII.]

When the Moon is near its full, either before or after, it frequently happens that, as the Moon rises in the sky on a cloudy night, the clouds break up and disperse as the night wears on. I regard this as a well-authenticated fact, which I observed myself many years ago before I knew that Sir J. Herschel had also put it in print, and I may add that I have often noticed it myself since, though Mr. W. Ellis, late of the Greenwich Observatory, once sought to controvert it. It seems to confirm the idea that the Moon imparts a certain but very faint amount of warmth to the Earth, as the direct observations of the late Earl of Rosse distinctly indicate.

Subject to the foregoing exceptions, it may be said that the following composition of some unknown "poet" (save the mark!)



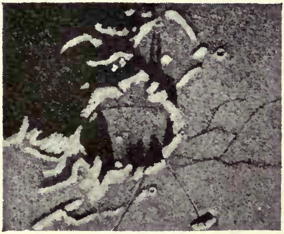
Hyginus.



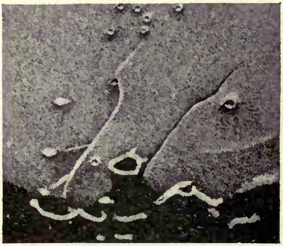
Messier.

Lambert.

Ukert.



Réaumur.



Cauchy.

Mountains on the Moon *(Stuyvaert)*.

Atlas and Hercules.

The Apennines.

Alphonsus.

Aristarchus.

Mountains on the Moon (*Stuyveart*).

[p. 37

correctly represents the facts as regards the Moon and the weather:

"The Moon and the weather
May change together,
But change of the Moon
Does not change the weather;
If we'd no Moon at all—
And that may seem strange—
We still should have weather
That's subject to change."

Besides the question of terrestrial weather, the Moon is credited with other influences, some genuine; some perhaps genuine, but more likely mythical. The most genuine lunar influence is its effect on the tides of the ocean--a subject of sufficient importance to demand a separate chapter hereafter. The influence which I have described as perhaps genuine is one which is wholly independent of the so-called changes of the Moon. It is that perhaps it is more often rainy during the increase of the Moon from New to towards Full than from Full to towards New. Moreover, that when the Moon is in perigee, or nearest the Earth, the chances of rain are greater than when it is in apogee, or farthest from the Earth.

Contrary to the prejudices of most people, perhaps one might say of the great mass of mankind, the epoch of New Moon is the period when changes of weather may be *least* looked for. The alleged lunar influences which must be regarded as mythical are too many to be recited here. Perhaps the most prominent is that which is enshrined in the word *lunatic*, which philologically may be taken to imply that the Moon has something to do with people going out of their minds; but, without going so far as this, one often comes across passages in books the writers of which insinuate that the rays of the Moon exercise a mischievous influence on human beings exposed to them. This is especially an idea current in the East, though it finds a counterpart in ideas met with nearer home. A writer named Carne has remarked :—

"The effect of the Moonlight on the eyes in Eastern Countries is singularly injurious. The natives tell you always to cover your eyes when you sleep in the open air; indeed, the sight of a person who should sleep with his face exposed to the Moon at night would soon be utterly impaired and destroyed."

Another writer, named Anderson, speaking of Batavia, is still more thrilling in his language :—

"One must here take great care not to sleep in the beams of the Moon uncovered; I have seen many persons whose necks have become crooked, so that they look more to the side than forwards."

A writer of very ancient date, Plutarch, remarked that the light of the Moon causes animal substances to putrefy; and it is said that Sicilian fishermen cover during the night fish which they expose on the sea-shore to dry, and for the same reason. Even before the time of Plutarch, Virgil, when describing the descent of Æneas into Hades, speaks of the *incertam Lunam sub luce malignâ*, "the Moon's doubtful and malignant light." [1] The old forest laws of France forbade the felling of trees except during the waning of the Moon, and a Scotch writer, many years ago, stated that peat dug during the increase of the Moon continues moist and never burns clear.

The writers of a very well-known book [2] make the following statement in it:

"Lunar influence seems to occasion phenomena of a very curious nature. It is confidently affirmed that it is not unusual for men on board a ship, while lying in the moonlight, with

[1] *Æneid*, book vi. line 270. I borrow from Milner's *Astronomy* the translation of "malignant" for *malignâ*; but Valpy renders it "faint and glimmering," which wholly changes the simile.

[2] *Voyages and Travels round the World*, by the Rev. D. Tyerman, and G. Bennett.

their faces exposed to the beams, to have their muscles spasmodically distorted and their mouths drawn awry—affections from which some have never recovered. Others have been so injured in their sight as to lose it for several months. Fish, when taken from the sea-water, and hung up in the light of the Moon during a night, have acquired such deleterious qualities that, when eaten the next day, the infected food has produced violent sickness and excruciating pains. We have conversed with people who have been themselves disordered after having partaken of such fish. It is hazardous to touch on this subject; we repeat what we have heard from those who ought to be believed, and who would not affirm that of which they themselves were not persuaded."

There is a circumstantial element of good faith in the foregoing quotations, which makes it impossible to disbelieve the facts stated. But where the writers have gone astray, and others have gone astray with them, is in their erroneous explanation of real facts. The explanation seems to be this. Animal substances may seem to putrefy, and peat to become moist, and human beings to become subject to bodily ailments when exposed to the light of the Moon, not because of that light, but because owing to the absence of clouds (the sky therefore being clear to permit a full display of moonshine), the radiation of heat from the Earth's surface is facilitated, so that objects, whether animate or inanimate, become colder than the surrounding air; the deposition of dew is therefore facilitated, and it is the moisture thus engendered which hastens the developement of muscular pains and bodily ailments in animated beings, and decomposition and putridity in inanimate objects.

The Moon travels round the Earth in 27 days, 7 hours, 43 minutes at a mean distance of 237,300 miles. Owing to the fact that its orbit is not a circle but an ellipse, the eccentricity of which is 0·05, it may sometimes be as near to the Earth as 221,600 miles, or may recede to as far as 253,000 miles. In consequence of this eccentricity its apparent diameter may vary between 29′ 21″ and 33′ 31″. Its diameter at mean distance is

31′ 5″ and its true diameter is about 2,160 miles. It will be sufficiently near the truth, for popular purposes, to say that its diameter as we see it is about $\frac{1}{2}°$, and is therefore about the same, apparently of course, as that of the Sun. Owing to the influence of the Earth's atmosphere the apparent diameter will differ somewhat according as we view the Moon when high up in the sky or low down near the horizon.

CHAPTER IV.

THE TIDES.

The tides matter of interest to the inhabitants of maritime countries.—Influence of the Sun and Moon in causing them.—Details of this influence.—That of the Moon greatly preponderates.—Spring Tides.—Neap Tides.—Daily differences.—Range of the tide.—"Establishment of the Port."—"Priming" and "lagging" of the tides.—Equinoctial tides.—Tides at the solstices.—Tidal irregularities of various kinds.—In and around Great Britain.—Amongst the South Sea Islands.—Influence of the barometer.—Journey of the tidal wave round the Earth.—The "Bore."

THE subject of the Tides of the Ocean is a mixed astronomical and geographical one, and it comes so much home to the inhabitants of an island kingdom such as Great Britain and Ireland that it must not be omitted from a volume which appeals to those interested in studying things which they can see. And it follows naturally chapters devoted to the Sun and the Moon, because those two luminaries are jointly concerned in causing the tides.

Diagrams illustrating the theory of the tides appear in every book on astronomy and need not appear here because, as it happens, it is possible to explain the matter without diagrams, which is a thing not always possible in dealing with some scientific problems.

Let us take, first of all, the case of the Moon. The Moon is the Earth's satellite, and as such is primarily responsible for the tides, though, as we shall see presently, the Sun is also concerned in a lesser degree.

The Moon, being the Earth's satellite, is in a sense held in its place by the attraction of the Earth; but there is a certain amount of mutuality in the matter—that is to say, though the Earth attracts the Moon, the Moon has a slight attractive power on the Earth, but it does not suffice to do much more than attract the water on the Earth, because the water is mobile. This is only half the truth, for the Moon does draw the Earth to a slight extent; but in doing so the water on exactly the opposite side is left behind, in a sense heaped up. Thus it comes about that, whilst it is high-water when the Moon is on, or near the meridian of the place of observation, there is also a condition of high-water on the opposite side of the Earth 180° removed in longitude from the meridian just spoken of. In other words, the coincident tides are separated from each other by 180°, or by half the circumference of our globe. Since the diurnal rotation of the Earth on its axis thus causes the tidal waves to pass successively right round the Earth once in about every 24 hours it follows that as there are two tidal waves constantly in motion, there are everywhere two high tides daily, with an interval of about 12 hours between them.

Now let us consider the influence of the Sun as brought into the matter. Though the mass of the Sun is so very much greater than the mass of the Earth, there are two reasons why the power of the Sun to raise or develope tides on the Earth is much less than its preponderating mass would lead us to suppose. Firstly, the greater distance of the Sun from the Earth, compared with the distance of the Moon from the Earth, diminishes the power of the Sun compared with what it would be were the distances on an equality; and, secondly, the developement of the tides is due solely to the *inequality* of the attractions in operation on different sides of the Earth, so that the greater the inequality the greater the resulting tide and *vice versâ*. The mean distance of the Earth from the Sun is about 11,720 diameters of the Earth, and consequently the difference between the distance of the Sun from one side of the Earth compared with the other will be only $\frac{1}{11720}$th of the whole distance. But in the case of the Moon, whose mean distance is only 30 diameters of the Earth, the difference between the distance from one side compared with the distance on the other side will be $\frac{1}{30}$th of the whole distance.

Inasmuch, therefore, as the height of the tidal wave depends on the inequality of the attraction and the inequality being in the case of the Moon represented by $\frac{1}{30}$, whilst in the case of the Sun it is only $\frac{1}{11720}$, the preponderance of the influence of one of these two bodies over the other is obvious. Worked out mathematically it was calculated by Newton to be about $2\frac{1}{2}$ to 1.

Thus far we have been supposing the Sun and Moon to be pulling together, but they only do that when they are in the same straight line, which is when the Moon is what we call New or Full. But when the Moon is in quadrature, or $\frac{1}{4}$th or $\frac{3}{4}$ths of the way round in its orbit, reckoned from the stage known as New or Full, then Sun and Moon do not pull together, and the resulting tide is only that due to the surplus influence of the Moon over that of the Sun; in other words, the resulting tide is a much smaller one than when they pull together. This explains the contrast which all residents on the sea-coast can realise between the high and low-water marks which they observe at the epochs of New and Full Moon compared with the rise and fall of the tides at the Quarters. The former tides go by the name of "spring tides," and give rise to the highest possible and lowest possible high-water and low-water marks respectively. The latter are known as "neap tides," and result in only a moderately high-water mark and a moderately low-water mark. The physical cause of these last-named circumstances will now be easily understood, for, whilst Spring Tides depend upon Sun, Moon, and Earth being all the same straight line, in the Neap Tides the Moon's attraction acts along a line perpendicular to that of the Sun ; in other words, the two bodies partly neutralise one another's action.

All the foregoing remarks have been based on the assumption (which is baseless), namely, that the Earth is a sphere covered all over by a layer of water of uniform depth ; but it is convenient to give the explanation on this assumption in order to make the matter more easily intelligible, and for this same reason the following propositions are framed on the same supposition, to be modified by subsequent explanations.

1. On the day of New Moon, Sun and Moon cross the meridian at the same time, namely, at noon ; then, after an interval, high-water occurs. Then the water begins to fall for 6 hours 12 minutes till it reaches its lowest position ; it then rises for 6 hours 12 minutes to a second maximum ; then falls for another interval of 6 hours 12 minutes, and rises again during a fourth interval of 6 hours 12 minutes. It has, therefore, two maxima and two minima in a period of 24 hours 48 minutes, which is called a "tidal day." The foregoing intervals are not quite correctly expressed, even in theory, for the water usually takes a longer time in falling than it does in rising, as may be noticed by any one sitting on the seashore.

2. On the day of Full Moon the Moon crosses the meridian 12 hours after the Sun, namely, at midnight, and the tidal phenomena are the same as stated in the previous paragraph.

3. As time is reckoned by the apparent motion of the Sun, the solar tide always happens at the same hour[1] at the same place ; but the lunar tide, which is the greater, and therefore gives a character to the whole, happens 48 minutes later every day. It therefore separates eastwards from the solar tide at that rate, and becomes later and later till, at the First and Third Quarters of the Moon, it happens at the same time

[1] I ignore here the question of the difference between apparent solar time and mean solar time and the customary adjustment of these times by what is called in the almanacks the "equation of time."

as the low-water of the solar tide: then the elevation of the high-water and the depression of the low will be the difference of the solar and lunar tides, and the condition of things will be represented by the term Neap Tide.

4. The difference in height between high and low-water is called the "range of the tide," and obviously may be measured in two ways: either horizontally along the shore or vertically on a post of suitable height, and suitably placed for the purpose. The former principle of measurement would be the one adopted by an unscientific seaside visitor, but the latter will often be noticed as measurable by numbered marks on the columns supporting a pier, or painted on the upright wall of a jetty or breakwater.

5. The Spring Tides are the highest, especially those which happen 36 hours after the New or Full Moon.

6. The Neap Tides are the lowest, especially those which happen 36 hours after the Moon is at one of its quarters, or in quadrature, to speak scientifically.

7. The interval of time between noon and the time of high water at any particular place is the same on the days both of New and Full Moon. The precise moment of high-water at any place when the Moon is New or Full is called by French writers *L'établissement du port*, and that expression has now been brought into use in English as the "Establishment of the Port," an awkward phrase which in itself conveys no meaning till explained.

The fact that an interval of time elapses at any given place between the meridian passage of the Moon and the time of high-water is due to another fact, namely, that the waters of the ocean are retarded by friction whilst they are in motion over the solid surface of the Earth; and so it comes about that both the lunar and the solar tidal waves are not found immediately under their respective luminaries, but follow them at a certain distance. Moreover, the tidal wave is affected in another way by the action of both these luminaires, and at certain periods of the lunar month the progress is either accelerated or retarded. During the First and Third Quarters the solar tide is W. of the lunar one; and consequently the actual high-water due to the combination of the two waves will be to the W. of the place at which it would have been if the Moon were acting alone; accordingly the time of high-water will be accelerated. On the other hand, in the Second and Fourth Quarters the Sun produces a retardation in the time of high-water. These effects are called the "priming" and "lagging" of the tides, and the effect is to derange the average retardation, which from a mean value of 48 minutes may be augmented to 60 minutes or be reduced to 36 minutes. It follows from this that a sea-bather who is watching for a chance of getting sand and not stones for his foothold, and on a certain day does just escape the stones, will not of necessity on the next day find himself exactly in the same pleasant position at a moment which is exactly 48 minutes different from the time shown by his watch on the previous day.

The highest Spring Tides occur when the Moon passes the meridian of the place of observation about 1½ hours after the Sun, for then the maximum effects of the two luminaries coincide.

The height of the tides is affected by another consideration—the positions of the Moon and the Sun with respect to the Equator; the nearer these two bodies are to the Equator the greater the height of the tide. Twice a year, at what we call the Equinoxes—that is to say, about March 21 and September 22, speaking roughly—the Sun is actually in the Equator. If at these dates the Moon should be in or near the Equator the tides will be the highest possible. Such tides are spoken of as the Equinoctial Spring Tides. On the other hand the smallest tides will occur at about the Solstices (June 21 and December 22) if the Moon attains its least or its greatest meridian height at the same time as the Sun.

Finally, the distances of the Earth from the Moon and the

Sun also affect the height of the tides. Other things being equal, the height of a tide is greater or less according as the Moon and the Sun are near to or far from the Earth. Accordingly the tides at or near December 22 are higher than those at or near June 21, the Earth being nearest to the Sun (perigee being in January) and farthest from the Sun in June (apogee being in July).

Thus far in our consideration of the tidal wave we have been keeping up the fiction, already referred to, of the Earth being a ball of solid matter with a smooth surface and covered all over with a layer of water of even depth everywhere. It needs not to be pointed out that this is pure fiction, some parts of the Earth being land and other parts being water, the two being distributed most irregularly, and the bottom of the Ocean everywhere being of varying depth, just as the elevation of the land is everywhere of varying height.

These facts have a most distracting influence on the times and circumstances of the movements of the Earth's water; and though the rotation of the Earth on its axis and the movements of the Moon and of the Sun all co-operate in imparting a motion of translation, so to speak, to the Oceans of water which exist on the Earth, local circumstances entirely destroy the theoretical conditions. In other words, the actual phenomena of the tides are exceedingly complicated, and incapable of being defined by cast-iron rules because of the irregular outline of the land, the uneven surface of the bed of the ocean, and the action of winds and of currents of air and currents of water, and so on.

The effect of all these disturbing influences cannot be better brought home to the mind than by a consideration of the following details. If the surface of the Earth were entirely covered by the hypothetical layer of water mentioned on a previous page, the height of a tide raised by the Sun's attraction would be 1 ft. 11 in., and of a lunar tide 4 ft., but the difference in the level of the waters in the ocean due to the disturbing causes just spoken of are, in the vast number of cases, entirely different, and in excess of these figures. In deep estuaries or creeks ending in narrow channels, which gradually converge inwards as a common wine-funnel does, the range is very much greater than along an open shore. For instance, in the Bristol Channel, off Chepstow, the range of rise and fall is as much as 38 ft., and in some similar situations in foreign countries the range is even greater.

I once had an opportunity of standing on the shore of the Bristol Channel on the Gloucester side of Chepstow, and the rapidity with which landmarks such as piles and rocks, near and around which I had walked a few minutes previously, were submerged, and deeply submerged, was very striking to me, whose experience of the rise and fall of the tides was limited to open shores on the South and East of England.

Along open shores the rise and fall, measured in feet, are comparatively limited, especially where promontories or headlands jut out into the sea. Thus, at the Needles in the Isle of Wight, the range is only 9 ft., whilst at Weymouth it is even less, being only 7 ft. On flat shores which bound large open expanses of water such as the Atlantic and Pacific Oceans, and confined seas like the Mediterranean, the elevation of the tidal wave is to be measured rather by inches than by feet. Thus at Toulon it is 1 ft.; at St. Helena 3 ft.

The barometric pressure of the atmosphere is also a factor to be taken into account in considering the probable range of the tide at a given place and at a given time. When the barometer is low an unusually high tide may be expected, and *vice versâ*; and it has been estimated that a depression of 1 in. in the column of mercury in the barometer has at the London Docks the effect of raising the level of the tidal water by the amount of 7 in., which at Liverpool would be 10 in. Thus it would come about that, supposing an unusual high tide in the Thames (as has happened) brought the water up to the level of the masonry of the Thames Embankment, a sudden fall of the barometer might unexpectedly bring the water over on to the highway, though no such risk had been previously contemplated. The influence of the wind also cannot be left out of account, for it is often very potential either in aggravating the destructive effects of a very high tide or of checking them.

It is in the Pacific Ocean and among the South Sea Islands that the most extraordinary anomalies in connection with the tides are to be observed. Many travellers and navigators who have performed voyages in those parts of the world have recorded their strange experiences. I have come across many such records, and transcribe the following as the most recent which I have seen :—

"This is, so far as I know, the only part of the world [Tahiti] where the tide is high but once a day, and regularly at the same hour—between 1 and 2 o'clock in the afternoon. The rise and fall does not exceed 1 ft. There must, I suppose, be a corresponding movement of the sea after midnight. It may be so slight that the regular evening breeze retards and renders it imperceptible. I have often questioned nautical men on the subject, but I have not been able to elicit any satisfactory explanations: nor do Nautical Almanacs, nor the sailing instructions issued by the Hydrographic Department, do more than chronicle the extraordinary fact."[1]

The following description of the course of the general tidal wave of the Earth is so clear and concise that it can neither be improved upon nor be abridged. I therefore quote it in full :—

"The Antarctic is the cradle of tides. It is here that the Sun and Moon have presided over their birth, and it is here, also, that they are, so to speak, to attend on the guidance of their own congenital tendencies. The luminaries continue to travel round the Earth (apparently) from east to west. The tides no longer follow them. The Atlantic, for example, opens to

[1] E. Reeves, *Brown Men and Women; or, the South Sea Islands*, p. 381, London, 1898.

4

them a long, deep canal, running from north to south, and, after the great tidal elevation has entered the mouth of this Atlantic canal it moves continually northward ; for the second 12 hours of its life it travels north from the Cape of Good Hope and Cape Horn, and at the end of the first 24 hours of its existence has brought high-water to Cape Blanco on the west of Africa and Newfoundland on the American continent. Turning now round to the eastward, and at right angles to its original direction, this great tidal wave brings high-water, during the morning of the second day, to the western coasts of Ireland and England. Passing round the northern cape of Scotland, it reaches Aberdeen at noon, bringing high-water also to the opposite coasts of Norway and Denmark. It has now been travelling precisely in the opposite direction to that of its genesis, and in the opposite direction, also, to the relative motion of the Sun and Moon. But its erratic course is not yet complete. It is now travelling from the northern mouth of the German Ocean southwards. At midnight of the second day it is at the mouth of the Thames, and wafts the merchandise of the world to the quays of the port of London. In the course of this rapid journey the reader will have noticed how the lines [on the map] in some parts are crowded together closely on each other, while in others they are wide asunder. This indicates that the tide-wave is travelling with varying velocity. Across the Southern Ocean it seems to travel nearly 1000 miles an hour, and through the Atlantic scarcely less ; but near some of the shores, as on the coast of India, as on the east of Cape Horn, as round the shores of Great Britain, it travels very slowly; so that it takes more time to go from Aberdeen to London than over the arc of 120° which reaches from 60° of southern latitude to 60° north of the Equator. These differences have still to be accounted for; and the high velocities are invariably found to exist where the water is deep, while the low velocities occur in shallow water. We must therefore look to the conformation of the shores and bottom of the sea as an important element in the phenomena of the tides." [1]

Theoretically, if the whole Earth were uniformly covered with water, the average velocity of the tidal wave round the

[1] JOHNSON, *Physical Atlas*.

Earth would be rather more than 1000 miles per hour, and the writer of the foregoing extract seems to think that this velocity is nearly reached in the Southern Ocean, where there exists a vast stretch of water not broken in upon by any important masses of land.

Though I have mentioned the islands of the Pacific as localities where special anomalies exist in connection with the tides, it must not be forgotten that much nearer home, to wit on the coasts of Hampshire and the Isle of Wight and some other localities, some strange departures from the normal condition of things tidal are often exhibited. In the case of Hampshire, owing to the fact that the tides in the Solent and at Spithead do not run easterly on the flood and westerly on the ebb, as is the case in the open Channel, but run from—

Half-flood to half-ebb—easterly,
Half-ebb to half-flood—westerly—

—Southampton and places up Southampton Water have four tides in the 24 hours instead of two, so that, after flowing to half-flood, and filling up with the west-travelling tide, when the tide changes outside Calshot Castle, there is a slack and a partial ebb, until the eastern tide brings enough water to push the flood home to its full. Likewise on the ebb, when the tide changes, there is a slack and slight flow, until the suction of the west-going tide draws the water away down Channel.[1]

The situation of the Isle of Wight as an island opposite an estuary may, no doubt, be taken to suggest that similar tidal vagaries exist elsewhere in the world.

As regards anomalies elsewhere in the British Isles, it is stated by a Scotch writer who studied very closely the geographical circumstances of the West of Scotland that in the strait between the island of Isla and the islets of Chenzie and

[1] I owe the foregoing account of the tides in the Solent to Mr. C. G. Brodie, F.R.A.S., an experienced yachtsman, and I have never seen this information in print.

Oersa the time occupied by the ebb-tide out of the theoretical 12 hours is $10\frac{3}{4}$ hours, whilst the flood-tide occupies only $1\frac{1}{4}$ hours.

The last matter to be mentioned in connection with the tides is the striking and remarkable phenomenon which, bearing various local names, is commonly called in English a "Bore." It is to be seen only at the mouths of rivers which contract at a sharp angle from a wide estuary to a narrow channel, and happens only when a spring-tide of unusual height rushes up the estuary into the narrow channel, carrying all before it with a great roar.

From all accounts the bore on the river Tsien-Tang-Kiang, in China, must be regarded as one of the most remarkable in the world; and there is the further fact attaching to it, that it has been made the subject of a very full and complete scientific investigation by a thoroughly competent observer, Admiral W. U. Moore, whose account was communicated in 1889 to the Institution of Civil Engineers. His remarks are so usefully comprehensive that a summary of them will make my account of bores in general much more complete than it could otherwise have been. [Plate XXXIII.]

To begin with the name "bore." The Admiral ascribes it to an Icelandic word meaning "billow." It is also called in England the "hygre," and "eagre"; also "egre." The Admiral derives "eagre" from the French "eau-guerre," or "water-war," which sounds ingenious, whether authentic or not. In France it is known as the "mascaret," and in Brazil as the "pororoca." It seems to occur in 6 or 8 rivers in the British Isles, including the Severn, the Wye, the Trent, and the Solway; in two or three French rivers—namely, the Seine, the Garonne, and the Loire; in some of the Indian rivers, including the Ganges, the Brahmaputra and the Indus; in the branches which compose the mouth of the Amazon in S. America; and in one river at least in China. It is rarely observed except at a spring-tide, and as a rule shows itself on the days of Full and New Moon, appearing with the first of every flood-tide for 3 or 4 days succeeding those phases; after which the tide comes in with only a swift rush unaccompanied by noise or violent commotion.

The 3 following conditions appear to be necessary to create a bore:—

1. A swiftly flowing river.

2. An extensive bar of sand, dry at low-water, except in certain narrow channels kept open by the outgoing stream.

3. The estuary into which the river is discharged must be funnel-shaped, with a wide mouth which is open to receive the tidal wave coming in from the Ocean.

If either of these 3 conditions is wanting there will be no bore. For example, in the case of the Thames, the third condition exists, but the first and second are wanting; for the Thames is not a swift river, and has no bar, dry at low-water. In the Severn all 3 conditions are found, and accordingly there is a bore; not a very large one, it is true, but still the most noteworthy in the British Isles.

The bore of the Tsien-Tang-Kiang has all 3 conditions well developed. The estuary into which the river falls has a vast area of sand at its head, and is favourably situated for the reception of the incoming tidal wave from the Pacific. The range of the tide immediately outside the Hang-Chau Gulf is 12 ft., but as the wave becomes compressed in advancing towards its head at the end of the navigable waters, it is as much as 25 ft. at ordinary spring-tides, and 34 ft. when there is the favourable combination of a wind blowing on shore, and a Moon in perigee at the time of Full or New. The navigable breadth of the estuary at its head (where the tidal wave rises to its greatest height) is about $\frac{1}{5}$th or $\frac{1}{6}$th of what it is at the mouth; and if there were no river discharging into the bay the range would probably be 60 ft. or 70 ft., as in the Bay of Fundy.

The speed of the advancing tidal wave was measured by the officers of H.M.S. *Rambler*, and found to be $14\frac{1}{2}$ statute miles an hour. The breadth of the bore is about 1 mile, and its front presents the appearance of a gleaming white cascade of bubbling foam, 8 ft. to 12 ft. in height. The noise is not the least impressive feature of this phenomenon. On a calm still night it can be distinctly heard 14 or 15 miles off, and more than an hour before it arrives. The noise increases very gradually until the bore comes abreast of an observer on the bank of the river, when he has to endure a roar but little inferior to that of the Rapids below Niagara.[1]

South America seems to offer an example of a bore of a very remarkable character. The following description of a bore on the river Amazon penned by La Condamine a great many years ago is a fitting pendant to Admiral Moore's account of the Tsien-Tang-Kiang bore :—

"During three days before the New and Full Moons, the period of the highest tides, the sea, instead of occupying six hours to reach its flood, swells to its highest limit in one or two minutes. The noise of this terrible flood is heard five or six miles off, and increases as it approaches. Presently you see a liquid promontory 12 or 15 feet high, followed by another, and another, and sometimes by a fourth. These watery mountains spread across the whole channel, and advance with a prodigious rapidity, rending and crushing everything in their way. Immense trees are sometimes uprooted by it, and sometimes whole tracts of land are swept away."

[1] Abridged and added to from Admiral Moore's paper in the *Minutes of Proceedings of the Institution of Civil Engineers*, Session 1889-90, vol. xcix. Part I. A still more detailed account will be found in the *Journal of the China Branch of the Royal Asiatic Society*, vol. xxiii. 1888. See also Sir G. H. DARWIN'S Treatise on *Tides*.

CHAPTER V.

THE PLANETS GENERALLY.

What the planets are.—May be conveniently divided into two groups.—The Inferior Planets.—The Superior Planets.—The Minor Planets.—Certain planets have satellites.—The purpose served by them.—Certain planets have phases.—The planets in Conjunction.—The planets in Opposition.—Transits across the Sun.—Characteristics common to all the planets.—Statement of these by Hind.—Kepler's Three Laws.—Sir J. Herschel's statement.—Conjunction of two planets.—Instances of this.—Various discarded planetary systems.—Suggested Intra-Mercurial and Trans-Neptunian planets.

ROUND the Sun, as a centre, there circulate a considerable number of bodies which we call planets[1]: these are now known to be, indeed, many hundreds in number, but we can count on our fingers those which alone are worthy of general attention. Those which are known to everybody and which have been recognised as planets from the earliest times are still fewer in number, and comprise only Mercury, Venus, the Earth, Mars, Jupiter, and Saturn. For the purposes of astronomy the Earth, though strictly a planet in the proper sense of the word, may be left out of consideration, because we, being on the Earth, cannot approach its study in the same way in which we deal with the other planets just named. The study of the Earth concerns the sciences of geography and geology in particular, and, except for the purpose of noting its place in the solar system, because it is one of the *cortège* of

[1] Greek, πλανήτης, a wanderer.

planets which travel round the Sun, the astronomer has not much concern with it. He uses it, however, for the arbitrary purpose of separating the planets into two groups, putting into one group those which are nearer the Sun than the Earth and into the second group all the other planets outside the orbit of the Earth.

The former are called "Inferior" planets, and, so far as we know, are only two in number, namely, Mercury and Venus: the others are called "Superior" planets, and include not only the other three named above (Mars, Jupiter, and Saturn), but two other large planets still farther off, Uranus and Neptune, together with some 700 miscellaneous planets known as the "Minor" planets, which circulate round the Sun in orbits lying between Mars and Jupiter.

It will be readily understood, from what has just been said, that the designations "Inferior" and "Superior" are not a little misleading, because both the Inferior planets are very much larger than nearly all the Superior ones, reckoned in respect of their numbers.

There is another important distinction between the two classes of planets. The Inferior ones have no satellites, whilst all the large Superior ones are provided with attendants, which are called satellites, though frequently spoken of as "moons," because serving the purposes served by our Moon. This distinction, as regards the possession or non-possession of satellites, may possibly be ascribed to design on the part of the Creator. Mercury and Venus, being so comparatively near to the Sun, do not need the benefit afforded by a satellite in the way of supplementary light. The Earth, as we have seen, is so favoured by having a companion to afford additional light, and probably it may be said with truth that, as all the other Superior planets have satellites, and, with the exception of Neptune, satellites greater in number than the Earth has, such satellites may be regarded as performing the special office of supplying in some degree to their primaries light by way of compensation for the limited amount of Sunlight which they receive because of their vast distance from the Sun. There is another important distinction between the Inferior and Superior planets. The former are subject to phases which are identical in character with the phases of the Moon—Crescents, Quarters, Full, and so on ; whilst the Superior planets, with the exception of Mars and Jupiter (in a slight degree), exhibit no appreciable phases.

The phases of Mercury and Venus involve the consequence that they pass round the Sun, sometimes on this side of the Sun looked at from the Earth, and sometimes on the farther side of the Sun. When passing on our side, then, at the moment at which Earth, planet, and Sun are exactly in the same straight line, the planet is said to be in "Conjunction" with the Sun. When on the opposite side, with the Earth, Sun and planet in the same straight line, the planet is said to be in "Opposition." A moment's thought will make it evident that when in these two positions (and also, unless they are at a certain distance, on either side) the planets will be lost in the Sun's rays, and will therefore be invisible to us.

There is one exception to the rule of these planets being invisible when in Conjunction, and that is when either of them is in a straight line, so disposed that the planet may be seen actually on and passing across the Sun's disc. This phenomenon, which is rare, constitutes what is called a "transit" of the planet. But the consideration of this in detail belongs to a later chapter.

The circumstances of the Superior Planets are altogether different. They never can be in Conjunction with the Sun in the same sense that the Inferior Planets can be, because they are always going round the Sun in orbits outside that of the Earth. The epoch of Conjunction with them puts them in a straight line but in a different order, namely, in the order of Earth, Sun, Planet. When this happens they are invisible from the Earth because lost in the Sun's rays ; and that state of things subsists for a certain length of time before and after Conjunction, dependent on the brilliancy of the particular planet and our optical means to view it when immersed to some degree in the Sun's rays, which means in some degree of twilight.

The Superior Planets are also on occasions in Opposition, but here again the term has not quite the same meaning as it has when applied to an Inferior Planet. An Inferior Planet is, as we have seen, lost in the Sun's rays; but a Superior Planet is at its very best, so far as the Sun is concerned, when in Opposition, because it is on the meridian at midnight when the Sun is on the meridian at midday, the order of position being Sun, Earth, Planet.

The only Superior Planet subject to a clearly evident phase is Mars, which in two positions in its orbit (Quadratures, E. and W.) suffers a slight encroachment first on one side and then on the other side of its disc. Theoretically, Jupiter should exhibit a slight phase under analogous conditions, but it is not very easy to appreciate it; still, it must be deemed, when at its quadratures, to be slightly gibbous (as the term is), but much less so than Mars. The defalcation of the light is on the limb of the planet which is farthest from the Sun.

There are certain characteristics common to all the planets, which have been stated by Hind in the following terms:—

1. They move in the same invariable direction round the Sun, their course, as viewed from the N. side of the Ecliptic, being contrary to the motion of the hands of a watch.

2. They describe oval or elliptical paths round the Sun, not, however, differing greatly from circles.

3. Their orbits are more or less inclined to the Ecliptic, and intersect it in two points, which are the "Nodes," one half of the orbit lying N. and the other half S. of the Earth's path.

4. They are opaque bodies, like the Earth, and shine by reflecting the light which they receive from the Sun.

5. They revolve upon their axes in the same way as the

Earth. This, we know by telescopic observation, to be the case with many planets, and, by analogy, the rule may be extended to all. Hence they will have the alternation of day and night, like the inhabitants of the Earth; but their days are of different lengths to our own.

6. Agreeably to the principles of Gravitation, their velocity is greatest at those parts of their orbits which lie nearest the Sun, and least at the opposite parts which are most distant from it; in other words, they move quickest in perihelion and slowest in aphelion.

Although the matter is somewhat technical, I think it well to mention here, in order to make these general statements complete, the laws regulating the movements of the planets which bear the name of Kepler. They may be stated as follows:—

1. The planets move in ellipses, having the Sun in one focus.

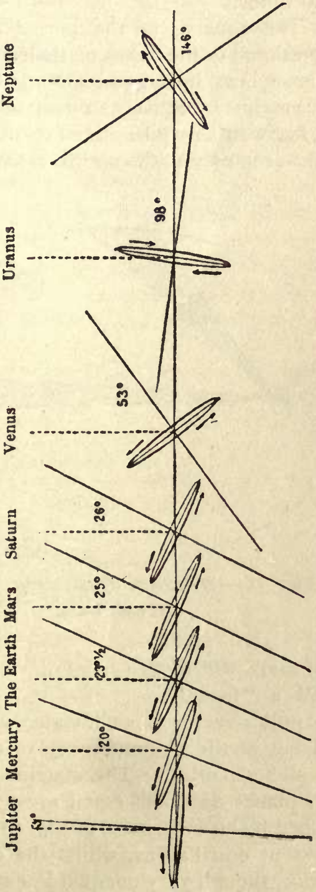


Fig. 70.—The Inclination of the Axes of the Planets to the Ecliptic.

2. The radius-vector of each planet describes equal areas in equal times.

3. The squares of the periodic times of the planets are proportional to the cubes of their mean distances.

These laws hold good for all the planets, and also for all their satellites relatively to their respective primaries.

A few words may be added to make these laws a little more clear to the non-mathematical reader. Everybody understands what the centre of a circle is, and that from the centre every part of the circumference is equidistant; but, in the case of an ellipse, there is no point inside it which is equidistant from the circumference; and, in order to draw such a figure, one must make use of two points inside. Each of these points is called a "focus."

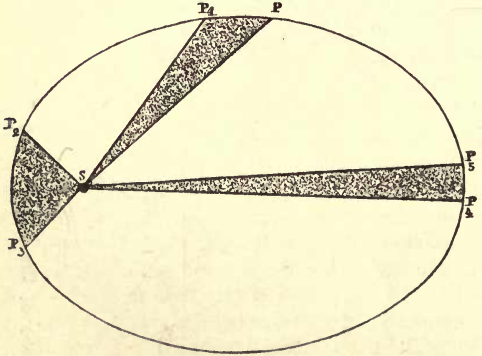


Fig. 71.—Diagram illustrating Kepler's Second Law.

A radius-vector is an imaginary line drawn from the Sun to a planet at the circumference of the ellipse which constitutes the planet's orbit. The statement that the radius-vector of each planet describes equal areas in equal times will be best grasped by an inspection of Fig. 71, where the shaded portions represent equal areas, whilst the distances along the circumference, though very unequal in extent, are yet traversed by the planet in equal periods of time. Such is the case because every planet moves faster when nearest the Sun than it does when farthest off from the Sun.

Kepler's Third Law involves a curious point: if the distance of the Earth from the Sun be taken as unity (1·0), and its period taken in days, then if the squares of the periods of the planets be divided by the cubes of their mean distances from the Sun, the result in quotients will be the same substantially for all the planets, the slight discrepancies in the quotients being due to inexactness in the observations on which the calculations are based.

This law applies to all the satellites, so that an identical quotient will be obtained for each group of satellites, though, comparing one group with another, the quotients will vary *inter se*.

The foregoing statement, calculated for the planets, is exhibited in the following table:—

Planet.	Distance from sun: a	Period in days: p	$\frac{p^2}{a^3}$
Mercury . . .	0·38710	87·969	133421
Venus	0·72333	224·701	133413
Earth	1·00000	365 256	133408
Mars	1·52369	686·979	133410
Ceres (as typical Minor Planet) . . .	2·77692	1679·855	132210
Jupiter	5·20277	4332·585	133294
Saturn	9·53858	10759·220	:33375
Uranus	19·18239	30686·821	133422
Neptune . . .	30·03627	60126·722	133413

To draw an ellipse, the following points must be borne in mind. The eccentricity of an ellipse is the ratio of the distance between the centre and either focus to the length of the semi-axis-major. It is usually given as a decimal fraction, the semi-axis-major being taken as unity, or 1·0. Thus, an eccentricity given as 0·25 means that the distance between the centre and either focus is $\frac{1}{4}$th of the semi-axis-major. This is sometimes symbolised by the Greek letter ϕ and with an angular measurement named. In that case the eccentricity is obtainable by finding from the tables what is the natural sine of the angle ϕ.

In order to draw an ellipse of a prescribed eccentricity first of all draw a line of any convenient length to represent the axis-major of the intended ellipse; bisect it and mark the point of bisection; then from the centre set off in each direction along the line, according to the selected scale, distances equal to the eccentricity; the points so determined will be foci of the required ellipse. Fix pins at these points and at one of the extremities of the axis, and then proceed as follows. Tie a loop of cotton or silk tightly round these pins; remove the pin which is at the extremity of the axis-minor; stretch the thread tightly with the point of a pencil and move the pencil round under the guidance of the thread kept tightly drawn.

Perhaps an actual example in figures will make the *modus operandi* of this more clear. Say you want to draw an ellipse of the eccentricity 0·75. Draw a line 10 inches long on stiff white paper or card-board; bisect it; set off on each side of the point of bisection distances of $3\frac{3}{4}$ inches (*i.e.* 7·5 half-inches); these points will be the foci of the required ellipse. Then proceed with the aid of the thread as above. Of course any units may be employed in devising a scale, but perhaps inches, as in the above example, will generally be found most convenient when it is desired to obtain the form of a planetary or cometary orbit.

Sir John Herschel put forth, many years ago, a fancy statement for the purpose of enabling a reader to obtain a rough general idea of the dimensions of the solar system and of its constituent planets. The statement needs some revision and expansion, to meet present circumstances—treatment which I have applied to it; and I now present it in the following form:

Imagine a large open common; on it place a globe 2 feet in diameter by way of representing the Sun; Mercury will then be represented by a mustard-seed at a distance of 82 feet; Venus by a pea at a distance of 142 feet; the Earth also by a pea at a distance of 215 feet; Mars by a small pepper-corn at a distance of 327 feet; the Minor Planets by grains of sand at distances varying from 500 to 600 feet; then a moderate-sized orange ¼th of a mile distant from the central point will represent Jupiter; a small orange ⅖ths of a mile, Saturn; a full-sized cherry ¾ths of a mile, Uranus; and lastly, a plum 1¼ miles, Neptune, the most distant planet yet known, though astronomers suspect there exists another planet still farther off and hope one day to find it.

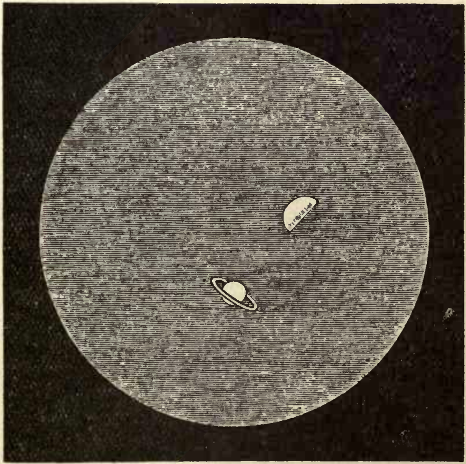


Fig. 72.—Conjunction of Venus and Saturn, Dec. 19, 1845.

Extending this scheme, the aphelion distance of Encke's Comet would be 880 feet; the aphelion distance of Donati's Comet 6 miles, and the nearest fixed star 7500 miles.

An idea of the absolute movements day by day of the planets in their orbits would be obtained by imagining Mercury to move every day 3 feet; Venus 2 feet; the Earth $1\frac{7}{8}$ feet; Mars $1\frac{1}{2}$ feet; Jupiter $10\frac{1}{2}$ inches; Saturn $7\frac{1}{2}$ inches; Uranus 5 inches; Neptune 4 inches. These figures serve also to illustrate the fact previously mentioned that the orbital velocity of a planet decreases as its distance from the Sun increases: and by a vast stretch of the imagination we might suppose a place in the Universe where a planet would not move round the Sun at all; in other words, where Gravitation would cease so far as our solar system was concerned.

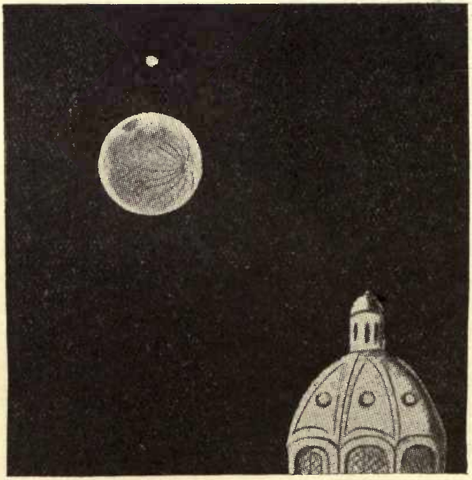


Fig. 73—Conjunction of Mars and the Moon, Sept. 28, 1909.

A matter of some interest, as a spectacle, is the occasional conjunction of two or three planets in the same part of the heavens. It is exceedingly rare to get more than two planets together in the same field of a telescope, but a combination of two only is not at all uncommon. Besides those which are here illustrated, some more recent instances may be mentioned.

In September 1878 Mercury and Venus were together in the same field of the telescope for some hours. According to Nasmyth, the contrast in the appearance of the two planets was very marked. Venus looked like clean silver, whilst Mercury had more the appearance of lead or zinc. This last statement is rather curious, because Mercury is generally credited with being of a rosy tinge.

On August 9, 1886, Venus, Saturn, and the bright star δ Geminorum were in the same field.

On May 6 of the same year Venus and Mars were very close to one another, Venus being 0° 5′ to the south.

That same month of May 1906 yielded two other conjunctions visible in telescopes armed with low-power eyepieces having large fields.

On May 11 Venus and Jupiter were close together, Venus being 1° 11′ to the N. A week later, on May 18, Mars and Jupiter were closer still together, Mars being 1° 6′ N. Such a succession of planetary conjunctions, conspicuous planets being involved, is unique.

On August 17, 1911, Mars and Saturn were within 21′ of each other, and therefore in the same field. McEwen, at Glasgow, remarked that :—

"Saturn presented a bright chrome colour in contrast to the bright ochre tint of Mars. It must, however, be admitted at a first glance that Mars did look somewhat insignificant compared with Saturn with its rings, although to the naked eye Mars appeared much the brighter of the two planets."

An observer in America, Conroy, at Los Angeles, wrote much to the same effect :—

"The difference in the colours of the two planets was not as pronounced as I had supposed it would be. Mars glowed with his usual strong, ruddy hue. To the naked eye, and still more in a field-glass, Saturn was decidedly yellow, with a greenish tinge."

The 18th century produced a planetary conjunction which, if correctly recorded, must have been singularly striking, for it is said that Venus, Jupiter, Mars, and Mercury were all seen together in the same field of the telescope.

Whilst we nowadays clearly understand that the Sun is the centre of our planetary system, yet the realisation of that fact is quite a thing of modern times, being hardly more than three centuries old. Our system has been called the Copernican System, from the Polish astronomer, Copernicus, who gave it shape, though not quite its final shape. Up to his time, and indeed for a century or more later, there were rival systems in the field. They may be named in something like the order of date as the Ptolemaic System, the Egyptian System, and the Tychonic System. But it seems hardly worth while to describe these in detail.

The question is a natural one : Are there more planets circulating round the Sun than those already spoken of? It is probably true to say that there are, and the question of a planet within the orbit of Mercury, and also of one beyond the orbit of Neptune, are matters which have attracted the thoughts of many astronomers, though without any very certain results.

The romance of an intra-Mercurial planet caused great searchings of heart 50 odd years ago, and many were fascinated with the story of the French doctor, Lescarbault. The idea of a Trans-Neptunian planet has not yet reached the stage of romance, much less that of fascination.

CHAPTER VI.

THE MOST INTERESTING AND FAMILIAR PLANETS.

A classification of the planets.—Mercury.—Difficult to observe.—Spots.—Phases.—Schiaparelli's observations.—Axial rotation.—Statistics.—How to find Mercury or Venus.—Venus.—Movements resemble those of Mercury.—Physical Features.—Possible mountains.—Atmosphere.—Alleged satellite.—Phases.—Galileo's anagram.—Statistics.—Mars.—The Earth's nearest neighbour.—Celebrated for its colour.—Subject to a slight phase.—This planet very accessible for observation.—Its apparent movements.—Physical appearance.—Much controversy as to this.—Polar snows.—Spots.—Markings very permanent.—Its colour.—Satellites.—Statistics.—Jupiter.—Easy of observation.—The largest planet.—Belts.—Spots.—Jovian spots and Sun-spots.—Satellites.—Large oncs easily found and followed.—Small ones very difficult.—Phenomena.—Velocity of light.—Statistics.—Saturn.—Its rings.—General description of them.—How designated.—Changes in the appearance of the rings from time to time.—Some details respecting them.—The ball.—The satellites as tests for telescopes.—Statistics.

THE classification of the planets in a previous chapter into 'Inferior' and 'Superior,' though desirable from a scientific point of view, is not one which appeals much to the popular observer of astronomical phenomena, who is concerned more particularly with what he is able to see. Accordingly, it will be convenient to adopt now a new classification, which cuts across the previous one, because of its being framed upon quite a different basis. Whilst one group responds readily to the general title of the "Interesting and Familiar Planets," it would be somewhat unphilosophical to gibbet the residue as the "Uninteresting Planets," for the statement would not be true of some of them, and I can only give them the vague title of "planets which do not attract the notice of the generality of readers."

Under the title of "Interesting and Familiar Planets" I shall deal with Mercury, Venus, Mars, Jupiter, and Saturn, all of them shining, as a rule, with a sufficient amount of general brightness to attract the notice of almost everybody from time to time; but Venus, Mars, and Jupiter, under all circumstances, do so most. Mercury and Venus, being within the orbit of the Earth, can never be very far from the Sun. Venus, however, on occasions, shines with such splendour that twilight has no appreciable effect in impairing it. Mercury, however, being so much nearer the Sun than Venus, is more difficult to find and follow, because it is never out of bright twilight. The other planets belonging to this chapter—Mars, Jupiter, and Saturn—are all intrinsically bright, especially Mars, and, as they wander all over the heavens, one or other of them is almost always in view at some hour of a given night. Inasmuch as all these five planets have special features of their own, it will be well to give them sections of this chapter to themselves.

MERCURY.

Mercury does not receive much attention, owing to the difficulty of seeing it, as already stated. Its greatest possible elongation or distance from the Sun not exceeding $27^\circ\ 45'$ (and it being in general much less), the difficulty is obvious. The greatest possible elongation on the E. side happens at the end of March or beginning of April, Mercury being an "evening star"; whilst the greatest possible elongation on the W. side happens in September, when Mercury is a "morning star."

The chances of seeing it are best for us in England when an elongation coincides with a northerly position of the planet in declination, even though the elongation is less than it might be at other times. It may often be seen with the naked eye, shining with pink or rosy light. It was so seen by many observers in April 1905.

The observations of Schröter at Lilienthal, and of Sir W. Herschel, led them to think they had obtained decisive evidence of high mountains on the planet's surface, and that one in particular in its southern hemisphere manifested its presence by the planet's southern horn having a truncated (or blunted) appearance near Inferior Conjunction, which might be due to a mountain obstructing the light of the Sun from reaching as far as the point to which the cusp theoretically extended.

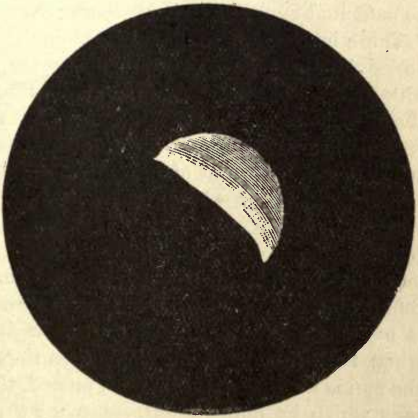


Fig. 74.—Mercury, Sept. 17, 1885. (*Guiot.*)

Denning, in 1882, saw some dark irregular spots upon the planet; also a brilliant spot and a large white area. The southern horn was also much blunted. He states that his results led him to infer that the markings upon Mercury are far more decided and more easily discernible than those of Venus, and that Mercury's surface resembles in physical appearance that of Mars. A French observer, Guiot, in 1885, remarked on September 17 that both the horns of Mercury (then almost a semicircle) were truncated; but that only the southern horn was so five days later. He mentions no signs of shading or spots.

I have already stated in a previous chapter that Mercury is subject to phases, and will repeat here the bare fact only by way of reminder ; and will merely add that it has sometimes been found that the illuminated portion is less than it should be, according to calculation. This statement rests upon the testimony of some competent observers, and remains unexplained. Explanation is the more difficult because there is no sufficient evidence that Mercury possesses an atmosphere.

There is some ground for the opinion that it is more easy to notice the appearance of this planet's surface than is the case with Venus. More than one observer besides Denning, quoted above, has gone so far as to suggest that, if viewed under favourable circumstances, the surface presents an aspect more nearly resembling that of Mars than any other planet.

The astronomer who in recent times has made the most systematic study of Mercury is Schiaparelli, some of whose conclusions are rather startling. First of all, he considered his best chances of studying the planet's surface to be when the Sun is above the horizon, and that the resulting inconvenience is less distracting than the tremors which manifest themselves when the planet is viewed low down towards the horizon when the sun is absent. He thought, indeed, that some of the markings which he noticed were permanent ; hence the supposed analogy between Mercury and Mars. But the most sensational of Schiaparelli's conclusions is that Mercury's axial rotation takes place, not in the 24 *hours*, or thereabouts, generally supposed, but in 88 *days*, being the period occupied by the planet in going round the Sun.

This conclusion is mentioned because of Schiaparelli's experience and standing as an observer, but it is impossible to accept it in the present state of our knowledge, though some other observers, including Lowell, in 1896, have seemed inclined to agree with Schiaparelli.

By means of a dark spot seen in April 1904, McHarg fixed the period of rotation at 24 h. 8 m., which accords with all previous values except Schiaparelli's.

Mercury revolves round the Sun in almost exactly 88 days at a mean distance of about 36,000,000 miles, which may vary between the limits of 43,347,000 miles and 28,570,000 miles. These great extremes in the distance of Mercury from the Sun at different times are due to the great eccentricity of the planet's orbit, which is greater than that of any of the older planets, though exceeded by many of the Minor Planets discovered in modern times. The apparent diameter of Mercury varies between $4\frac{1}{2}''$ in Superior Conjunction and $13''$ in Inferior Conjunction. The real diameter may be taken to be about 3000 miles, or perhaps a little less.

It may be useful to many of my readers to suggest to them a convenient method for finding either Mercury or Venus in daylight by means of a telescope unprovided with an equatorial mounting or circles. For the successful use of the method certain favourable but simple conditions respecting the telescope and the planets are required. The telescope must be perfectly steady on a substantial stand, and anchored in some way so that it will not move after having been once placed in a definite position, to be presently named; and it must be provided with an eye-piece of low power having the largest possible field. The planet to be sought must have a declination, which shall not differ more than about 3° or so from that of the Sun, and the planet's right ascension must be greater than that of the Sun. If the difference of declination much exceeds 3° the chances of picking up the planet will be much diminished.

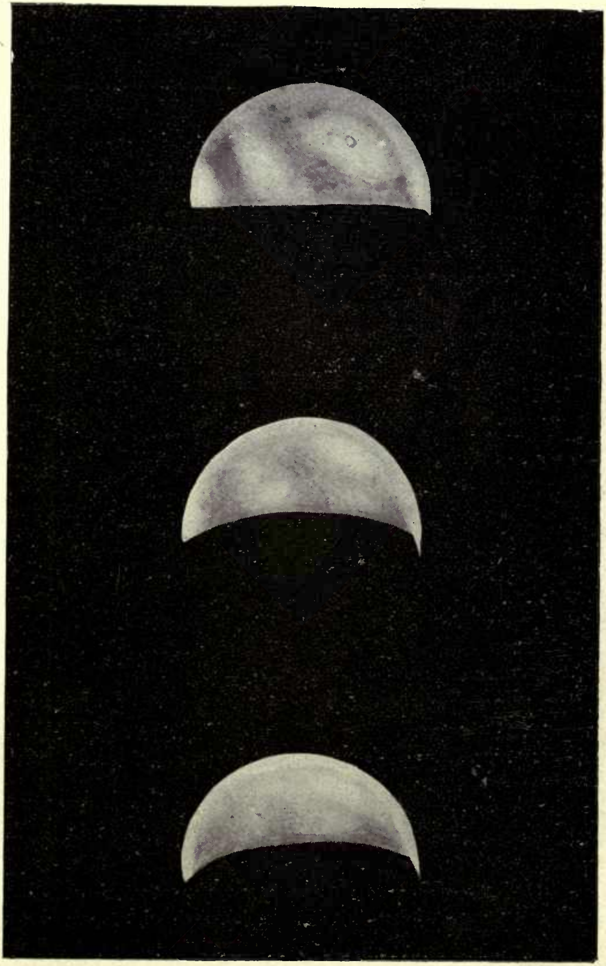
The above conditions being fulfilled, the method consists in using the Sun to find the position in the sky which corresponds with the planet's declination; and, the telescope being pointed to what is believed to be about the planet's declination, the observer has only to wait until, by the rotation of the Earth, the planet is brought into the field of the telescope. Two further preliminaries must be observed: the telescope must be carefully focussed either on a Sun-spot or by means of the Sun's limb. A dark glass must be used in doing this, and when this has been done a pale neutral glass should be used whilst the planet is being swept for.

Accurate focussing of the telescope is very important; otherwise the planet may escape the eye which is looking for it, because a diffused image is easily overlooked. The focussing having been assured, the Sun must be carefully brought into the centre of the field, and the line along which it travels into and out of the field must be carefully noted. This is done most easily if the eye-piece of the telescope is provided with two wires crossing each other.

The Sun having been brought to the centre of the field, the telescope must be moved upwards (or downwards) at right angles to the apparent line of the Sun's movement by the amount of the difference (estimated from the centre of the Sun) between the Sun's right ascension and the planet's right ascension, the centre of the field being taken in both cases as the point aimed at.

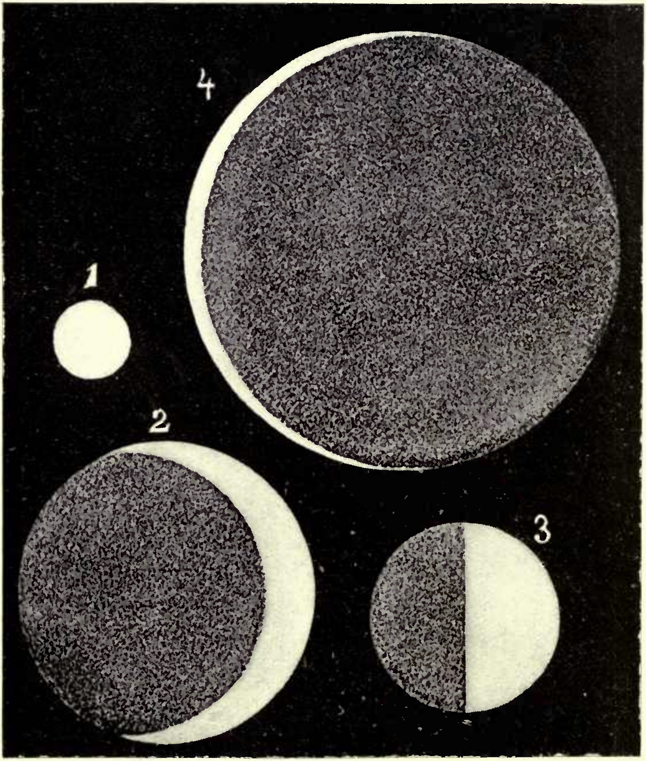
No circles being available, the observer should remember that, the diameter of the Sun's disc being approximately $\frac{1}{2}°$, the telescope must be moved vertically by as many half-degrees as equal the difference between the declinations of the Sun and the planet respectively. For instance, if the difference is $2\frac{1}{2}°$, the telescope must be moved by the amount of 5 diameters of the Sun. The observer has now nothing more to do but to wait with his eye at the telescope until there has elapsed the time in minutes which is the amount of difference between the R.A. of the Sun and that of the planet.[1]

[1] For further details and examples of this method, which was put forward by Dr. R. J. Ryle, see *The Journal of the British Astronomical Association*, vol. xv. p. 100, December 1904.



(1) Nov. 5, 18 h. 49 m. (2) Nov. 6, 18 h. 55 m. (3) Nov. 8. 19 h. 30 m.

Mercury in 1881 (*W. F. Denning*).



The Various Phases of Venus.

Fig. 79.—Venus near its inferior conjunction. (*Schröter.*)

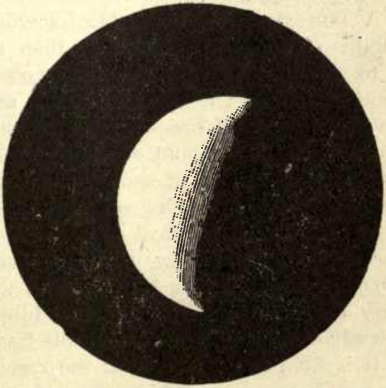


Fig. 80.—Venus, Dec. 23, 1885. (*Lihou.*)

VENUS.

What has been said already with respect to Mercury will have paved the way for some of the things which will now have to be said respecting Venus; but, as regards one matter—its brilliancy on occasions—Venus stands out in advance of all the planets. Such is the case especially whenever we look at it in the evening or the morning, fulfilling the functions, in popular parlance, of the "evening star" or the "morning star." But on certain occasions, at rare intervals, when the planet is at or near its greatest N. Latitude and about 5 weeks from Inferior Conjunction, it shines with surpassing splendour, equal to, or even greater than, that of Sirius (α Canis Majoris). This only happens about once in 8 years, and occurred last in 1910, and will recur in 1918. The brightness is sometimes such that the planet casts a shadow. Such was the case on January 12, 1902, as recorded by Giacobini at Nice.

The further fact will therefore seem to follow quite naturally that the planet is often readily visible in the daytime, especially if, by means of graduated circles, the seeker knows exactly where to look for it.[1] It is the opinion of those who have made a special study of Venus that, on account of its brilliancy, it is easier to detect its physical features by daylight, or in quite early twilight, rather than when it has a dark sky behind it. These features include shadings or patches of shade, and the truncature of one or both horns when the planet shows as a crescent; and these facts indicate beyond doubt not only that the visible surface is not even, but that mountains exist on it. It is not, however, usual to speak definitely of the existence of mountains, less precise words, such as markings, or shadings, or spots being used.

A Portuguese observer, M. Lacerda, has stated that the southern horn is always longer than the northern one; that is to say, that the northern one is often more blunt than the southern one. The same observer remarked that the most favourable times for viewing the planet were always between half an hour before and one hour after sunrise; and that the corresponding times at sunset, when the planet was in the W., never afforded him such good results.

As regards the physical appearance of the surface of Venus the difficulties are very much the same as those which are encountered in viewing Mercury, and the visual results are not very different; that is to say, in addition to the blunted horns already mentioned, spots are visible from time to time.

It is from these facts that the conclusion has been drawn that, as in the case of Mercury, mountains probably exist; but

[1] See p. 71, *ante*.

there is a conflict of opinion as to whether these mountains have an objective existence on the body of the planet, or whether the shadings, which have been assumed to be mountains, are merely shadings in an atmosphere which simulate mountains.

The fact that Venus has an atmosphere of considerable density seems well established, especially by the appearance presented by the planet when under observation during transit across the Sun. A further proof of the existence of an atmosphere was furnished on July 26, 1910, on the occasion of an occultation of the star η Geminorum by the planet. The star's brightness diminished rapidly during 2 or 3 seconds before immersion, and increased rapidly during $1\frac{1}{2}$ or 2 seconds after emersion. It was thought by the French observers who noted these results that a variation of light during 2 seconds would be explained by the existence of an atmosphere about 68 miles in height. There is such a considerable coincidence in the various figures arrived at as regards Venus's atmosphere that its reality and considerable extent are open to no doubt. Perhaps even it is more dense than that of the Earth.

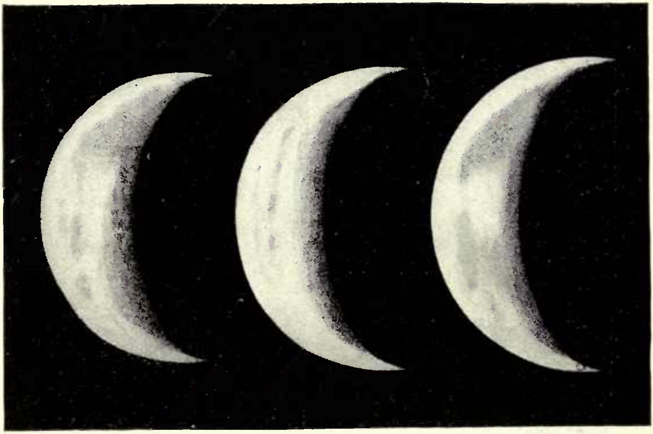
When Venus is near its Inferior Conjunction there may sometimes be noticed an appearance not unlike the *Lumière cendrée*, or "ashy light," frequently visible when the Moon exhibits a narrow crescent, as mentioned in the previous chapter. (*Ante*, p. 36.)

Though this phenomenon has been seen and recorded by many observers during a long period of time, the most careful and complete observations are those which were made by Zenger at Prague in 1883. Without quoting the details generally which he noted, it may suffice to state that he considered all the phenomena which are presented by Venus when its disc is partly illuminated and partly unilluminated find a complete counterpart in what we see when scrutinising the Moon; and that the varying tinges, sometimes simply dark, are analogous to what we often see in looking at a "young" Moon, or the

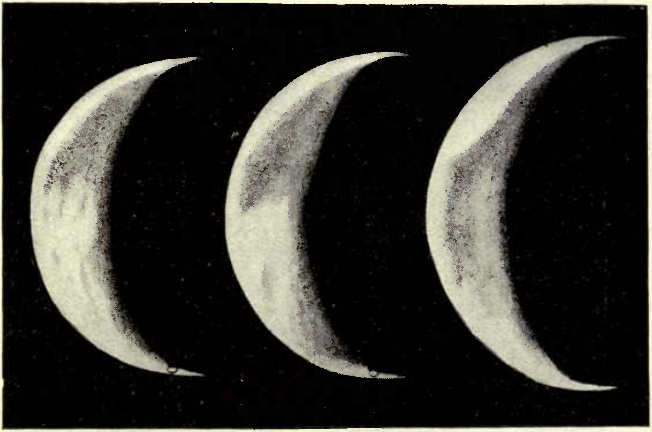
Moon eclipsed. In other words, that, as we know the variations in the Moon's appearance which we see from time to time under such circumstances depend on the varying conditions of the Earth's atmosphere, so the different appearances presented by Venus depend upon the varying conditions of the atmosphere of Venus. We have seen that, in the case of Mercury, the measured breadth of its phase, when half illuminated, does not always accord with the theoretical breadth which ought to be shown at that particular stage. The same discrepancy occurs in the case of Venus.

There once raged a long controversy, spread over many years during the 18th century, as to whether Venus had a satellite. The testimony to that effect was varied and strenuous, and proceeded from many observers; but there is now no question but that they deceived themselves, and in their small telescopes mistook stars for companions to the planet, for it is quite certain that if Venus did possess a satellite, it would have been recognised long ago in some of the many great telescopes which were brought into use in the second half of the 19th century.

The planet Venus has always occupied a prominent place in the literature of poets and historians during more than two thousand years. It would occupy too much space to offer any quotations, but there is one literary trick (I can use no better word) which is associated with the planet and which deserves mention, especially because, as we go along, we shall find that the same trick confronts us in the case of another planet. In olden times, say three centuries ago, before the days of Copyright and Patent Laws and "Merchandise Marks Acts," when a man discovered something the honour of which he desired to attach to his own name, he announced it in obscure phraseology, which secured him the priority of credit without disclosing his discovery in detail. Thus it was that Galileo, who discovered the phases of Venus, is said to have announced his discovery in the following Latin logogriphe, or anagram;



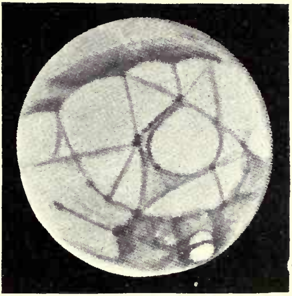
March 22, 6 h. March 26, 7 h. March 28, 6½ h.



March 30, 6¾ h. March 31, 6¼ h. April 5, 6¼ h.

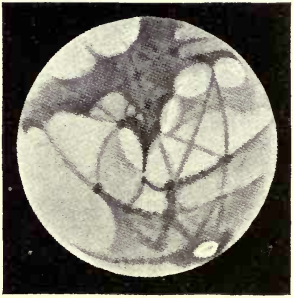
Venus, 1881 (*W. F. Denning*).

May 14, $8\frac{1}{2}$ in spec. (*W. F. Gale*).

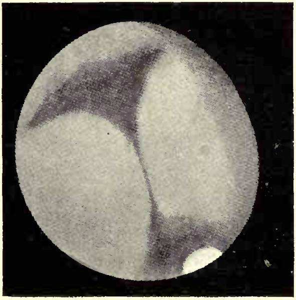


April 14, $12\frac{3}{4}$ in spec. (*P. B. Molesworth*).

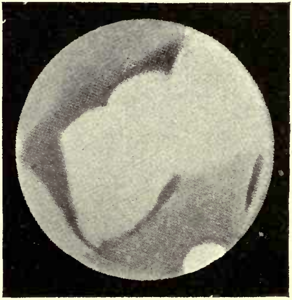
April 19, $9\frac{1}{4}$ in spec. (*T. E. R. Phillips*).



April 21, $2\frac{3}{4}$ in spec. (*P. B. Molesworth*).



May 21, 5 in O.G. (*R. Killip*).



April 8, $6\frac{1}{2}$ in spec. (*H. Corder*).

Mars, 1903.

"Hæc immatura a me, jam frustra, leguntur—oy" ("These things not ripe; at present [read] in vain [by others] are read by me"), the "me" being Galileo.

This Latin sentence, when transposed, becomes: "Cynthia figuras æmulatur Mater Amorum" ("The Mother of the Loves [Venus] imitates the phases of Cynthia [the Moon]").

The letters "oy" are, it will be observed, redundant, so far that they cannot be made use of in the transposition.

There seems reason to believe that the special brightness of Venus at its best is due to some exceptional condition of things which enables it to reflect a larger proportion of the Sun's rays falling upon it than is the case with Mercury.

It is good practice for an amateur to try and ascertain up till how long before, and how soon after, Inferior Conjunction he can see Venus in a telescope. The interval ought only to be one of hours, and not many of them.

Venus travels round the Sun in 224 days at a mean distance of 67,000,000 miles. The orbit is nearly that of a circle, its eccentricity being the smallest of all the orbits of the large planets, but several minor planet orbits are more nearly circular. The apparent diameter of Venus varies between 9″ in Superior Conjunction and 65″ in Inferior Conjunction. At its elongations its apparent diameter is 25″. The real diameter is about 7500 miles; that is to say, Venus is nearly, but not quite, so large as the Earth. The period of its axial rotation is disputed, but it probably amounts to about 23¼ hours.

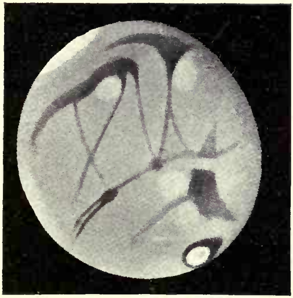
MARS.

We will now proceed to the important planet, Mars, passing over the Earth for the reasons already given: that, though the Earth is a planet, and a very important one too, we cannot, because we are on it, study its appearance in the way in which, with the assistance of telescopes, we study the appearance of other planets.

Mars and Jupiter, which will occupy our attention in the next section, are the planets which most often attract our notice in the sky by night because one or other of them is almost always visible at some time or other between sunset and sunrise. Moreover, Mars, by reason of its normal fiery colour, can never be mistaken, or at any rate should never be mistaken, for any other planet or for any star.

Mars exhibits, on occasions, a slight phase, but it is not very noticeable. When the planet is in Opposition—that is to say, is on the meridian at midnight—it presents a perfectly circular disc; but at other times it is gibbous, the maximum defalcation of light occurring when the planet is in Quadrature, or 6 hours away from the Sun, either E. or W. At these epochs the planet resembles the Moon 3 days on either side of the epoch of Full Moon.

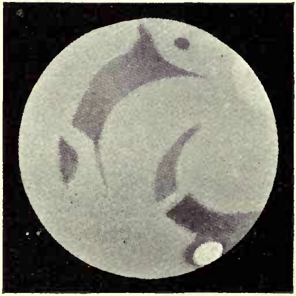
By reason of its proximity to the Earth, it comes into Opposition about once in every two years, or, to be more exact, every 780 days, this being what is called its "synodic period." When in perihelion (that is, nearest to the Sun) and in perigee (that is, nearest to the Earth) at the same time, which coincidence occurs every 15 years, Mars rivals Jupiter in brilliancy. This happened last in the summer of 1909, and will not occur again until 1924. But the fact that we get a good view of Mars at the short interval of every two years gives us great facilities for studying it, and should be an encouragement to tracing its movements in the heavens amongst the stars. This is not so conveniently done in the case of the other Superior Planets because they take so many more years in making their circuits round the Sun, and move so much slower amongst the stars. It will be interesting, therefore, to state in detail what those movements are as we on the Earth see them. Starting when Mars has just passed through Conjunction, it emerges from the Sun's rays, rising some minutes before the Sun, and having a direct, that is, easterly motion; but as this motion is only half that of the Earth in the



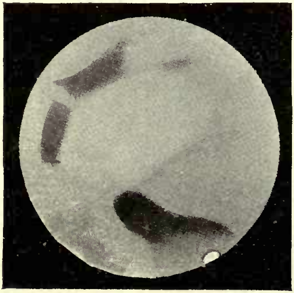
May 12, $9\frac{1}{4}$ in spec. (*T. E. R. Phillips*).

April 30, $12\frac{3}{4}$ in spec. (*P. B. Molesworth*).

March 31, $8\frac{1}{2}$ in spec. (*E. M. Antoniadi*).

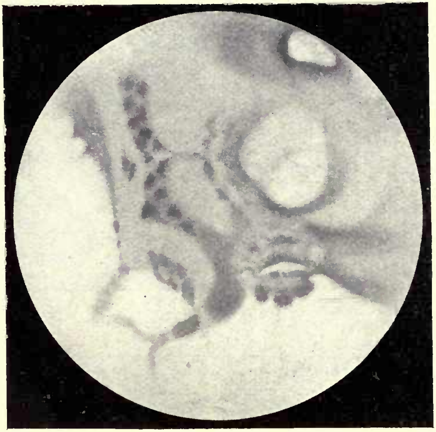


March 31, $6\frac{1}{2}$ in spec. (*E. A. L. Attkins*).



March 31, $6\frac{3}{4}$ in spec. (*W. J. Hall*).

May 7, $9\frac{3}{4}$ in spec. (*T. E. R. Phillips*).



Sept. 20, 1909.

Nov. 5, 1909.

Mars (*Antoniadi*).

same direction, Mars appears to recede from the Sun in a westerly direction, notwithstanding that its true motion amongst the stars is towards the E. This continues for nearly a year, and ceases when it has attained an angular distance from the Sun, measured along the Ecliptic, of about 137°. Then for a few days it does not seem to move at all. After that its motion becomes retrograde or westerly among the stars, and so continues until it reaches a point 180° from the Sun, or, in other words, is in Opposition or on the meridian at midnight, when therefore it is seen at its best by us. At this time its retrograde motion amongst the stars attains its greatest rapidity, but it soon slackens and becomes slower and slower until it has arrived at a point 137° from the Sun. Then its motion again becomes direct and so continues till once again the planet is lost in the Sun's rays, soon after which it reaches Conjunction, and another two-year period of changes begins. Though they are renewed on the same principles, there will be changes in the details; the retrogradation does not always commence or finish at 137°, for it may begin as soon as 128° is reached, or may not begin until 146° is reached, the arc described varying between 10° and 19½°. The duration of the retrograde motion in the former case is 60 days, and in the latter 80 days. The period in which these changes take place, at the interval between two successive Conjunctions or two successive Oppositions, constitutes the synodical period of 780 days already mentioned.

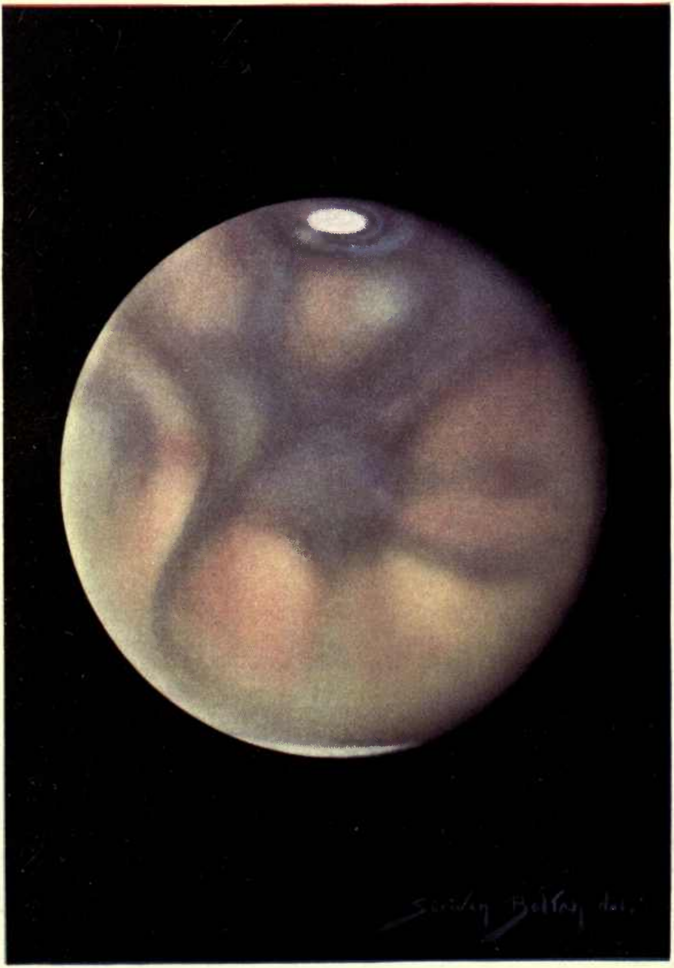
The physical appearance of Mars as seen in our telescopes may be regarded as not subject to much change except in one particular. I say this advisedly, because although during the past 30 years there has been a flood of controversy respecting the appearances presented by the surface of Mars, and there has been a great disposition to indulge in extravagant language, there is abundant evidence to show that there are certain defined marks which are unchanged and are probably unchangeable.

I will deal with and dispose first of all, of the appearances which are mentioned in the preceding paragraph as being the one particular exception to the rule of unchangeability. This statement refers to the spaces around the poles, which are commonly reputed to be signs of the existence of snow. I think this may be taken to be a certainty, because they are observed to diminish when brought under the influence of the Sun at the commencement of Mars's summer, and to increase again on the approach of Mars's winter. The illustrations annexed are sufficiently self-descriptive.

Some anomalies have been noticed from time to time in regard to these polar patches, not sufficiently great, however, I think, to negative their being masses of snow, but still somewhat strange. For instance, whilst both Mädler and Secchi found the north patch to be concentric with the North Pole of the planet, yet that the south patch was not concentric with the South Pole. Sir W. Herschel, as far back as 1784, noticed that the patches were not exactly opposite to one another.

Spots on Mars are frequently seen, and have enabled astronomers to arrive at very consistent conclusions as to the period of the planet's axial rotation, which may certainly be set down at 24 hours 37 minutes.

The geography (to use the obviously wrong word) of the surface of Mars has been attentively studied during the three centuries which have elapsed since the invention of the telescope, and drawings of every kind, by astronomers of every sort, using telescopes of every size, exhibit a consistency which is very remarkable. No wonder the whole globe has been mapped out into areas, hypothetically regarded as land and water, to which names, many of them very bizarre, have been given. The original series of names was restricted in number, and included the names of some twenty leading observers of note in the astronomical world. Without saying that these names have been formally discarded, yet a new series of names, Latin in form and in a certain sense mythical, have



MARS. (*S. Bolton*)

October 21, 1909.

been brought into use and seem to be meeting with acceptance from astronomers.

After the polar patches spoken of already the one most obvious feature which most generally attracts notice when that particular hemisphere of Mars where it is situated happens to be under observation is that known as the "Kaiser Sea," sometimes called the "V" mark, from resemblance to that letter; but which much more readily brings to mind the continent of South America, if one could imagine a piece stuck on at the southern tip at right angles to the general trend of that continent. The shape of a leg of mutton has also been suggested.

The ruddy colour of Mars has been notorious from the earliest times in which written mention of the planet has been handed down, and Sir John Herschel ascribed it to "an ochrey tinge in the general soil like what the red-sandstone districts on the Earth may possibly offer to the inhabitants of Mars, only more decided." This idea is not so far-fetched as might at first be thought.

There are parishes in Gloucestershire, one of them named Red Marley, which, to those who have visited them, would bring home Herschel's idea. There might easily be imparted to the Earth, when viewed from Mars, a very distinct reddish colour supposing that there were many thousands of square miles all geologically resembling the soil of the parish of Red Marley.

Another long-standing idea with respect to the surface of Mars is that it is visibly divided, as the Earth is, into land and water, the ruddy areas being land and the almost equally greenish areas being water.

The great controversy of the present day respecting Mars is the reality, or otherwise, of an immense number of "canals" said to exist all over it, and to show themselves in the form of numerous dark lines, very straight, and so well defined as to indicate for them an artificial origin. The observer who first put forth this alleged fact and its explanation has found a few supporters, or men who have been claimed as such because

6

they thought they had seen markings on the planet which might be regarded as straight lines intercepting one another at various angles. On the other hand, it is undoubtedly true that the vast majority of observers, using telescopes of every size and kind, have never suggested the existence of any such precise markings, or been able to find them when invited to look for them.

Professor W. H. Pickering, taking an intermediate view, has reviewed the controversy respecting the markings on Mars in the following terms:—

"It has lately been shown by Messrs. Lane, Maunder, and Evans that many of the finer Martian canals are probably non-existent, their appearance being due to certain singular optical illusions. Most of the broader canals, however, in the dark regions of the planet undoubtedly exist, and the same is almost certainly true of some of those in the light regions, such as *Nilosyrtis* and *Nectar*. The chief cause of the illusion seems to be the system of lakes, or oases, as they are sometimes called, which were first discovered in large numbers at Arequipa.

"There is a curious tendency of the human eye to see such dark points united by faint narrow lines, and it has been shown by means of diagrams that these lines sometimes appear when the diagram is at such a distance that the dark dots are themselves invisible. But even without the dots the lines may sometimes appear, joining different portions of the dark regions. We must therefore divide the Martian canals into two classes: those that are genuine and those that are not. . . .

"This phenomenon of spurious canals is certainly very singular, but we must be careful that its interest and unexpectedness do not lead us into the error of affirming that, because many Martian canals are spurious, therefore all Martian canals are imaginary. It seems indeed a great pity that so much time and energy should have been expended in many observatories in mapping canals in the bright regions of the planet, and comparatively so little time spent on the darker regions, where changes are constantly taking place, and where we should naturally expect the more interesting developements to occur."

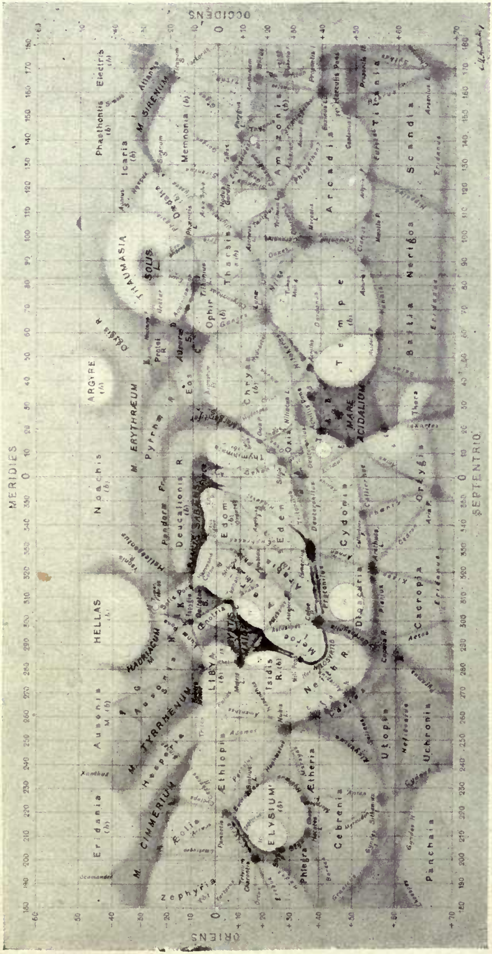
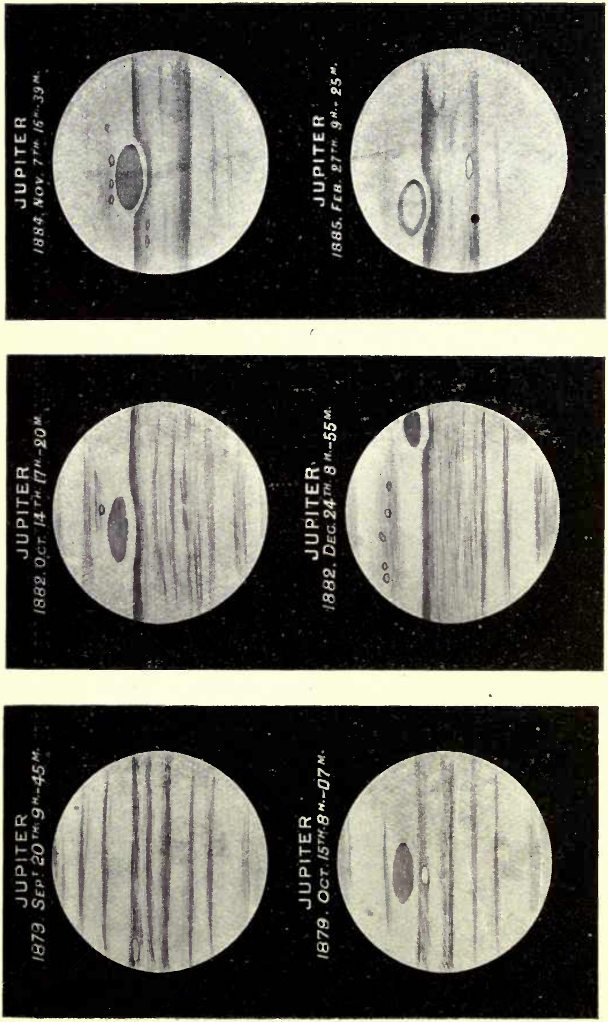


Chart of Mars on Mercator's Projection (*drawn by E. M. Antoniadi*).


JUPITER
1884. NOV. 7TH 16H.–39M.
JUPITER
1885. FEB. 27TH 9H.–25M.
JUPITER
1882. OCT. 14TH 17H.–20M.
JUPITER
1882. DEC. 24TH 8H.–55M.
JUPITER
1879. SEPT. 20TH 9H.–45M.
JUPITER
1879. OCT. 15TH 8H.–07M.

Jupiter.

At one time it was urged that, not only was Mars crossed and recrossed by sharply defined dark lines, but that many of these lines were doubled : hence arose the word "germination" as applicable to them. Weighing the *pros* and *cons* of the controversy on the principles of the law of evidence as applied by lawyers, I cannot consider that the arguments put forth in support of the multiplicity of sharply defined markings is established, and think that the only thing which is established is, that there are numerous markings on Mars which take various shapes, and, when clearly visible, are at best ill-defined, and that very often they are not clearly visible. Finally, that their visibility depends in no small degree on the personality of the observer and on atmospheric and other circumstances.

There is one matter connected with Mars which has yet to be mentioned, namely, its satellites. Though these cannot be said to concern the general reader because of their diminutive size, yet a certain amount of historic interest attaches to them. They were only discovered as recently as the year 1877, when an American observer, A. Hall, conceived the idea of turning to account the favourable Opposition of that year to search for a satellite, as he had at command the fine refracting telescope of the Washington Observatory, carrying an object-glass 26 in. in diameter. His efforts were soon rewarded by the discovery not only of one, but of two satellites, which have been named Phobos and Deimos, the names of the steeds said by Homer to have drawn the chariot of Mars.

When it is stated that Phobos at its best is no brighter than a star of Magnitude 11, whilst Deimos is as faint as a star of Magnitude 13, it will be realised at once that only telescopes of very large size can observe them. Historically it is interesting to note that, in *Gulliver's Travels*, the astronomers of Laputa are spoken of as having discovered that Mars had two satellites, whilst Voltaire, in his "Romance of Micromegas," ascribes to some of his characters also the discovery of two Martial satellites "which had escaped the scrutiny of our astronomers."

It is to be presumed that Voltaire was only a copyist of Dean Swift.

Mars travels round the Sun in 686 days, at a mean distance of 140,000,000 miles. The eccentricity of the orbit, though a good deal less than that of the orbit of Venus, is nevertheless very considerable, so that the planet's distance from the Sun may on occasions be as great as 154,000,000 miles, or as little as 128,000,000 miles. The planet's apparent diameter varies between 4″ in Conjunction and 30″ in Opposition. Owing to the great eccentricity of the orbit the apparent diameter, as seen from the Earth, will also differ greatly at different times. The real diameter may be regarded as almost exactly 5000 miles.

JUPITER.

On the whole, Jupiter may be said to be the planet most easily brought within the reach of everybody, and for this reason ; it is generally visible for many months in every year ; it is more or less conspicuous owing to its normal brightness, and, from the standpoint of the mere sightseer, its belts and 4 principal satellites are within the reach of quite small telescopes. Indeed, instances are on record of the satellites, when sufficiently near to join forces as regards their combined light, have, under very favourable circumstances of atmosphere and the observer's keenness of vision, been visible to the naked eye.

Jupiter is the largest of all the planets, having a diameter of about 88,000 miles. So large a body rotating on its axis in the short time of 10 hours or thereabouts, it follows that, by the laws of rotatory motion, the compression of the polar diameter is very marked, amounting, according to the best authorities, to about $\frac{1}{16}$th of the equatorial diameter.

The belts have long been known as a notable feature of the planet. There is a certain amount of permanency about them, yet it cannot be said that they are permanent. To look at them, they are dusky streaks of different breadths, which

FIG. 108

breadths vary from time to time. Sometimes they chiefly appear as two or three broad belts, at another time the observer will notice a greater number of belts, all much narrower than those he may have seen on some previous occasion. They are all parallel to the planet's Equator, though commonly absent actually under the Equator. On very rare occasions a single belt may be noticed lying askew to the general trend of the belts. The latest recorded instance of this was in April 1910, S. Bolton being the observer. It may be taken for granted that in looking at Jupiter we are not looking at anything in the nature of a solid body, but only at a cloudy envelope, which may or (more likely) may not encompass a solid globe. It has been suggested that the changes visible on Jupiter are proofs of the manifestation of energy in the form of heat on the planet.

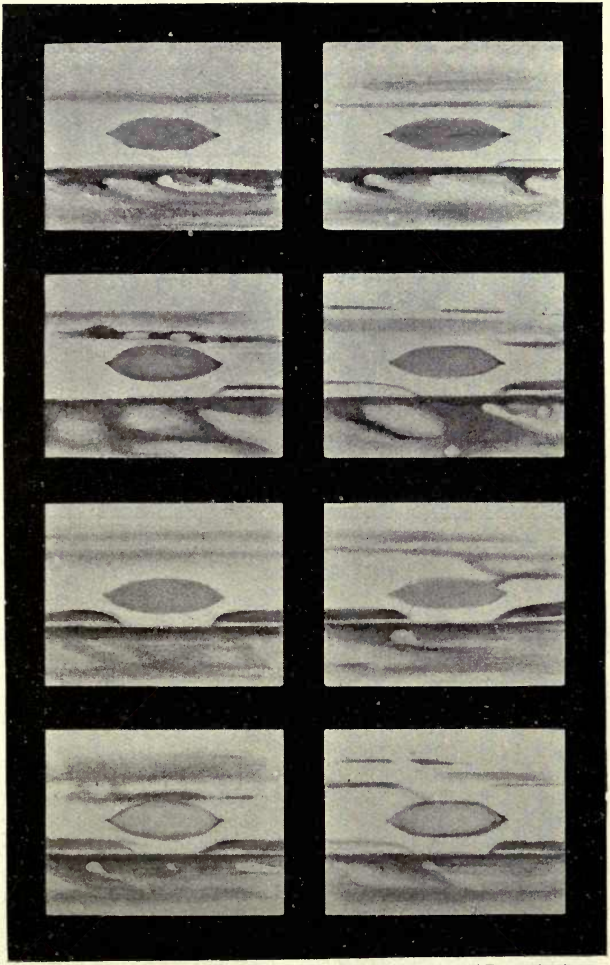
The question as to their colour sometimes arises, because, though generally grey or greyish, distinct tinges of brown may be traced, whilst in 1877 a great red spot burst forth, which remained for many years a striking and permanent feature. The later history of this spot is very remarkable, and there is a mystery about it which is still unsolved. It retained its shape and colour for about four years, up till the autumn of 1882, when it began sensibly to fade; and during the ensuing year it became extremely faint, though still preserving its form. In the years between 1884 and 1906 it underwent various changes, never recovering its original bright colour. In 1906, whilst the shape remained, the tinge of colour was no more than grey, though something slightly warmer was sometimes suspected. In 1909 the spot was all but invisible, though its outline could be detected; but it more than ever presented the appearance of being something which was floating in a basin or hollow. In 1910 it again became visible, though only for a few weeks, and now one can hardly say more than that its place can be discovered.

The illustrations annexed will indicate the fact that during the red spot's visibility, dating from 1878, its original outline was oval, and that, notwithstanding the loss of colour, which marked many subsequent years, yet at times it seems to have closed up and lost its oval shape. The question has been mooted whether the oval spot of 1878, with its strongly defined colour, could be identical with an elliptical ring which was observed and occupied the same position in latitude in 1869 and 1870, but which did not possess any definite colour. That elliptical ring seems to have disappeared unnoticed, but the red spot of 1878 at one time showed signs of becoming itself transformed into an elliptical ring and closing up. The red spot, minus nearly or all its colour, seems still to be visible, or at least traceable, but there is distinct evidence that it has in the course of years moved on—that is to say, does not occupy the same position in longitude which it did when first discovered, and for many years afterwards.

This history, though very condensed, will justify the remark that there is something mysterious about this spot, for which no counterpart can be found anywhere in the domain of astronomy. It remains to be added that though we talk about the red spot as having been discovered in 1877, there seems considerable evidence that a spot of the same shape was noticed very many years earlier: indeed, as far back as 1666, as witness the accompanying copy of an old sketch (Fig. 129), ascribed to Azout and Cassini jointly.

White spots have also been noticed of various sizes at various times, and also occasionally dark spots, but no explanation of the physical character of them is available. We have evidently a good deal to learn respecting Jovian spots, and several surmises have already been put forward. Whilst it has been thought that some connection exists between Sun-spots as regards their period and the position of Jupiter in its orbit, the idea has been extended to the point that there is an identity in time between the prevalence of spots on the Sun and spots on Jupiter. Whether these spots stand to one another as

1 2 3 4 5 6 7 8



Jupiter's Red Spot and the Regions near (*Denning*).

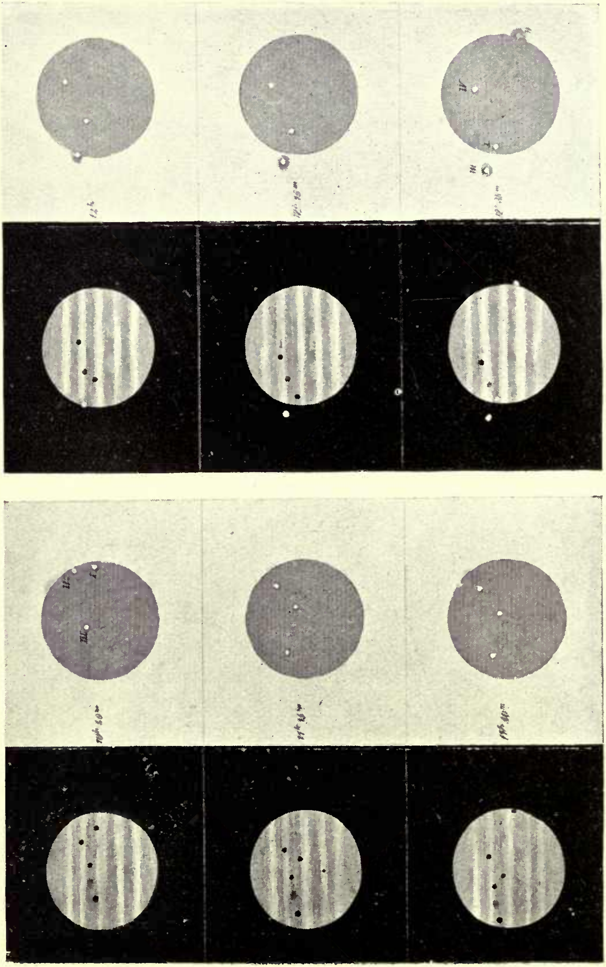
		H.	M.			H.	M.
1	1880, Nov. 19	9	23	2	1881, Sept. 28	13	11
3	1881, Dec. 7	10	40	4	1882, Oct. 30	16	10
5	1883, Oct. 15	15	37	6	1884, Feb. 6	9	29
7	1885, Feb. 25	12	50	8	1885, May 9	8	8

Geocentric position of the Satellites.

Shadows of the Satellites.

Geocentric position of the Satellites.

Shadows of the Satellites.



Jupiter with its Satellites, Aug. 21, 1867 (*Tempel*).

cause and effect, or whether both are indications of disturbances of cosmical origin from outside the solar system is a matter on which no opinion can be pronounced with our present limited knowledge.

As regards Jupiter's belts taken collectively it seems not open to doubt that they exhibit from time to time not only distinct traces of colour, such as pale purple, or brown, or orange, but that this colour varies from time to time in a way which almost implies that its greatest developement is coincident with a maximum display of Sun-spots. This was Browning's idea, put forth many years ago; but I am not aware that any recent observer has given his attention to the matter from this standpoint.

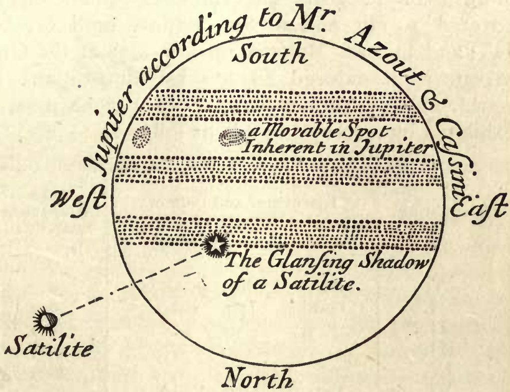


Fig. 129.

The satellites of Jupiter, 8 in number, have two distinct histories, so to speak; that is to say, that the newly discovered ones have a history and individual characteristics which entirely dissociate them from the 4 original satellites, as they may be conveniently termed. The original 4 were discovered by Galileo in January 1610 as the first-fruits of the application of the telescope to the observation of Jupiter. A man named Simon Marius, who put in a claim for priority over Galileo, named them Io, Europa, Ganymede, and Callisto; but this claim was so universally (but perhaps not rightly) considered to be fraudulent that astronomers agreed to show their opinion by ignoring the names prescribed by Marius, and simply to identify the satellites by their order of distance from their primary, designating them as I., II., III., IV. The condition of things here implied remained undisturbed until 1892, when a distinguished American astronomer, E. E. Barnard, discovered a 5th satellite, very much smaller than all the others, revolving round its primary within the orbit of I. Rather more than 12 years later another American, Perrine, discovered a 6th and a 7th satellite, both revolving outside IV.; and in 1908 Melotte, an assistant at the Greenwich Observatory, introduced an 8th satellite to the astronomical world. These various discoveries can be most conveniently exhibited by resort to a table as follows:

Designation.	Discoverer and Date of Discovery.	Mean Distances in Radii of ♃.	Sidereal Period.
			d. h.
V.	Barnard, Sept. 9, 1892		0 12
I.	Galileo, Jan. 1610	6·0	1 18
II.	,, ,, ,,	9·6	3 13
III.	,, ,, ,,	15·3	7 4
IV.	,, ,, ,,	26·9	16 18
VI.	Perrine, Dec. 3, 1904		251
VII.	,, Feb. 1905		265
VIII.	Melotte, Feb. 28, 1908		26 months

All these new satellites are, as may have been expected, so very small as to be beyond the reach of any but the largest telescopes in the world. I shall therefore here dismiss them, and confine my remarks to the four old satellites. These well deserve the attention of the amateur astronomer, not simply because of the fact that they are easily visible in the most ordinary telescopes, but because they are incessantly moving about ; and their movements give rise to certain phenomena called transits and occultations. A transit occurs when a satellite passes in front of the planet, as seen from the Earth, and an occultation when the satellite passes behind the planet. When an instance of the former phenomenon appears the observer will see, by careful scrutiny, the satellite's disc and the black shadow cast by the satellite on the planet. These two appearances must be carefully discriminated, for the satellite itself is apt to escape notice, whilst its shadow is mistaken for the satellite itself. An occultation is, in its essential features, the same as a total eclipse of the sun. In a total solar eclipse the bright body of the sun is wholly concealed by the superposed Moon. Similarly, in an occultation of a Jovian satellite the bright satellite is entirely concealed by the planet. But there is this difference: in a solar eclipse the Moon, which does the work, is not only opaque, but black ; but in a Jovian occultation the occulting body which does the work, namely, the planet, whilst it is opaque is nevertheless illuminated, because nothing happens either to weaken or put an end to the light which the planet, like every other planet, receives from the Sun. These phenomena obtain full recognition in the various national Nautical Almanacs, and the information given in the British *Nautical Almanac* is borrowed by *Whitaker's Almanac*, and so is brought within the reach of everybody, and no further amplification of the subject is necessary here.

Under ordinary circumstances the satellites exhibit simple illuminated discs, but with adequate optical assistance it is found that they have markings or shadings of irregular shape. Comparing one with another, it would appear that III. is commonly the brightest and IV. the faintest ; but no very positive statement can be made as to I. and II., or even as to the relative brilliancy of any one of the four compared with the others, for it seems certain, or probable, that all of them are subject to changes of brilliancy. There is no clear evidence of their ever showing any signs of colour. W. H. Pickering has noted the curious fact that, twice during each revolution, and at intervals of 34 hours, the third satellite exhibits a marked elliptical outline, and that its chief shading is not a band, but is forked. He thinks also that there is something abnormal in the circumstances of II. and IV. as distinguished from I.

Observation of the satellites of Jupiter as far back as 1675 led to the discovery that light is not transmitted instantaneously through space, but takes an appreciable time. A Danish astronomer, Römer, was the hero of this. He found that the observed times of the eclipses did not tally with the calculated times, and that the differences were systematically affected by opposite signs of error, according as Jupiter was near to or remote from the Earth. This fact led him to suspect that the varying differences in the distances was the cause of the varying differences in the times; in other words, the greater the distance of the planet from the Earth the longer the time occupied in the light making itself manifest to us on the Earth. Römer's conclusions were that light travelled at the rate of 192,000 miles per second, a conclusion remarkably near the truth, considering Römer's inferior instruments, for by more modern methods, with altogether superior instruments, it has been found that Römer's figures are only wrong by being about 2000 miles in defect, the true velocity being 194,000 miles per second.

Jupiter revolves round the Sun in rather more than $11\frac{3}{4}$ years at a mean distance of 483,000,000 miles. The eccentricity of its orbit is small, so that its greatest possible and least possible distances do not differ very much from its mean distance, being 506,000,000 miles and 460,000,000 miles respectively. The planet's apparent diameter varies between 60″ in Opposition and 30″ in Conjunction. The equatorial diameter is rather more than 88,000 miles, making Jupiter the largest planet in the solar system.

SATURN.

There are probably very few people who have any knowledge of anything scientific who have never heard of Saturn and its ring. The planet, though inferior in lustre to Mars and Jupiter, is always to be found without difficulty when in a dark sky, shining, as it does, like a star of the second or third Magnitude. It compares, however, unfavourably with its rivals because it has a dull, leaden hue.

Though its appendage is often spoken of as "the Ring," using the word in the singular number, yet it is really a system of rings which surrounds the planet, and the number grows with the size of the telescope used to scrutinise it. Whilst a small telescope will only show one ring, a larger one will show this one divided into two; a still larger one will show the outermost of the two again divided into two. In addition to these there is a third main ring, which is the innermost of all. Unlike the rings just spoken of, this innermost ring is not bright, but dusky; and the name originally given to it on its discovery, rather more than half a century ago, of the "crape ring," has not quite fallen into disuse, and is not altogether inappropriate.

The history of the discovery of this ring is rather curious, and suggests a mysterious origin and developement of it. In 1838 a distinguished German astronomer, J. G. Galle, published an observation in which he said he had noticed a shading-off of the innermost bright ring towards the planet. His remark seems not to have attracted any particular notice until 1850, when G. P. Bond in America, and Dawes in England, independently discovered the dusky ring, and recognised it distinctly to be a ring, but transparent in so far that the body of the planet could be seen through it.

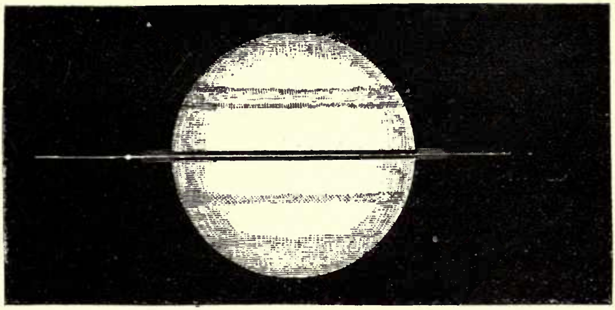
This dusky ring is now a recognised feature of Saturn, and it would seem to be wider and more easily visible than formerly, and a division of the dusky ring into two rings has been suspected. The germs of its discovery are to be seen in Galle's note of 1838; whence, perhaps, it is permissible to suggest that the ring has gone through stages of developement during the last three-quarters of a century. There is no trace in the writings of either of the Herschels of their having detected any traces of a ring inside the innermost bright one, though it must be confessed that Picard in 1673, and Hadley in 1723, saw *something* which might perchance be identifiable with the dusky ring of the observers of the 19th century.

Saturn and its system, treated as a whole, is not only a very remarkable and interesting object, regarded as a spectacle, but every 30 years undergoes interesting transformations which must now be described. For convenience of reference it is customary to call the outermost bright ring A, the innermost bright ring B, and the dusky ring C.

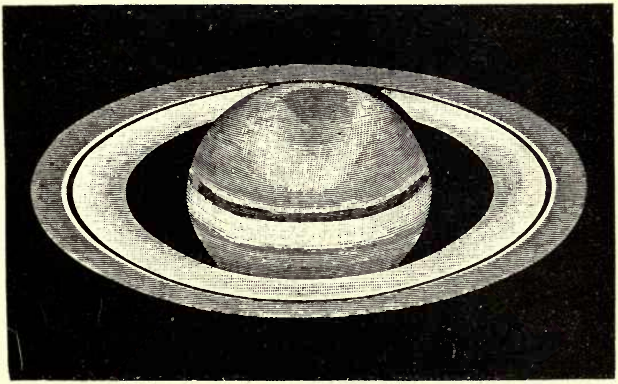
Figs. 136-137 show the interior edge of the crape ring as drawn in March 1888 by J. G. E. Elger. The irregularities are very noteworthy, but I am not aware that they have ever been confirmed; at any rate, in anything like the form suggested by Elger.

Though under ordinary circumstances—that is to say, during a considerable succession of years—we see Saturn as a ball surrounded by its rings, yet, owing to the orbit of Saturn being inclined to the plane of the Ecliptic, we see the rings at intervals either opened out very wide or not opened out at all, but presented edgeways.

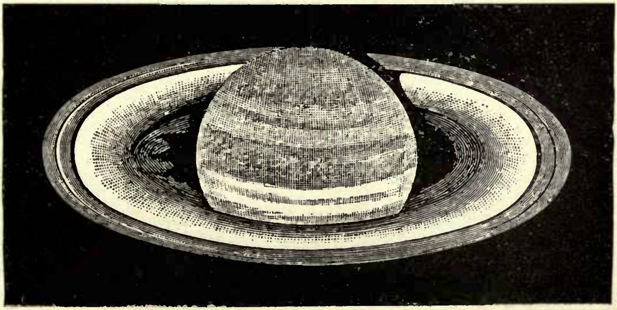
Perhaps this will be made a little more clear by giving some dates. In 1907 the Earth was in the plane of the rings; they were more or less invisible for a short time (October 1907—January 1908), being placed edgeways to the view of us on the Earth. In 1907 the Sun began to illuminate the southern side of the rings, after having for $14\frac{3}{4}$ years shone upon the northern side. After 1907 the planet moved on, the rings beginning to open out and become wider every year until 1915, when they



Jan. 5, 1862 (*Wray*).

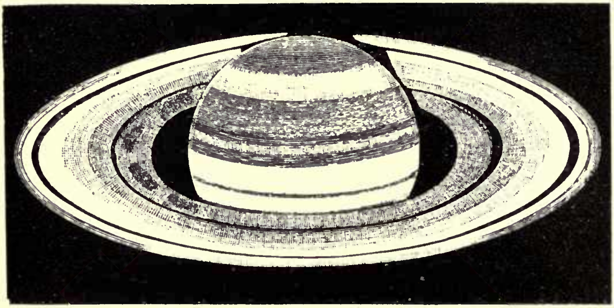


Feb.-March 1884 (*Henry*).

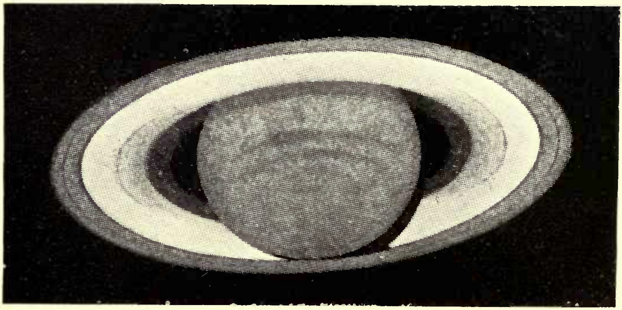


Feb. 1887 (*Terby*).

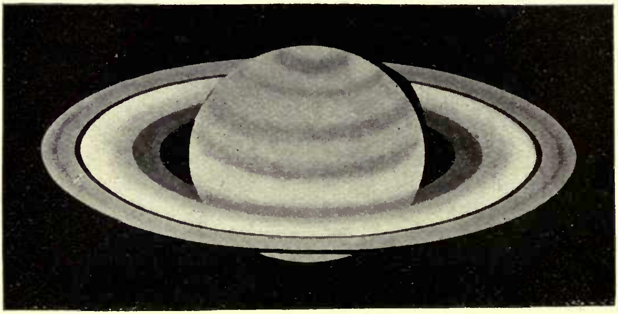
Saturn.



March 18, 1887 (*Elger*).



July 30, 1899 (*Antoniadi*).



Jan. 27, 1912 (*Phillips*).

Saturn.

will attain their maximum breadth. After that they will again, to our vision, become narrower.

When 1922 is reached the planet will have accomplished one-half (approximately) of a revolution round the Sun, and will again have reached the condition of being seen edgeways, the sun beginning to illuminate the northern side of the rings. For the previous $14\frac{3}{4}$ years we shall have seen one and the same side of the rings, but henceforth for $14\frac{3}{4}$ years to come we shall see, also continuously, for that period the same side of

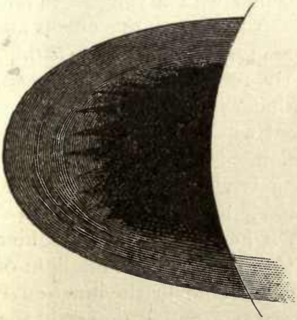


Fig. 136.—Ring C, March 21, 1887.

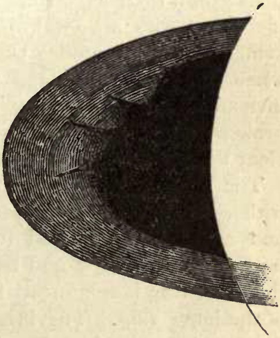


Fig. 137.—Ring C, March 27, 1887.

the rings; but it will be the opposite side to what we had seen previously, because now the planet with its rings will have passed to the opposite side of the Ecliptic.

Continuing our predictions, on or about 1928 the rings will again have attained their maximum opening, but we shall see, of course, the opposite side of them to what we saw in 1914. Continuing our calendar of changes, the rings will, about 1936, reach the same stage identically as had been reached in 1907; that is to say, the planet will have completed one entire circuit of the Sun, and will start again on precisely the same succession of changes as that with which it had commenced in 1907, the Sun beginning again to illuminate the southern side of the rings.

From the foregoing it will be clear that from now, and for several years after the first publication of this book, the planet will be at its best for observation in telescopes of all sizes.

The changes which have just been sketched out involve, both theoretically and practically, many incidental details too numerous to be gone into here ; but the reader will no doubt understand that, as we are dealing not with a ring all in one piece, but with a bundle of rings, so to speak, the effects are somewhat complicated. One of the most natural effects is that, when the edgeways stage is nearly reached, or just passed, instead of the edge being a continuous line of light, it is a broken line. The diagrams annexed will make this sufficiently clear without any detailed explanation.

The outer edge of the outer ring is visible throughout, but with extreme difficulty when standing by itself as between *b* and *c* and *f* and *g*, and towards *a* and *h* ; but the brighter portions from *c* to *d* and from *e* to *f* indicate that the light of the outer ring is reinforced by that reflected by the inner edge of the inner ring. The bright knots at *b* and *g* represent the light of the outer ring strengthened by the concurrent reflection from the inner edge of the outer ring, and the outer edge of the inner ring, which last-named reaches us through the inter-space between the two main rings, which is often called the Cassini Division, from the name of its discoverer, J. D. Cassini.

One curious fact seems well established, namely, that the rings are not concentric with the ball. This is a peculiarity which one would not naturally have expected, but it has been shown mathematically to be essential to the stability of the ring system ; and if this feature did not exist, and if the rings did not revolve round the planet, they would collapse on to the planet. Thus expressed, the statement suggests that the rings are solid, but it is generally considered that such is not the case ;

on the contrary, that they are made up of myriads of discrete particles of matter, so closely compacted together that to our remote eyes they appear as a solid mass. Considered as a system the rings are sensibly more luminous than the planet, and B is brighter than A, B itself being least bright at its inner edge.

Measurements and opinions vary as to the thickness of the rings. Sir J. Herschel thought that 250 miles would be an outside limit for the thickness; G. P. Bond put it at no more

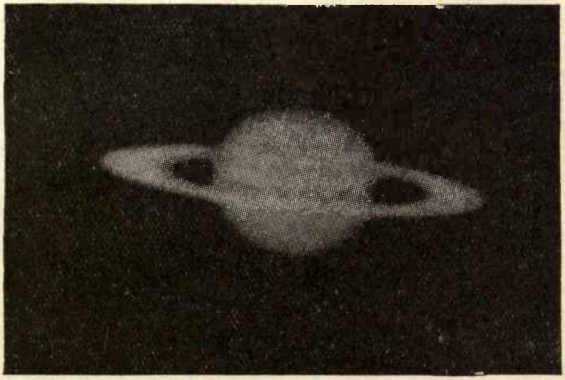


Fig. 138.—Saturn, Feb. 7, 1890.
Photographed at Mount Wilson, U.S.

than 40 miles; probably 100 miles is near the mark. The general dimensions may be exhibited in the following table, which represents the latest and best measures obtainable, being those of Prof. E. E. Barnard, put forth in 1895.

	Miles.
Outer diameter of outer ring	172,310
Inner diameter of outer ring	150,560
Outer diameter of inner ring	146,020
Inner diameter of inner ring	110,200
Inner diameter of crape ring	88,190
Width of the Cassini division	2,270

To the foregoing may be added, from another source, 18,640 miles as the distance of the ring B from the ball.

Thus far I have said nothing about the physical appearance of the ball. It has certain features in common with Jupiter—that is to say, faint belts may often be seen upon it, and occasionally a bright spot; but these are very rare.

Taking the planet as a whole, it was suggested by Lassell that the South Pole is generally darker and more bluish in tinge than the North Pole. The general hue of the planet is yellowish-white, which to the naked eye is commonly regarded as dull grey—a seeming contradiction. There exists no clear evidence that Saturn has an atmosphere in the usual sense of the term, though its existence seems probable, from the central portions being brighter than the circumference. Theoretically it should exhibit in Quadrature a slight phase, but it must be so small that no wonder none has ever been noticed.

Saturn is attended by satellites, 10 in all, of such diverse sizes that they furnish excellent tests for telescopes. The largest is that known as Titan, which is supposed to be about 2700 miles in diameter. All the satellites have received names, and those which come next in order of visibility are Iapetus, Rhea, Dione, Tethys, and Enceladus. Telescopes of the largest size are required to show Mimas, Hyperion, Phœbe, and Themis. It is obvious, from the foregoing statement, that, with the exception of Titan and Iapetus, amateur observers will not need to give much attention to these satellites. Titan may be compared to a star of Mag. 8 and Iapetus to one of Mag. 9; but Iapetus is generally considered to vary in brightness, being brightest when in the western part of its orbit.

Saturn revolves round the Sun in 29½ years at a mean distance of 886,000,000 miles, in an orbit slightly eccentric. Its apparent diameter varies between 15″ in Conjunction and 20″

in Opposition. According to Barnard, its equatorial diameter is 76,470 miles, and its polar diameter 69,770, which figures imply a polar compression of $\frac{1}{11}$. This result is not altogether in accordance with the results of previous measures which have made the compression more considerable. Hind put it as much as $\frac{1}{9}$.

CHAPTER VII.

THE LESS KNOWN PLANETS.

The Planets of this chapter of little interest to the amateur.—History of the discovery of Uranus.—Difficulties as to its orbit.—Suspicions of the orbit being disturbed by another planet.—The search for it.—The researches of Adams and Leverrier.—The discovery of Neptune.—Brief description of the planet.—Its one satellite.—The Minor Planets.—First organised search for them.—Early discoveries.—Recent discoveries facilitated by photography.—The planets now very numerous.—And few of them of any interest.—Their fantastic names.—Some particulars of the first four.—Summary respecting their orbits.

THE planets which will come under our notice in this chapter are of no intrinsic interest whatever to the amateur star-gazer, who, if he tried to find them, would in general have great difficulty in doing so ; and, having found half a dozen of the brightest of them, which perhaps he might do, he would very quickly come to the conclusion that they were not worth the search. In spite of this, however, certain of them have great historic interest, the tale of which must now be unfolded.

On the evening of March 13, 1781, Sir W. (then Mr.) Herschel was examining some small stars near H Geminorum, and one of them attracted his special attention. With a view of seeing what he could make of it with a stronger eye-piece, he replaced the eye-piece which he had been using by one of greater power.

A star thus examined by the use of different eye-pieces always retains its stellar character of rays emanating from a point; but

Herschel found that the object which he had under view did not behave thus, but that increasing the power increased the diameter considerably, thus proving that, whatever the object was, it was at any rate not a star. Apparently no suspicion entered his head that he was looking at a new planet, for the idea of there being any new planets never, up to that time, seems to have entered seriously into anybody's head.

Finding that the object was in motion amongst the stars, he jumped at the conclusion that he had found a new Comet, and he announced it as such to the Royal Society on April 26. But previously to this, as early as March 17, the stranger had been examined by Maskelyne, the Astronomer Royal, at Herschel's instigation. Maskelyne seems to have suspected the planetary nature of the new body almost from the first. Notice of the discovery of something having been made public the stranger was observed at various European observatories for many weeks, still treated as a comet.

When its movements were subjected to calculation on the supposition that it was a comet, and, like most comets, one moving in a parabolic orbit, it was soon found that this supposition broke down, its course, on the parabolic theory, being falsified more and more as the observations were prolonged.

The final stage in the researches as to the real nature of the newly discovered visitor were reached when Lexell authoritatively announced that the object which astronomers had been following was not a comet but a planet, hitherto unknown, revolving round the Sun in a nearly circular orbit.

This announcement came as a shock, in a certain sense, to many people, because it seems to have been thought that the number of the moving luminaries visible to the naked eye, recognised as 7 from the earliest ages,[1] was a perfect number which it was almost an outrage to challenge. A long controversy, which was not really finally closed till the middle of the

[1] The Sun, Mercury, Venus, the Earth, Mars, Jupiter, Saturn. The Sun was always, in early times, considered a moving body.

19th century, arose as to the name to be given to the new planet. Herschel, in pursuance of the fashion of the times, proposed to call it the "Georgium Sidus," a suggestion naturally not very acceptable to foreigners, nor indeed very reasonable. The French proposal, put forth either by Lalande or Laplace, to call it "Herschel" was equally irrational; and, finally, there was a large preponderance of opinion in favour of a mythological name which would harmonise in some sense with the name of the next nearest planet, Saturn. Agreement thus far did not immediately settle the matter, and Neptune, Astræa, Cybele, and Uranus all had their supporters. Finally, however, the last of these names, urged by Bode, gained the day.

The conservatism of the English mind even in things astronomical was shown by the fact that the names "Herschel" and "Georgium Sidus" in one shape or other were kept up for a very long time in England, and the word "Georgian" did not disappear from the *Nautical Almanac* until the volume for 1850 published in 1846. The actual name used for many years had been in the English form, "The Georgian," instead of Georgium Sidus, which only lasted a very few years after 1781.

The question, Did anybody catch sight of Uranus before Herschel? naturally suggested itself to astronomers; and search amongst old records of observations of stars eventually led to it being ascertained that the planet had been observed on 20 occasions between 1690 and 1771; by Le Monnier, in particular, on no less than 12 occasions. Had this astronomer possessed a methodical, orderly mind it seems almost certain that he could have anticipated Herschel in determining the planetary nature of the "star" so many times seen by him; but he was not a man of an orderly mind, if we may rely upon Arago's statement that he had once been shown by Bouvard one of Le Monnier's observations of the planet written on a perfumer's hair-powder paper-bag.

The physical appearance of Uranus, owing to its great distance from us, and small apparent size at its best, need not detain us. Suffice it to say, therefore, that belts and spots on it have been suspected by observers with telescopes sufficiently powerful to grapple with it. It has also been thought to have some inherent light of its own besides what it derives from the Sun.

Sir W. Herschel thought he had discovered 6 satellites as belonging to Uranus, but it is now recognised that only two of these were genuine discoveries. Two other satellites were found in 1847 by Lassell and O. Struve respectively, and the assured number stands at present only at 4. They have been named Ariel, Umbriel, Titania, and Oberon, in the order of distance from the planet, reckoning outwards.

Uranus revolves round the Sun in rather more than 84 years at a mean distance of 1,781,000,000 miles. The orbit is somewhat less eccentric than that of Jupiter. Its apparent diameter varies but slightly, and may be taken at something under 4″, the real diameter being about 31,000 miles. One of the difficulties which had to be solved in connection with Uranus was the choice of a symbol for it. The one in use is a composite affair embracing a capital H, the initial of Herschel's surname ; but the Germans employ one "made in Germany" which does not differ much from the symbol in common use for Mars.

The next section will bring the name of Uranus before us again in a very striking connection.

NEPTUNE.

The story of the discovery of the planet Neptune has often been told, but it will bear repetition ; at any rate, this volume would not be complete without the story being told again, even if only in a concise form. It involves, indeed, the history of Uranus, some part of which must be given as a preface to the story of Neptune. It has already been stated that Uranus had been observed on numerous occasions before the official date of its discovery by W. Herschel, and that these observations began as far back as 1690.

It is the practice of astronomers, in calculating the orbit of a new planet or comet, to base their calculations on as long a chain of observations as possible, and from the undoubted fact that when they began to calculate the path of Uranus round the Sun they were able to start their chain from as early a date as 1690, they had great hopes that very trustworthy details of the orbit would soon be evolved. The man who took this matter in hand was the French astronomer, Alexis Bouvard.

Bouvard, who in 1821 produced his first detailed results, was obliged to confess that those results were very unsatisfactory, in so far that those which depended upon the careful observations made in 1781–1820 would not harmonise with those made during the 91 years prior to 1781. He thought only of one way of getting over the difficulty, and that was by the summary process of rejecting all the earlier observations as worthless.

For a while this seemed to remove all difficulties, and the conclusions from theory published in 1821 and based on the then recent observations, appeared to fit in quite satisfactorily with the observations then being made. But this happy state of things only lasted a few years. Discordancies soon appeared between the places which ought to have been occupied in the heavens by Uranus according to Bouvard's theory of the character of its orbit and the places in which, by observation, the planet was actually found. It seemed to be affected by some influence which at one time pushed it forwards and at another time pulled it backwards in its orbit.

It gradually became certain that there was some cause at work which disturbed the planet's movements, and the conclusion was eventually arrived at that the cause was some unknown planet revolving round the Sun in an orbit outside that of Uranus. An English amateur, the Rev. T. Hussey, seems to have been the first to have put forward this idea in a positive form, which he did to Professor G. B. Airy, the Astronomer Royal, but who had been Professor of Astronomy in the University of Cambridge.

Other astronomers accepted the idea, but the first to take overt action was a young Cambridge Undergraduate, J. C. Adams, who as early as 1841 made up his mind to investigate the question. Lack of time prevented him seriously starting his labours until 1843. He carried them on for 1¾ years on the supposition that there really was an undiscovered planet, and in October 1845 he forwarded to Airy provisional elements of the orbit and probable mass of a planet which would explain the irregularities in the movements of Uranus. This, on the theoretical side of the question, was the settlement of the question, but, most unfortunately for the credit both of Adams and Airy, the latter ignored at the time the young Cambridge student and his labours and conclusions.

The scene now changes for a time to France. In the summer of 1845 a young Frenchman, U. J. J. Le Verrier, of Paris, took up the question of the anomalous movements of Uranus, and in November of that year published his first Essay to show what was *not* the cause disturbing the orbit of Uranus. A few months afterwards, namely in June 1846, he published a second Essay, in which he showed what was the cause, namely, the attraction exercised by an unknown planet. He assigned elements to it, just as Adams had done 8 months previously.

A copy of this second Essay reached Airy on June 23, and when he found how close was the accord both between the suggested elements and the suggested position of the planet in the heavens, as assigned by the two young mathematicians working in ignorance of one another, it at last dawned upon him that perhaps Adams's labours were not so unworthy of consideration as apparently he had thought when they first came into his possession many months previously. Impressed for the first time, he communicated with Professor Challis, at Cambridge, who had the command of a large telescope suitable for hunting up the planet, and Challis began his search on July 1 ; but he was confronted by one serious difficulty : he possessed no star-map of the particular part of the heavens in which it might be expected that the planet would be found. He therefore had to make a map for himself, and this of course was a time-taking matter which hindered rapid progress. However, he eventually prepared the necessary chart, and when it was ready he set to work to use it ; but it was not until September 29 that he found an object whose appearance attracted his attention. This subsequently proved to be the planet he was searching for.

Further consideration showed that he had observed it, regarding it as a star, on August 4 and 12, and that the supposed star of August 12, was missing from the chart of July 30.

Meanwhile, still in ignorance of what was going on in England, Le Verrier published in August a third Essay assigning more positively the probable position of the planet in the heavens. He sent a summary of this revised information to Encke, the Director of the Berlin Observatory, and invited him to examine the heavens in and near the predicted place. Encke, fortunately, had just become possessed of a newly published map of the locality where the planet was expected to be found, and therefore he was not called upon to waste time in making a map for himself, as Challis had been obliged to do.

Encke had with him two young assistants, whose names afterwards became famous in the astronomical world, J. G. Galle and H. L. D'Arrest. These men, under Encke's directions, set to work the same night that Le Verrier's letter arrived, Galle calling out one by one the stars visible in the telescope, whilst D'Arrest checked the map. This work had gone on for a certain time when Galle found what seemed to be an 8th mag. star which was not marked on the map. It was seen again on September 24, and, having moved, was soon proved to be the planet wanted. An examination of the dates just given will make it quite clear that the honour of the discovery was shared in fairly even proportions by England and France.

Adams and Le Verrier both assigned a position for the planet which proved to be nearly true and substantially identical (with a slight preponderance in favour of Le Verrier), whilst Challis was the first to find the planet, and Galle the first to recognise that the object seen was the planet. It should be added that it was not until October 1, two days after he had suspected that he had found the planet, that Challis became aware of Galle's definite conclusion arrived at six days previously. In the language of the gamester, we may with perfect accuracy say "honours divided."

It was a long time (many years, in fact) before French men of science settled down philosophically to accept the verdict, which may now, however, be regarded as the verdict of the world, though even to this day one may find French writers glossing over or suppressing Adams's name in connection with Neptune's discovery.

The remarkable feature about it was that two men of different nationalities, working in different ways, with different materials, each unknown to the other, should have fixed the position in the heavens of a planet which nobody had ever seen, accurately within $2\frac{1}{2}°$ in Adams's case, and within about $1°$ in Le Verrier's case. I may well end my statement of the matter in the words of Hind :—

"Such is a brief history of this most brilliant discovery, the grandest of which astronomy can boast, and one that is destined to a perpetual record in the annals of science—an astonishing proof of the power of the human intellect."

After much discussion "Neptune" was the name agreed upon for the new planet. Galle suggested "Janus," but this name was disapproved of as too suggestive of the idea that the orbit of Neptune marked the entrance into the solar system from outside. And perhaps it was well that this suggested alternative name was rejected, now that we seem drifting into the belief that there is yet another planet farther off than Neptune waiting to be discovered.

Information is sadly lacking as to the physical appearance of Neptune, owing to its immense distance and small apparent size. Markings in the nature of belts, and even a ring, have been hinted at by several observers; but it may be said that practically we know nothing on the subject. If a ring existed it would only open out every 82 years, being the point of a semi-revolution round the Sun; so it might be many years yet before its existence could be certainly known.

The existence of one satellite seems to be assured, and a second has been suspected, but here again there is a great lack of assured knowledge, and it is not a little surprising that, with the large telescopes lately brought into use, especially in America, so little attention should have been given to Neptune.

Neptune revolves round the sun in 164 years at a mean distance of 2,791,000,000 miles. The eccentricity of the orbit is small. The planet's apparent diameter only varies between 2·6″ and 2·8″. Its true diameter is about 37,000 miles.

THE MINOR PLANETS

The discovery of the planet Uranus had other after-influences besides leading to the discovery of Neptune. The fact that the ancient tradition of seven moving heavenly bodies, and no more, had been broken in upon put it into the minds of certain astronomers that, as there was an eighth planet (Sun and Moon having anciently been treated as planets), namely Uranus, why not others?

The actual circumstances which gave a practical start to the idea that there were more planets to be found if they were looked for are rather curious. A certain J. D. Titius, of Wittemberg, in Germany, discovered the following curious coincidences.

Take the numbers 0, 3, 6, 12, 24, 48, 96, 192, 384, each of which after the 3 is double its predecessor; add 4 to each number and we get 4, 7, 10, 16, 28, 52, 100, 196, 388.

Now these numbers approximately represent the distances of the planets from the Sun, taking the Earth's distance as the unit or standard, calling it 10.

This statement will be more clear if it is tabulated thus:

Planets.	True distance from ☉.	Distance by Bode's Law.
Mercury	3·87	4·00
Venus	7·23	7·00
Earth	10·00	10·00
Mars	15·23	16·00
[Ceres, not known in 1772] . .	[27·66]	28·00
Jupiter	52·03	52·00
Saturn	95·39	100·00
[Uranus, not known in 1772] .	[191·83]	196·00
[Neptune, not known in 1772] .	[300·37]	388·00

Another German astronomer, J. E. Bode, became acquainted with Titius's figures, and, adopting the idea as his own, and noticing at that time (1772) that there was no planet represented by the figures 28, 196, and 388, predicted that more planets existed and should be looked for. It does not appear that W. Herschel was influenced in any way by the foregoing figures as regards Uranus, but in 1800 some German observers, six in number, assembled at Lilienthal and formed themselves into a society of explorers, under Schröler as President, to search for additional planets. Such zeal was soon rewarded, and the first-fruits were the planets Ceres, Pallas, Juno, and Vesta. No more seeming to be forthcoming, the work was abandoned in 1816; but a Prussian amateur named Hencke, at Driesen, took up the work on his own account about 1830, but with no immediate success.

The discovery of Neptune in 1846 infused new life into the movement for hunting up small planets, one of which indeed, afterwards named Astræa, had been found on December 8, 1845, by Hencke at Driesen, whose single-handed labour has just been mentioned. The year 1846 produced none. Three were found in 1847, one in 1848, one in 1849, three in 1850, and two in 1851. Thenceforward the discoveries became much more rapid, and by the end of 1860 a total of 62 had been reached; 1870 brought the number up to 111; and since then they have grown with ever-increasing rapidity up to the present total, which exceeds 700.

The system of looking for them has latterly been materially altered. For many years after the search was first begun it was carried out very much on the lines on which the search for Neptune was conducted, namely, by ocular comparison of the stars visible in a telescope with maps of the stars in the same locality; but of recent years the extensive introduction of photography has greatly facilitated the discovery of new planets. I am very sceptical as to the usefulness of these discoveries being continued. The actual interest attaching to these bodies is in nearly every case *nil*, and the labour involved in keeping pace with their record and in calculating their orbits is out of all proportion to the ultimate useful result. That this would appear to be the opinion of astronomers generally is shown by the fact that practically the whole work is now concentrated in German hands, no other nation seeming to pay much attention to these planets. Under these circumstances, I shall sum up in very concise form the rest of the information which I shall give.

It will excite no surprise that these planets are in a constant state of confusion as regards their identity. Let us suppose that one is found by having imprinted itself on a photographic plate; the question at once arises, Is it a new one? or is it an old one which, having been missing, has turned up again? Here are endless traps for the astronomical author who wishes to make an accurate enumeration of these planets. It may also be added that of those which have been found and duly enrolled no fewer than sixty are now ticked off as "lost"—very likely lost for ever; or, if rediscovered, may never have their positions at rediscovery brought into touch with their positions years ago, and so proof of their identity may never be attainable.

These objects have borne various generic names. "Minor Planets" may now be taken as their recognised name, whilst the name first proposed for them by Sir W. Herschel,

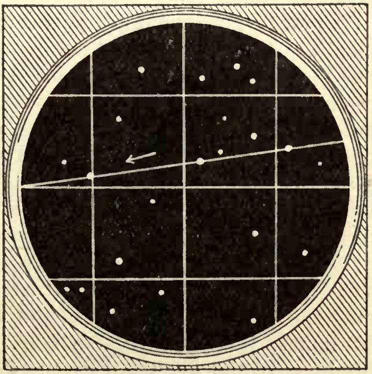


Fig. 139.—How Minor Planets are recognised as such.

"Asteroids," though no longer recognised by the scientific world, is nevertheless a designation not unfrequently met with. This remark, in a lesser degree, applies also to the name "Planetoid." As regards their individual names, at the outset names taken from the mythologies of ancient Greece and Rome, together with the old Latin names, in some cases, of the places of discovery, were almost exclusively employed; but of recent years, reasonable names having become exhausted, invented and made-up names, many of them of the most ridiculous and fantastic character, have been chosen.

Female Christian names abound, the origin of which will often not bear investigation from the standpoint of dignity and etiquette; for instance, the planets Lumen, Bertha, and Zelia are said to immortalise the daughters of a well-known French astronomer. The difficulty now of finding new planets and of getting hold of the older ones is sufficiently shown by the successive deterioration which has taken place in the size of those discovered as discoveries multiplied. The average brightness of the first ten, reckoned in star magnitude, was $8\frac{1}{2}$; of the second ten it was $9\frac{1}{2}$; of the third ten it was $10\frac{1}{2}$; of the fourth ten it was 11. From this average figure the average has progressively gone down, and I suppose that none are now found which are brighter than the 13th or 14th magnitude—a sufficient justification, I think, for saying that they are not worth looking after.

The 4 oldest and Eros are really only those in the slightest degree worth consideration. Ceres is sometimes as bright as a star of the 7th mag., and sometimes shines with a reddish tinge, and has been thought to possess an atmosphere. Pallas, when nearest the Earth at Opposition, is of the 7th mag., and is of a yellowish tinge. Juno is of the 8th mag., and reddish. Vesta is the brightest of the lot, and occasionally rises to the 6th mag., shining with a light which some consider to be pure white, while others ascribe to it a yellowish tinge.

After these 4 oldest and probably largest of the Minor Planets, the only one which has any intrinsic interest or importance is Eros. The annexed diagram, Fig. 140, shows the fact that Eros, owing to the character of its orbit, comes on occasions very near the Earth, and on that account is available for enabling us to ascertain the distance of the Earth from the Sun, and it has been so used accordingly. Unfortunately, its existence was not known on the last occasion, in which it was at its nearest distance to the Earth, which was in 1894, and it will not again be at its least distance from the Earth until 1924.

As regards their sizes, Barnard has given the following figures for diameter: Ceres 520 miles, Pallas 304, and Vesta

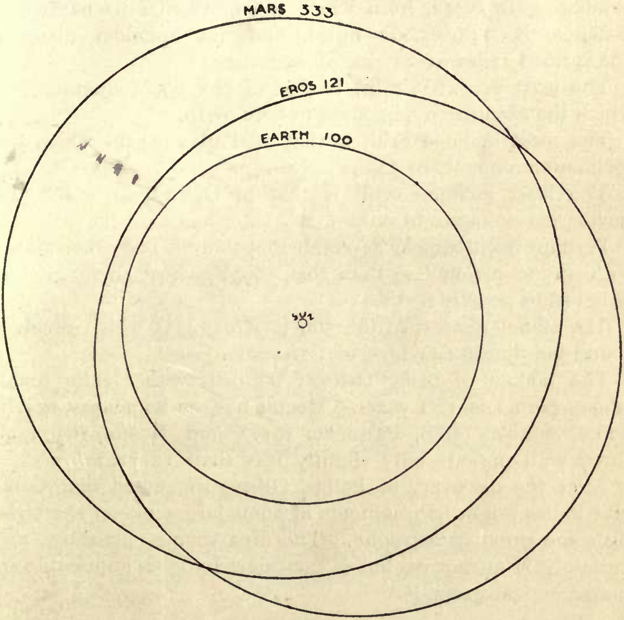


Fig. 140.—The Orbits of Eros, Mars, and the Earth.

211. Except, perhaps, Juno, Hornstein thinks that none of the others are larger than 25 miles in diameter, and most of them much less—from 15 to 5 miles.

One remarkable fact about these planets is that their orbits are in many cases much more inclined to the Ecliptic than any of the orbits of the older planets. Hence the term "ultra-zodiacal planets" was once suggested.

Many orbits are eccentric to a very extreme degree ; No. 699 seems to have the most eccentric orbit, the eccentricity amounting to 0·412, from which it follows that its perihelion distance is 142,285,000 miles and its aphelion distance 292,871,000 miles—remarkable extremes.

The least eccentric orbit is that of No. 699 (unnamed), in which the eccentricity amounts to only 0·010.

The most inclined orbit is that of Pallas (2), in which the inclination amounts to 34° 44′.

The least inclined orbit is that of Ortrud, in which the inclination amounts to only 0° 26′.

Perhaps it will appear hereafter that there is one other planet with an inclination less than this, 1893Y, whose inclination is believed to be only 0° 18′.

The planet nearest to the sun is Eros (433), which revolves round the Sun in 643 days, or 1·76 years.

The honour of being farthest off rests with Hector (624), whose period is 12·1 years. Hector has, as its nearest neighbours, Achilles (588), Patroclus (617), and Nestor (659), all three with periods only slightly less than 12 years.

After the discovery of Pallas, Olbers suggested that Ceres and Pallas might be fragments of some larger planet shattered by some great catastrophe. The idea sounds plausible, and certainly is attractive, but is considered to be impossible on mathematical grounds.

CHAPTER VIII.

ECLIPSES.

The Principles of eclipses.—Other kindred phenomena.—Two anecdotes.—The difference between eclipses of the Sun and of the Moon.—Total eclipses.—Partial eclipses.—Annual number of eclipses.—The Saros.—Method of using the Saros.—Eclipses of the Sun considered.—The accompaniments of a large partial eclipse of the Sun.—Of a total eclipse.—The terror of savages.—Instances of this.—The darkness.—The fall of temperature.—The red flames.—Baily's Beads.—The Corona.—Details relating thereto.—The Moon's shadow.—Shadow-bands.—Bushes of light.—The Corona, a solar appendage.—Connection between its shape and spots on the Sun.—Coming eclipses.—Eclipse expeditions.—Eclipses of the Moon.—The Moon when totally eclipsed.—Anecdote of Columbus.—Incident in the South African War.—Transits of Mercury and Venus.—Method of measuring the Sun's distance.—Transits and eclipses of the satellites of Jupiter.—Occultation of planets and stars by the Moon.—Occultation of stars and planets by planets.

THOUGH the title of this chapter is given as "eclipses" simply, the reader will find, when he gets towards the end of it, that it includes some other phenomena which are of kindred character, and which are technically known as "Transits" and "Occultations."

The word "eclipse" usually brings to one's mind certain occasional events which are specially connected with the Sun and the Moon, and which, so far as their principles are concerned, are in the highest degree simple; but, simple as they are, it is strange how little they are understood even by people of education and position, as the two following anecdotes will show.

Some years ago—less than twenty—there lived in the town of —— two sisters, who were recognised as cultivated and well-educated women. They had prepared to watch an eclipse of the Moon which began on one day but ended on another day, according to the customary civil reckoning; that is to say, it began late in the evening of one day, and ended after midnight in the early hours of the next day.

Accordingly, the almanac gave the date as, we will say, December 21–22. Through some mischance the sisters failed to begin to watch the eclipse on the evening of the 21st, and comforted themselves by saying, "It is coming again to-morrow night, because the almanac says that it will happen on the 21st *and* on the 22nd!"

The second anecdote concerns the eclipse of the Sun of August 28, 1905. A royal personage then at —— said to a gentleman of her suite, "I want to see the eclipse to-day; please make the necessary preparations [smoked glass, etc.], and call me at the proper time out on to the terrace." Of course she received a suitable answer, which included the words, "You must be ready at ten minutes to 11." The hour of 10.50 arrived; then 10.55; then 11: still no royal sight-seer on the terrace. The gentleman sent a very pressing message into the house, with the only result that a head appeared out of an upper window, followed by the somewhat irritable remark, "I'm coming! why are you in such a hurry?" Which not unnaturally evoked the reply, "I'm not in a hurry, ma'am; but the eclipse is in a hurry, and you are likely to lose the most striking feature of it."

Eclipses, commonly so-called, are either of the Sun or of the Moon; and according to the degree, considerable or inconsiderable, of the loss of light involved, so they bear different specific names. Eclipses of either luminary may be either "total" or "partial," whilst an eclipse of the Sun may also bear a third name: it may be "annular."

To understand the general principles of eclipses should not

AN ERUPTIVE PROMINENCE.

A QUIESCENT PROMINENCE.

"Red Flames" on the Sun, now generally termed "Prominences."

be a difficult matter, bearing in mind that eclipses of the Sun and eclipses of the Moon depend upon totally different principles.

The Moon, in the course of its monthly journey round the Earth, passes, at the stage of New Moon always, not far from the Sun, travelling either higher in the heavens or lower in the heavens than the actual place of the Sun. But on rare occasions it may happen to pass quite in front of the Sun. This will result in an eclipse of the Sun. The eclipse will be total if the Moon passes centrally over the Sun and the Moon is suitably placed in its orbit to cover the whole of the Sun; it will be annular if the Moon, though centrally placed in front of the Sun, is not large enough to cover the whole of the Sun; it will be partial if it passes only over the upper portion of the Sun or the lower portion. Something also depends upon the position on the Earth of the observer. One observer, A. B., may be so placed that the centre of the Earth, the centre of the Moon, and the centre of the Sun are all exactly in the same straight line. A. B. will therefore see a central and total eclipse.[1]

Another observer, A. B.'s brother, whom we will call B. B., is on the Earth in a latitude several hundred miles more northerly or more southerly than A. B. To such a one the Moon will be displaced from the position in which A. B. sees it: B. B. will therefore only see the Moon passing over the southern or the northern part of the Sun. He will therefore only see a partial eclipse.

If the Moon were always at the same distance from the Earth, and Earth and Moon were always at the same distance from the Sun, every eclipse might be total, and would be the same; that is to say, the Sun would always be covered with the same overlap, and the time during which it remained covered would be always the same.

But the distances referred to are not always the same; they

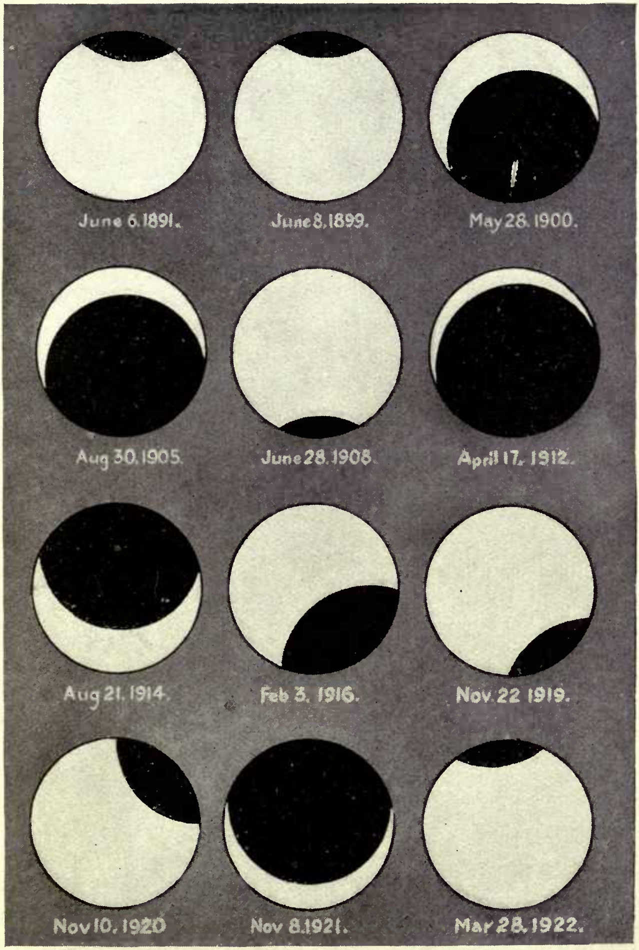
[1] Unless it is only an annular one.

vary considerably. It follows therefore that if, when the Moon is nearest the Earth, the Sun should be at its farthest possible distance from the Earth, the Moon would look its largest and the Sun would look its smallest. This would have the effect of making the overlap during totality the largest possible, and therefore the duration of the Sun's invisibility the longest possible. If, on the other hand, the Moon was at its greatest distance from the Earth, and the Sun at its nearest, the Moon would look its smallest and the Sun its largest. Under such circumstances, the Moon would be too small to conceal the whole of the Sun ; and such are the circumstances under which the eclipse would be annular to an observer viewing it from such a latitude on the Earth as would make the Earth, the Moon, and the Sun to be in the same straight line.

Another consequence follows from the ever-varying position of the Moon as regards its distance from the Earth. An eclipse may be total at one place, but in the course of an hour or two the Moon's distance from the Earth may have varied so that it has become more distant and therefore looks smaller, and an observer on the Earth and on the central line at the same time will see that the apparent diameter of the Moon has become diminished, so that it is no longer large enough to cover the whole of the Sun. To such an observer the eclipse will rank as an annular or semi-annular one. Such was the eclipse of April 17, 1912.

Turn we now to eclipses of the Moon. Though, so far as names go, such eclipses are either "total" or "partial," yet the totality or partiality depends upon principles quite different from those which bring about the same nominal results in the case of the Sun.

The Earth and the Moon being both illuminated by the Sun, both, of course, cast a shadow into space, just as every opaque object put in front of a source of light has its shadow thrown behind it. If, therefore, at the time that the Moon is in that position of its orbit known as the Opposition (when it is on the



Solar Eclipses visible in England, 1891–1922.

South. S.W. West. W.N.W.

Saturn. Mars. Venus. Sun. Mercury.

Total Eclipse of the Sun as seen in the Wabash Valley, near Vincennes, U.S., Aug. 7, 1869.

meridian at midnight), and Moon, Earth, and Sun happen to be exactly (or nearly) in the same straight line, the Moon, in its progress round the Earth, will plunge into the Earth's shadow, either wholly or partly, and the result will be that the Moon will be wholly or partly lost to the view of all the inhabitants of the hemisphere which is turned away from the Sun. The Moon, when completely plunged in the Earth's shadow, may either become completely invisible or signs of its presence in the sky may be obtainable from the fact that a faint reddish tinge seems to pervade its surface, and so keeps it dimly in view. This visibility or invisibility has nothing to do with the principles of the eclipse ; but I shall discuss the matter under another head later on.

It is now time to go somewhat more fully into details respecting these eclipses. If the orbits of the Earth and the Moon were in the same plane an eclipse of the Sun would happen once in every month at the epoch of New Moon ; and an eclipse of the Moon would also happen every month at the epoch of Full Moon ; but the Moon moves round the Earth in an orbit which is inclined to the ecliptic at an angle of about 5°, and therefore it is only on occasions that the Moon will be found immediately in front of the Sun so as to bring about an eclipse of the Sun, or immediately behind the Earth (looked at from the Sun), and so bring about an eclipse of the Moon. The effect of this inclination, coupled with certain other disturbed conditions which subsist with respect to the Moon's orbit, brings about a result that the possible number of eclipses in the course of a year are limited, and vary. There must always be two, and cannot be more than seven, eclipses in a year. When there are only two they must always be of the Sun. In the case of the seven, five of them *may* be solar, in which case only two can be lunar, though under no circumstances can there be more than three lunar eclipses in one year, and in some years there may be none at all.

If the almanacs for a *few* successive years are consulted it would seem that the succession of the eclipses is very irregular, yet that is not so in reality if the almanacs of 18 successive years are consulted, and, better still, the almanacs of thrice that period, or 54 years, are examined. If either or both of these things are done it will be found that eclipses recur almost in the same order every 18 years 10 days, or in every 54 years 31 days.

This fact was known more than 3000 years ago to the Chaldæan astronomers. They called the scheme the "Saros," and it furnished them, as it would furnish us, with the means of predicting eclipses for any number of years in advance. It does something more, for it not only enables the amateur to predict eclipses for himself, but also enables him to say in advance what will approximately be the path of an eclipse across the Earth. If we take any given eclipse, say of the Sun, visible at any particular place, a nearly similar eclipse will be visible nearly in the same locality 18 years and 10 days later, but the locality will be a certain number of miles different, and S. of the previous line of central eclipse.

To give a concrete instance. There was a total eclipse of the Sun visible in the north of Norway on August 9, 1896, at the hour of 4.30 in the morning. That eclipse will recur on August 21, 1914, but the central line, still in Norway, will be so many miles S. of the line of 1896, and the time will be much more convenient, because it will be nearer the breakfast-hour of most people. The gradual transformation of the central lines of eclipses will be realised by a perusal of the following particulars of the eclipse of the Sun of June 1295, when it appeared at the North Pole. In 1367 it had got forwards to the month of August, and southwards to the North of Europe; in 1439 it was visible all over Europe; at its nineteenth appearance in 1601 it was central in London; on May 5, 1818, it was also visible in London, and was again nearly central in the metropolis on May 15, 1836. At its next appearance on May 26, 1854, the central line passed over North

Africa; on June 6, 1872, it crossed France; on June 17, 1890, it crossed North Africa and Turkey in Asia; on June 28, 1908, it was central in Mexico, Florida, and across the Atlantic to Senegambia. At its thirty-ninth appearance on August 10, 1980, the Moon's shadow will pass S. of the Equator, and, as the eclipse will take place near midnight, it will be invisible in Europe, Africa, and Asia, and visible only in South America. At every subsequent period the eclipse will go more and more towards the S., until at its seventy-eighth appearance on September 30, 2665, it will go off at the South Pole of the Earth, and therefore the series will have ended.

Thus far we have been considering eclipses of the Sun and Moon as mixed up in regard to certain general principles; but we must now deal with solar and lunar eclipses separately, because they differ so much in the details relating to their observation that it is necessary to keep them distinct. An eclipse of the Sun in cases where only a portion of the Sun is obscured offers really no features of interest unless the portion obscured is very large, not less than nine-tenths of the Sun's diameter. When this amount of obscuration occurs there are a few subsidiary occurrences calculated to interest the student of nature; for instance, the reduction in the sunlight available for lighting up the landscape is very marked, and, though not a cloud is visible, yet the sky puts on a dark, lurid appearance suggestive of a severe thunderstorm being at hand. The temperature of the air becomes much reduced, perhaps to the amount of 5° Fahrenheit, or even more, and the personal sensation of chilliness experienced is even greater than the thermometer implies. Birds distinctly manifest their knowledge that something special is taking place, for, even if they do not definitely go to roost, they are evidently uncomfortable and suspicious. If any trees near are in leaf images of the crescent Sun will be cast on flat surfaces such as a board, or even a book, laid on the ground so that images of the Sun may pass through the foliage. Finally, the maximum phase is accompanied by a sudden gust of wind. All these phenomena were seen in different parts of England on the occasion of the large eclipse of April 17, 1912.

It is when a total eclipse of the Sun happens that a solar eclipse shows to the greatest advantage, many of the features manifested being of a very sensational character, the excitement of the spectators being greatly accentuated by the rapidity with which the transformations take place, and the limited amount of time available for looking at them. I am here speaking of eclipses of the Sun observed by educated and sensible people, who know all, or at any rate something, about the matter. But when the spectators comprise ignorant natives, whether Indians or Negroes or Aborigines generally, a total eclipse of the Sun is usually the occasion of remarkable scenes in which alarm and despair and anger are intermingled. From the various records which I have gathered up of such scenes, I select the following as typical of many such narratives. But the first quotation will show that we need not go so far off as the lands inhabited by Indians for an example of an eclipse panic.

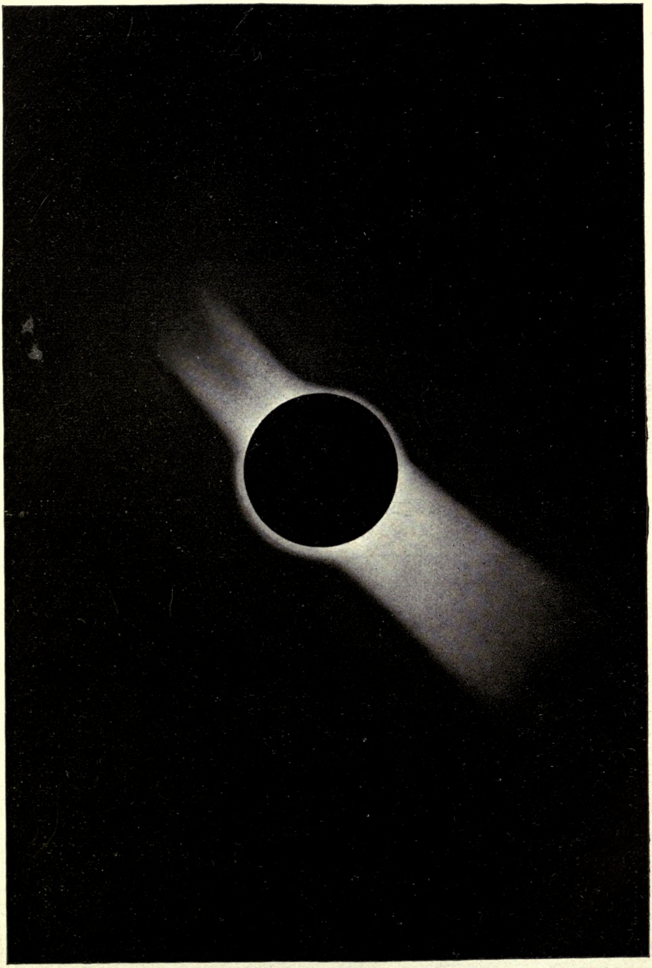
The Earl of March quotes from a letter written by a certain Sir Thomas Prendergast, from Pantglase, under date of August 3, 1748, the following sentence :

"I would have spun out a few lines more in relation to the eclipse, such as the care taken to get in all the hay before it ; prayers said in churches, preparatory and preventive ; and many other demonstrations of terror and religion."[1]

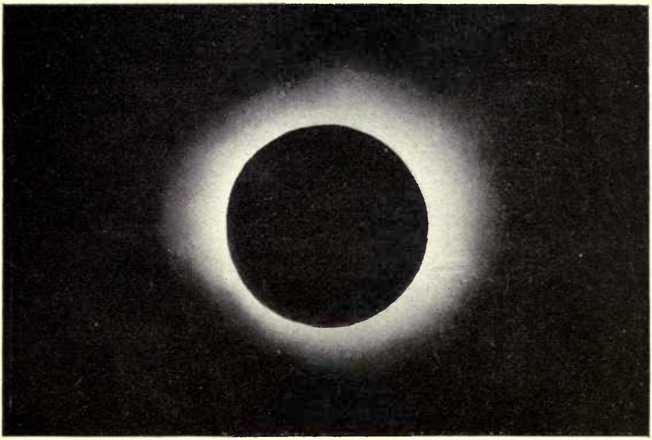
What happened on the occasion of the total eclipse of July 29, 1878, was thus described in an American newspaper by a spectator resident at Fort Sill, Indian Territory :

"On Monday last we were permitted to see the eclipse of the Sun in a beautiful bright sky. Not a cloud was visible. We had made ample preparation, laying in a stock of smoked glass

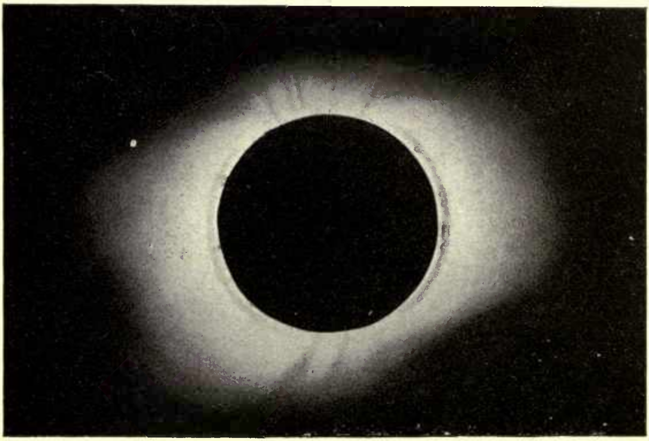
[1] "A Duke and his Friends" (London, 1911).



The Solar Corona, July 29, 1878 (*J. P. Murphy*).



The Solar Corona, August 29, 1886 (*Harvard Annals*, xviii.).



The Solar Corona, Dec. 22, 1889 (*Perry*).

several days in advance. It was the grandest sight I ever beheld; but it frightened the Indians badly. Some of them threw themselves upon their knees and invoked the Divine blessing; others flung themselves flat on the ground, face downward; others cried and yelled in frantic excitement and terror. Finally, one old fellow stepped from the door of his lodge, pistol in hand, and, fixing his eyes on the darkened Sun, mumbled a few unintelligible words, and, raising his arm, took direct aim at the luminary, fired off his pistol, and, after throwing his arms about his head in a series of extraordinary gesticulations, retreated to his own quarters. As it happened, that very instant was the conclusion of totality. The Indians beheld the glorious orb of day once more peep forth, and it was unanimously voted that the timely discharge of that pistol was the only thing that drove away the shadow and saved them from the public inconvenience that would have certainly resulted from the entire extinction of the Sun."

We will now go back to the general concomitants of a total eclipse of the Sun as they present themselves to a rational observer, who can deal with the matter in a calm and philosophical spirit. When the Moon has reached the Sun, and its forward limb has broken in upon the Sun's disc, nothing remarkable is to be noted until the Moon's movement has so far progressed as to have made a substantial encroachment on the Sun. When perhaps half of the Sun has become obscured a fall in the temperature of the air around the observer will begin to be felt. The next thing which will be noticed will be a change in the appearance and colour of the sky. The ordinary blue will become much deeper, soon passing into a dull dark slate colour which will eventually reach purple.

This purple colour has been likened to a canopy overhanging the sky nearly, but not quite, down to the horizon; for the lowermost strip, so to speak, of the canopy reaching actually to the horizon is not purple, but orange, more or less, in colour, which hue is due to the fact that the Sun's light which reaches the observer from the horizon has to pass through a very thick stratum of atmosphere which absorbs much of the violet light of the spectrum.

This will indicate that the total phase is at hand, and that instant and the two or three minutes (according to circumstances) which will follow constitute the high-water mark of the excitement of the spectators. Though the duration of totality might, according to theory, reach such an extreme as seven minutes, this extreme never is reached, and from two to four minutes is the general duration of the eclipses which have been observed during recent years. This means that an immense amount of work, such as photographing and note-taking, has to be compressed into a very limited amount of time, and amid much nervous excitement.

The first feature which suddenly springs into view are jets of Red Flames, now more generally called Prominences, which spring up at various points round the Sun's circumference. It was at one time supposed that these Red Flames were only to be seen during total eclipses, but modern instruments and methods have brought it about that they can always be seen, so far as their positions and shapes are concerned. These Red Flames are now recognised to be masses of incandescent gas mixed with other gases, one of which, now called helium, is not found on the Earth.

Almost coincident with the appearance of the Red Flames, or even before them, numerous beads of light spring up along the forward limb of the Moon. These are known as "Baily's Beads," having been first systematically described by the late Mr. Francis Baily in 1836. Their explanation is somewhat obscure. It has been supposed that they are outstanding portions of the solar disc peeping through lunar valleys, whilst the adjacent mountains project far beyond the smooth circular outline of the Sun's disc, which is no longer visible as a continuous circle. This may be one of the causes which give rise to the Baily's Beads, but the optical phenomenon known as the irradiation of light is no doubt a contributory cause.

The most important feature of a total eclipse of the Sun is the Corona, but there is so much to be said about this that it will be preferable to dispose of the other accessory details of a total eclipse before embarking on the Corona.

The first and most obvious proof that the moment of totality has been reached is the general darkness (virtually that of night) which prevails everywhere, darkness usually so great as to necessitate the use of lamps for reading clocks and watches. This intense degree of darkness is not, however, invariably experienced, for under special circumstances which cannot always be foreseen or explained the darkness is very much less intense than the typical darkness just alluded to. The two total eclipses which I have had the good fortune to witness were marked by both these characteristics. During the eclipse of 1900 the darkness was, I apprehend, normal, but in 1905 the darkness may be described as having been rather disappointing. The evident cause was the prevalence of so much cloud all over the sky, and probably that would be the explanation of all cases in which the darkness was not very intense. But incidentally the special circumstances of any particular eclipse would have to be taken into account. The duration and the extent of the apparent overlapping of the Sun by the Moon, whether much or little, would certainly affect the intensity of the resulting obscurity.

The shadow cast by the Moon on the Earth of course moves progressively along the recognised central line of the eclipse, and its movement can be seen and followed by an observer suitably placed. The words "suitably placed," in this connection, mean that the spectator occupies an elevated position, say on the top, or high up on the side, of a hill, or on the top of a church-tower—that is to say, occupies some coign of vantage which enables him to scan a far-distant horizon. Doing this, he will be able to catch sight of the shadow coming up to his own position, hanging over it momentarily, and then rapidly passing off in the opposite direction. The necessity for an observer being wide awake who is desirous of catching sight of this shadow will be understood by the statement that it travels at the rate of thirty miles in a minute.

Another very curious and interesting feature of a total eclipse of the Sun is one which has only come into prominence of recent years, namely the "Shadow Bands." They become visible a few minutes before totality, say five. They are wavy streaks of light and shade which dance across the landscape, and are best seen if the observer can so place himself as to face an upright, white-plastered, or stone wall to serve as a screen to receive the shadows as they pass along. Nothing is known of their cause, or of any laws which regulate them. They vary at different eclipses in distance apart, in breadth, and in the speed with which they travel.

One other thing may be mentioned: the brushes of light which precede the immediate appearance of the Corona on the side of the dark Moon opposite to the disappearing crescent of the Sun. It does not seem that these brushes of light are directly associated either with the Corona or with Baily's Beads, or indeed with any phenomenon already mentioned. They appear, in point of fact, to have an entirely independent existence, and I am not acquainted with any well-considered explanation of their origin.

The Corona is, after all, the one special feature of every total eclipse of the Sun on which every observer, as a rule, concentrates his attention, unless he is officially turned off to something else. Briefly described, the Corona is a broad ring of light seen to surround the Moon at the instant of totality, lasting during totality, and disappearing on the return of the Sun to visibility. It is usual to consider the Corona in a twofold aspect—that is to say, we speak of the "inner Corona" and the "outer Corona." The two together constitute a broad bright ring of light of varying diameter, or perhaps it will be best to consider the inner Corona as a ring averaging $\frac{1}{2}°$ in breadth, whilst the outer Corona extends 1, 2, or more degrees from the Sun, at which distance it generally has ost its more or less

The Solar Corona, 1898 (*C. Michie Smith*).

FIG. 148 PLATE XLIII.

The Solar Corona, May 28, 1900.

circular outline, its edges developing into long rays or streamers of varying length, and stretching from various parts of the Sun's circumference. I say "Sun's circumference" because it is now well understood that the Corona belongs to, and is an appendage of the Sun, but looked at merely from the sight-seeing point of view it might equally seem to be a ring around and belonging to the Moon. Indeed, in early days it was considered to be a lunar appendage, and it was only during recent years that it has become certainly established that the Corona, whatever it is, belongs exclusively to the Sun. Its general appearance will be best understood by a careful examination of the accompanying illustrations, which represent its appearance at many different dates, and as portrayed by various observers ; some by resort to hand-drawing, but the majority due to photography.

By far the most interesting recent discovery connected with the Corona is the fact that its variations in shape depend upon an undoubted law, but the circumstances of that law are not all understood. The law, stated baldly, is that the outline of the Corona varies in a most marked degree according to whether the eclipse coincides (or nearly coincides) in point of time with an epoch of maximum or an epoch of minimum Sun-spots. In the former case the general outline of the Corona is roughly circular and compact, whilst in the latter case it is not only exceedingly irregular, but is characterised by remarkable streamers extending 2° or more on each side of the Sun in prolongation of the solar Equator, accompanied by narrow flames of light at either pole.

Speaking generally, I think we are entitled to assume that the Corona is something in the nature of an atmosphere surrounding the Sun ; but its indescribable texture (so to speak), and the uncertainty and irregularity of its streamers, and its undoubted connection, in some way, with the presence or absence of Spots on the Sun render it one of the great mysteries of modern astronomy, the perfect unravelling of which has yet to be accomplished.

A question is often put by that well-known personage, "the man in the street," in the dual form of "What is the good of an eclipse of the Sun?" and "What is the good of taking so much trouble and incurring so much expense to observe an eclipse of the Sun?" Perhaps no very direct answer can be given, and a cynical mind might take pleasure in recalling Sir George Cornwall Lewis's classic denunciation of astronomy, which he stigmatised as a "science of pure curiosity." The remark, though by no means fair or strictly accurate if applied to the science of astronomy as a whole, has some application to the special subject of Eclipses. They are only observed and can only be observed to satisfy human curiosity, which desires to know as much as possible about the occult things of the universe, in this case the physical constitution of the Sun, well described by Proctor in the title of one of his books as the "Ruler, Light, Fire, and Life" of the system.

The elaborate observations of the last 35 years in particular have thrown a flood of light on the origin of those phenomena which form the accessories of a total eclipse of the Sun, and so indirectly help to reveal the constitution of the Sun. Of the special sights which present themselves during a total eclipse, beyond doubt the Corona is the most interesting and most striking. In the early days of exact observations the question was long in controversy whether the Corona was connected with the Moon or the Sun. It is now a matter of perfect certainty, as has been already stated, that the Corona is a solar and not a lunar feature, and that the Moon has only a secondary share in the matter for the reason that its own solid body blocks out the sunlight from observers on the Earth, and so enables them to see the display of light which emanates from the Sun and constitutes the Corona.

The question of the shape of the Corona, as connected with the prevalence of Sun-spots, is such an important one that it is worth while to recapitulate the facts in a slightly different form; thus: When a total eclipse of the Sun occurs at or near the epoch of the Sun-spot maximum, the Corona takes a distinctly compact shape, with its outline of very much the same breadth all the way round the Sun, whatever streamers or special off-shoots may be visible. On the other hand, when an eclipse occurs at an epoch of Sun-spot minimum, there is a marked deficiency in the breadth of the Corona at the N. and S. poles of the Sun, but in the equatorial regions, both E. and W., the Corona throws out broad, elongated streamers, which on some occasions have been traced to a distance of 4° from the Sun's limbs. The meaning of these differences is at present unknown, but the facts are unquestionable. It is interesting to note that the eclipse of 1900 was the first that was made the subject of a prediction, that as it coincided with an epoch of few or no Sun-spots, its outline would be elongated in the Sun's equatorial regions; and this proved to be the case.

The Corona itself is no new, or even modern, discovery. The record of its existence certainly goes back to 1567, and perhaps even much further than that. What is modern and newly recognised is that the general outline of the Corona varies periodically, with some relation to the spots on the Sun.

It may interest the reader to hear something about the eclipses which will happen during the next few years. The information which follows is taken chiefly from the *Nautical Almanac*, and the Rev. S. J. Johnson's *Historical and Future Eclipses*.

1913, *March* 22.—Total eclipse of the Moon, invisible at Greenwich, but visible in Polynesia. (Mag. 1·576.)

1913, *April* 6.—Partial eclipse of the Sun, invisible at Greenwich, visible in North-West America and North-East Asia.

1913, *September* 1.—Partial eclipse of the Sun, invisible at Greenwich, visible in Labrador. (Mag. 0·15.)

1913, *September* 15.—Total eclipse of the Moon, invisible in Greenwich, visible in the Indian Ocean. (Mag. 1·43.)

1913, *September* 29.—Partial eclipse of the Sun, invisible at Greenwich, visible in the South Polar regions. (Mag. 0·82.)

1914, *February* 24.—Annular eclipse of the Sun, visible only in the South Polar Regions.

1914, *March* 12.—Partial eclipse of the Moon, partly visible at Greenwich in the early morning.

1914, *August* 21.—Total eclipse of the Sun, visible at Greenwich as a partial eclipse (Mag. 0·651). The central line passes through Southern Russia, north-westwards through Norway.

1914, *September* 4.—Partial eclipse of the Moon, invisible at Greenwich, and visible only in Polynesia.

The foregoing statement of the eclipses of 1913 and 1914 embraces *all* the eclipses of these years, but considerations of space require me now to continue the statement on a principle of selection, and I give, therefore, now only eclipses of the Sun, and only such as are either annular or total, and also visible either in England or within easy reach of England.

1916, *February* 3.—Total eclipse visible in the Atlantic, just missing the shores of Ireland.

1921, *April* 8.—Annular eclipse, visible about the Shetland Islands.

1925, *January* 24.—Total eclipse, visible in North America and across the Atlantic to beyond the N. of Scotland.

1927, *June* 29.—Total eclipse, visible in North Wales, Lancashire, North Yorkshire, and Durham, but total for only about 20 seconds or a little more. This eclipse is actually the first total eclipse visible at all in England since 1724.

After 1927, England will have no chance of another total eclipse until August 11, 1999, when the shadow-line will cross a part of Cornwall and Devonshire.[1] In point of fact, many centuries will elapse ere another eclipse will occur fulfilling the four following conditions presented by the eclipse of 1905: such a long duration of darkness; a locality with so good a promise of a clear sky; such a high altitude for the Sun above the horizon; and a *locale* so accessible from the shores of

[1] This is what is commonly stated, but according to the map in Oppolzer's *Canon der Finsternisse*, the central line does not touch England, but passes a certain number of miles to the S. and so into France.

England as was Spain. Finally, it may be stated that on October 7, 2135, there will be an eclipse the central line of which will pass over the middle of England.

Speaking generally, total eclipses of the Sun may be said not to vary very much in number from century to century, but the greater facilities for travel which we can now command, compared with the limited opportunities possessed by our ancestors, or even by our grandfathers, make the subject of eclipses much more familiar to us nowadays than was formerly the case ; and the eclipses since the middle of the 19th century, observed as they have been in many parts of the world which used to be more or less inaccessible, have yielded the numerous and important disclosures respecting the constitution of the Sun which have been mentioned earlier in this chapter.

As regards the question of instruments, it is no longer sufficient to be content with simple eye-observations of the visible sights offered by an eclipse to persons armed with only ordinary telescopes. Of course a telescope (which need not be a very large one) is necessary, or, at least, very useful for observing the outward appearances exhibited during the progress of a solar eclipse. Indeed, an opera-glass, or even the naked eye, suffices to disclose many interesting features; but, to perform eclipse observations of the highest value in the most up-to-date fashion, a good deal more is wanted than a mere telescope. Moreover, the astronomer requires the active assistance of a photographer and of a practical chemist, to say nothing of an outfit of clocks and of time-keepers to manage them. Accordingly, the *impedimenta* of a fully equipped eclipse expedition are vastly more numerous, more heavy, more bulky, than was the case in by-gone days ; and it is only the modern application of steam to railways and ships which enables astronomers of the 20th century to do the work which the scientific exigencies of the century demand.

Even with the facilities here referred to, it will easily be understood that it is no joke to organise and carry to a successful issue eclipse expeditions from England to such far-off localities as India, or Polynesia, or the West Indies, though such things have been done several times within recent years. When, however, English astronomers in England had, in 1905, the chance of a total eclipse of the Sun no farther off than Spain, perhaps 700 miles away, it was obvious that there would be a rush to see it, which would not have occurred if it had been a question of a voyage to Java, or Tierra del Fuego. Hence it came about that the eclipse of 1905, already mentioned, had been looked forward to with great interest by vast numbers of English people, astronomers and non-astronomers. These may be said to have had their appetite whetted by the eclipse of May 1900, also visible as near to England as Spain and Portugal. But this eclipse was under the important disability that its duration was very short, only $1\frac{1}{2}$ minutes—a period too brief wherein to see or do much. On the other hand, the eclipse of 1905 was due to last $3\frac{1}{2}$ minutes, an interval to be deemed substantial, seeing that under no circumstances, as already stated, can the most favourable totality last for more than about 6 or 7 minutes.[1]

Therefore the probabilities were that large numbers would flock to Spain from England (and, for the matter of that, from France and Germany) to see the eclipse of 1905. Accordingly, some account of the preparations which had to be made (indeed which always have to be made before total eclipses) will probably interest the reader.

Preparations began much further back than a few months before the great event. Though it is rather the fashion to run down Spain and things Spanish, it must be stated, to the credit of the Spanish Government, that more than 4 years in advance did the Madrid Observatory begin taking steps to prepare for the eclipse, first by the issue of a very good map of the path of the central line across Spain, and afterwards by the issue of additional maps and a pamphlet of suggestions and

[1] Whitmell, *Monthly Notices, Royal Astronomical Society*, vol. lx. p. 435.

advice. These preliminary documents proved most useful to the English Astronomical Societies and private individuals who undertook to organise the necessary travelling arrangements.

In all such matters there are certain very important points to be handled, to which all others must be subordinate. First and foremost comes the question of probable weather at possible observing stations situated in or near the central line. Information as to this had to be sought from existing records already published by Spanish meteorological authorities. These were obtained, consulted, and tabulated with the following general results.

It was found that there was a probability of fog and haze prevailing at the end of August on the N. coast of Spain, at or near the actual coast-line, though this could be evaded by journeying 50 miles inland by roads or railways to towns without hotel accommodation. Still further inland, especially at and near the important city of Burgos, it was found that eligible positions could be selected for observing the eclipse, all the more eligible because, Burgos being at a considerable elevation above the sea, a fair amount of fresh air at a moderate temperature was understood to be obtainable

The question of temperature constituted all along a great difficulty in making up eclipse-observing parties, it being well known that the summer temperature of the S.E. of Spain is quite tropical in its character. Next after the question of temperature came the question of sleeping accommodation, beds and bedding to the taste of Mr. and Mrs. John Bull being difficult to obtain, indeed almost non-existent in Spain.

When the eclipse came within a measurable distance—that is to say, about a year and a half before the appointed day—the British Astronomical Association nominated a special committee to consider the travelling and observing arrangements which it was expedient to make. The question of travelling was dealt with first. The difficulties which it was known would have to be faced in respect of the extreme heat and the general lack of comfortable sleeping accommodation led the Committee, in the first instance, to contemplate the employment of a large ocean-going steamer, which should land parties to settle themselves at different places on the S.E. coast, with Valencia as the permanent headquarters for the steamer, for a week or more, making use of the steamer, as much as possible, as a floating hotel.

Several steamship companies applied to one and all refused to negotiate with the Committee except on terms and conditions which were so excessive as to be prohibitive. The contemplated grand expedition in its complete form had then to be abandoned, and the 70 or more scientific excursionists who had given in their names to go somewhere or other were left to make arrangements for themselves as best they could.

The redoubtable Cook then came upon the scene, and offered personally to conduct parties overland through France to Burgos, and, partly by land and partly by sea, to the Balearic Islands *via* Marseilles.

The Polytechnic Institution offered to organise another party from London to Burgos at a helter-skelter pace and cheap fares. Their number (20) was soon made up. Besides the foregoing there were attempts made, with more or less (generally less) success, to get up detachments for Gijon, on the N. coast of Spain, for Valencia on the S.E. coast, and for Philippeville in Algiers.

The merits of these various subsidiary observing centres generally turned on the facilities available for local travelling from the chief centre and on the question of hotels ; for, happily so far as the Mediterranean portion of the eclipse area was concerned, there was never any serious doubt or risk about fine weather and a clear sky being assured.

Observations of eclipses of the Sun differ from all other astronomical observations in a very important particular. Most observations are performed by one chief observer with or without some assistance from a subordinate, who will perform such minor duties as calling out or writing down times as indicated by a clock, or opening or shutting photographic shutters and slides. An ordinary observer, with or without a little help from a junior, can, as a rule, take his own time in performing the task which he has undertaken, or which has been allotted to him. Things are quite otherwise, however, when a total eclipse of the Sun is in question. There is then no opportunity for leisurely work. A dozen different things have to be performed, or looked at, practically all at once—at any rate, within the compass of a few minutes, which seldom exceed three or four at the outside.

A well-disciplined eclipse observer has, therefore, to make up his mind, not only that he cannot see everything himself, but that he can hardly hope to see even one-tenth of everything. The work, therefore, calls for much self-denial on the part of the earnest votary of science, who must patiently resolve to concentrate his mind on some one or two special points, whilst his next-door neighbour on one side concentrates his thoughts on a third or fourth special point, and another neighbour gives his mind perhaps to a fifth, or sixth, special point ; and so all the expected phenomena are, by judicious pre-arrangement, shared out amongst the different members of a party or expedition.

Before every eclipse it is usual for the members of a party, especially if they belong to some public or State Observatory, to go through a sort of military rifle and aiming drill, to practise what they will have to perform during the critical brief minutes of totality, and to make sure beforehand that each understands his own duty and his own instrument, etc., and will not trespass upon the duties of his coadjutors, or have a fiasco with his own instruments or apparatus. Prior to the eclipse of 1900 the Astronomer Royal's party at Greenwich had a grand rehearsal, which was afterwards repeated with models of a sham eclipse, much to the amusement of the spectators, at a meeting of the Royal Astronomical Society at Burlington House.

Inspired by this precedent, one day in July 1905, the Eclipse Committee of the British Astronomical Association gathered together a number of those who intended to observe the eclipse, and carried out a very useful, though informal, exchange of ideas as to what observations were possible with the instrumental appliances at the command of each with a view of avoiding to some degree, by pre-arrangement, waste of time and waste of labour on the great day. And some of those who were posted up in the intricacies of French and Spanish railway travelling, and Spanish hotel life, unfolded their experiences for the benefit of novices present.

As regards the work which was to be performed—that is, the observations which were to be made—the Eclipse Committee just named entrusted the preparation of an "agenda" to Mr. E. W. Maunder, of the Royal Observatory, Greenwich, and it is needless to add that the work was well and judiciously done. It had scarcely been accomplished when Mr. Maunder had to resign his secretaryship of the Eclipse Committee because the Canadian Government had honoured him with an invitation to join their observing party, which was going to the far-off locality of Labrador, and which, therefore, rendered it necessary for him to leave England some weeks before the Spanish parties did so.

At well-nigh the eleventh hour, when all other attempts to negotiate an expedition, wholly or almost wholly, by sea, had failed, it was discovered that the P. & O. Mail steamer leaving Tilbury on August 25 was due to cross the line of central eclipse, or totality as it is generally called, on the very day, and almost at the very hour, of the eclipse, and negotiations were entered into with the Company with a view of arranging that the ship should heave-to for two or three hours to enable the passengers to have a leisurely view of the phenomenon. So soon as this decision was arrived at it was communicated to all the members of the British Astronomical Association, and others who had desired to see the eclipse without incurring the many disagreeables of a land journey across France and Spain during the hot days of August. Thanks to the officials of the P. & O. Company, the details were soon worked out.

This review of the situation will enable the reader to understand something of the nature of the preliminary matters which had to be handled ; but my statement of them is very far from being exhaustive, for I have limited myself to matters affecting those who were going abroad from England.

I have said nothing about what the Americans proposed to do, and the Americans always carry out their scientific expeditions in good style, and with thoroughness ; nor have I said anything about French or German efforts. France has an Astronomical Association, run very much on the same lines as the English Association, and it was at one time hoped that some sort of organised co-operation might have been arrived at between the two bodies ; but this did not come about, chiefly because the travelling necessities of the two nations were diverse, the English having to cross the water to get to Spain, whilst the French were already next door.

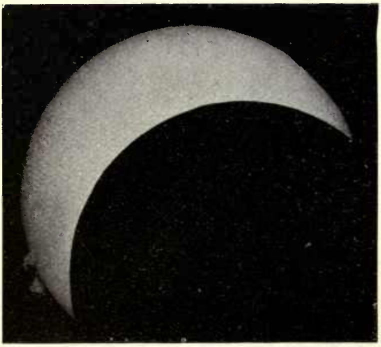
Since the eventful month of December in the eventful year 1870, when the distinguished French astronomer, Janssen, escaped from beleaguered Paris in a balloon in order to observe the total eclipse of the Sun of December 22, 1870, there have been many expeditions to all parts of the world to observe occurrences of the same phenomenon. So far as I can remember, there has never been an instance, till the year 1905, of an expedition of astronomers and astronomically-minded people having been avowedly organised to observe an eclipse at a " station " on the high seas.

The nearest approach to this would seem to have been the stoppage for an hour or two in mid-Atlantic, on May 29, 1900, of the ss. *Austral*, of the Orient Line, on its outward voyage to Australia in order that its passengers might view the total phase of that day. There was, however, no set purpose on the part of the steamship company to provide this special show for the benefit of the passengers. The episode was contrived by Colonel Markwick, R.A., F.R.A.S., who had obtained an assurance that the steamer would cross the eclipse line at the right place and time. The eclipse of April 17, 1912, was by an arrangement with the captain viewed by Mr. W. B. Gibbs, F.R.A.S., on board the Union Castle s.s. *Balmoral Castle* off the coast of Portugal.

Nor do I think there was any set purpose in the mind of the captain of the French man-of-war *Le Comte d'Artois*, who, in the middle of the 18th century, observed at sea the eclipse of February 9, 1766. Possibly, however, it was by design that the Spanish Admiral, Don Antonio Ulloa, saw the total eclipse of June 24, 1778, at sea, when passing from the Azores to Cape St. Vincent. His observations, published in the *Philosophical Transactions*, 1779, considering their early date, are extremely interesting.

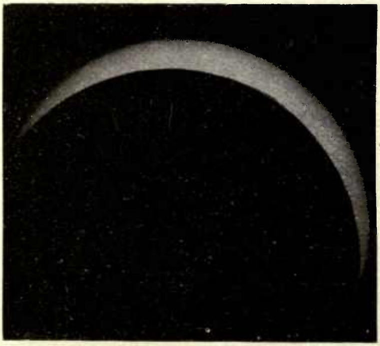
The land observations in 1905 call for no special notice in this place as regards the personal adventures of the observers who chose *terra firma* in Spain for their work, but the fortunes of the sea-going party, of whom I was one, are worth a brief mention because of their novelty. This section of observers took ship at Tilbury on board the P. & O. steamer *Arcadia*, Captain Cubitt. After an uneventful voyage, only varied by landing for a few hours at Gibraltar, we arrived in the forenoon of the eventful day, August 30, at the exact spot in the Mediterranean, not far from the Balearic Isles, in the precise latitude and longitude which it was calculated would put us on the central line of the eclipse; and so it did, and we saw everything most successfully, thanks to Captain Cubitt's kind and painstaking co-operation.

Before the eclipse we knew that there was one special problem to be solved which dominated all others: could we find the proper position, and, having found it, could we keep it



No. 1.—11 h. 46 m. 30 s. G.M.T.

No. 2.—12 h. 5 m. G.M.T.



No. 3.—12 h. 11 m.

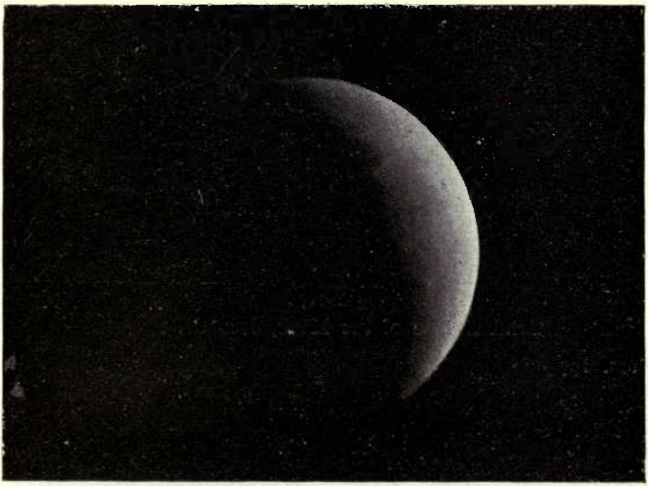
The Eclipse of the Sun, April 17, 1912, as seen at Bournemouth.
(*E. W. Barlow, photo.*)

[(Notice that 2 and 3 represent crescents of the Sun of the same form, but a different part of the Sun is exposed to view.)

1st stage.

2nd stage.

Total Eclipse of the Moon, Jan. 28, 1888.



3rd stage.

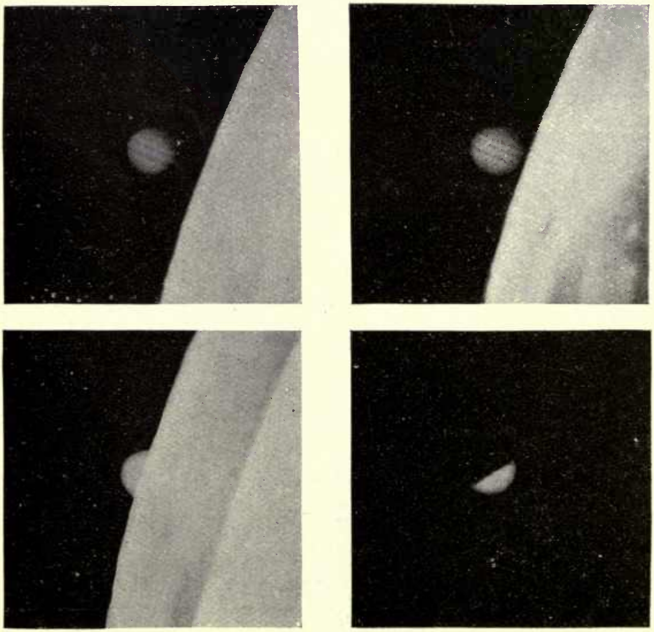
4th stage.

Total Eclipse of the Moon, Jan. 28, 1888.

5th stage.

Total Eclipse of the Moon, Jan. 28, 1888.

FIGS. 157–160



Occultation of Jupiter by the Moon, Aug. 12, 1892 (*W. H. Pickering*).

for two hours, and especially for the 10 minutes which would include the critical events of the eclipse; and would the ship be steady enough on the water to enable the necessary observations to be made? Everything happened just as was wanted,

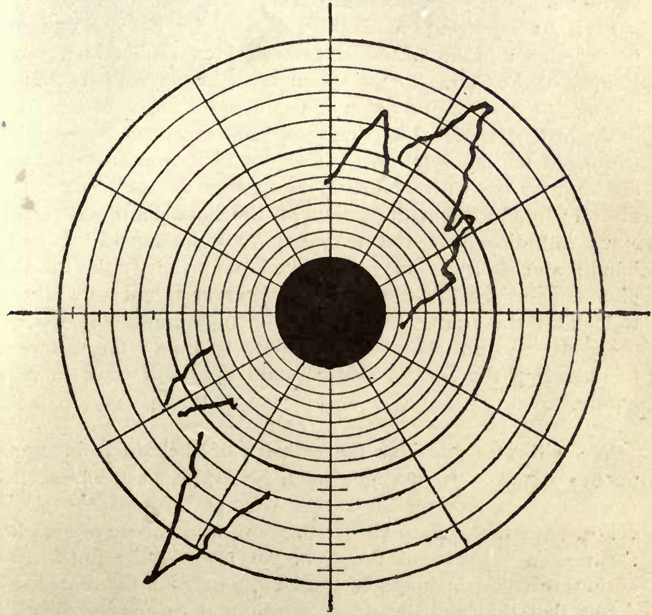
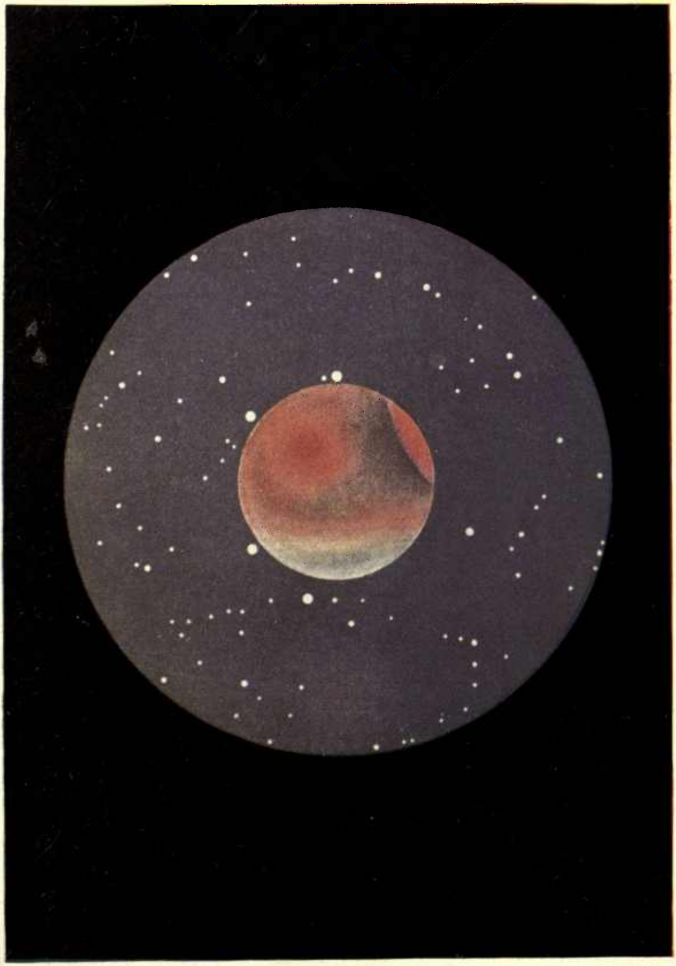


Fig. 161.—The Corona, Aug. 8, 1896, as sketched by E. J. Stone's system.

the most remarkable thing of all being the steadiness and the fixity of the ship. This last was accomplished by the ship being kept moving at the calculated speed of three knots an hour, which neutralised the strong set of the current in the reverse direction. All of us, or most of us, were able to observe the usual concomitants of total eclipses of the Sun ; but the only feature needing notice here was the lack of darkness of the usual intensity, or anything like it. Probably that was the result of our viewing the eclipse with nothing but water surrounding our place of observation.

Fig. 161 represents a diagram devised by E. J. Stone for noting down in haste the streamers, etc., visible in a total Eclipse of the Sun. The diagram is an instance of its actual use by Stone on the occasion of the Total Eclipse of the Sun of August 9, 1896. The diagram, however, may be usefully employed for other purposes if copies of it, printed on cards, are kept for use with a telescope. In the case of occultations of stars by the Moon the points on the lunar limb, where the stars will disappear and reappear, may be marked beforehand ; and so time may be saved, and the stages of the phenomenon not lost because the observer is not sure where to look for the stars. Other uses for such cards will present themselves to an observer from time to time ; for instance, in observing the Sun or double stars they will come in very handy.

We will now consider the eclipses of the Moon in some further detail. It may be said, generally, that whilst, for reasons mentioned in an earlier part of this chapter, these eclipses are more often visible to those who choose to look for them than eclipses of the Sun, yet they kindle much less enthusiasm than eclipses of the Sun, partly for the reason, no doubt, that they are devoid of sensational features of display and points of general interest. Indeed, almost the only matter which an intending observer of a total eclipse of the Moon has to put down on his agenda is the question, What will be the aspect of the Moon when most deeply immersed in the Earth's shadow? will it be visible at all? or will it be invisible? or, if visible, how will it look? Of course one may say that, by rights, it ought to be altogether invisible, and so very frequently it is ;



TOTAL ECLIPSE OF THE MOON. (*Tempel*)

1867.

but, on the other hand, it is frequently visible between the extremes of showing traces of its existence, and showing its whole disc quite prominently of a more or less bright coppery colour. There are no discoverable laws which regulate these variations, and it can only be said, very vaguely, that they depend upon the variable condition of the Earth's atmosphere.

If the portion of the atmosphere through which it so happens that the Sun's rays have to pass are highly saturated with aqueous vapour, the red rays will be transmitted freely, and the Moon's surface will be highly illuminated. If, on the other hand, aqueous vapour is deficient, the red rays will be more or less absorbed, and, as the blue will predominate, the illumination will be extinguished.

When, on the occasion of a total eclipse, some parts of the Moon's disc are visible and others invisible, the variation may be considered due to the prevalence of moisture in some parts of the atmosphere through which the Moon's rays reach us, and its absence in other parts, thus emphasising the distinctions just pointed out. It is right to add that, by various competent authorities, the foregoing explanations are deemed unsatisfactory; but nothing better has as yet been offered in substitution.

There have been total eclipses of the Moon recorded which have played a part in certain mundane events. An experience which befel Christopher Columbus is a case in point. In February 1504 Columbus found himself at the island of Jamaica in great straits for want of provisions, which the islanders refused to provide, and he was therefore at his wits' end to know what to do. What followed shall now be told in the words of his son :—

"He bethought himself that, within three days, there would be an eclipse of the Moon in the first part of the night; and then sends an Indian of Hispaniola with us to call the principal Indians of that province, saying he would talk with them about a matter of concern. Being come that day before the eclipse was, he ordered the interpreter to tell them that we were Christians and believed in God, who dwelt in heaven and took care of the good and punished the wicked . . . that, as for the Indians, seeing how negligent they were in bringing provisions for our commodities, He was angry with them, and had decreed to punish them with plague and famine; which because, perhaps, they would not believe, God had appointed to give them a manifest token of it in the heaven, that they might plainly know the punishment was to come from Him. Therefore, he bid them observe that night when the Moon appeared, and they should see her rise angry and of a bloody hue, to denote the mischief God intended should fall on them. Having said this to them, the Indians went away, some afraid and others looking upon it as an idle story; but the eclipse, beginning as the Moon was rising, and increasing the higher she was, the Indians took notice of it, and were so frightened that they came running from all parts loaded with provisions, crying and lamenting, and prayed the admiral by all means to intercede with God for them, that He might not make them feel the effects of His wrath, and promising for the future carefully to bring him all he wanted. The admiral said he would speak with God, and shut himself up while the eclipse lasted, they still crying out to him to assist them; and when the admiral saw the eclipse began to go off, and the Moon would soon shine, he came out of his cabin, saying he had prayed to his God for them, and promised Him in their names they would be good for the future, and use the Christians well, bringing them provisions and other necessaries; and that therefore God forgave them, and as a token of it they should see the angriness and bloody colour of the Moon would go off. This proving so, just as he spoke it, they gave the admiral many thanks, and praised God, continuing so till the eclipse was quite passed. From that time forward they always took care to provide all that was necessary, ever praising the God of the Christians; for they believed the eclipses they had seen at other times had denoted mischiefs to befall them; and, being ignorant of the cause of them, and that they happened at certain times, not believing it possible to know on earth what was to happen in the heavens, they certainly concluded the God of the Christians had revealed it to the admiral."[1]

[1] See Pinkerton, *Voyages*, vol. xii. p. 148.

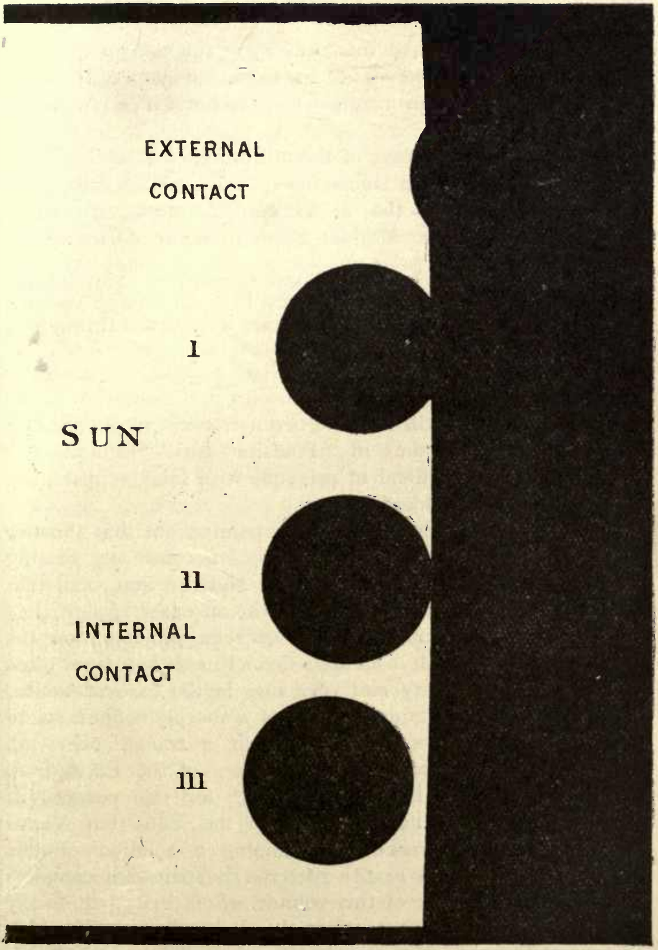


Fig. 163.—Phases of the Transit of an Inferior Planet.

This story records alike the credulity of the natives and the mingled piety and astuteness of the great navigator. It might well be regarded as an example of that worst of all frauds, a "pious fraud."

The most recent instance of the utilisation of a total eclipse of the Moon occurred on December 16, 1899. What happened is thus described by the *Times* correspondent with Lord Methuen's army at the Modder River in South Africa:—

"The Full Moon has prevented satisfactory search-light communication lately, but Kimberley took advantage eagerly of the eclipse last night to get important despatches through."

Akin to eclipses of the Sun are two astronomical phenomena which go by the names of "Transits" and "Occultations." They are entirely identical in principle with solar eclipses, but involve other celestial bodies.

In a previous chapter it has been pointed out that the two Inferior Planets, Mercury and Venus, are constantly passing round the Sun, and between the Earth and the Sun; and that when the Earth, Planet, and Sun are in an exact straight line the planet, whichever it be, will be seen projected on the Sun's disc. On such occasions (which are not very often in the case of Mercury and very rare in the case of Venus) the planet presents the appearance of a sharply defined round black spot. The occurrence of such a transit offers an opportunity for determining the distance of the Earth from the Sun. Mercury is not so suitable for this purpose as Venus, because of its proximity to the Sun; but Venus has frequently been used for obtaining a solution of this problem. The actual *modus operandi* is somewhat complex and beyond the scope of this volume. Suffice it, then, to say that it depends for its success on the skill and care with which observers at remote distances from one another on the Earth can determine micrometrically the exact points on the Sun, as viewed from northern and southern stations on the Earth, at which the planet appears to enter and to quit the Sun's disc in the course of its passage across the Sun. By the application of trigonometry (or mathematics applied to angles) the distance desired to be known can be calculated.

The satellites of Jupiter also perform transits over their primary's disc the observation of which, though of no important scientific value, furnish interesting spectacles from a star-gazing standpoint. They also suffer eclipse by passing behind the planet. Both these Jovian phenomena are dealt with in the various almanacs which embrace scientific events.

An Occultation, in the literal meaning of the word, is the covering over of one celestial body by another. Accordingly, in a dictionary sense, when a total eclipse of the Sun takes place the Sun is occulted by the Moon; but the word "Occultation" is by usage confined to cases where the Moon hides a planet or a star, or one planet hides another planet or a star. Occultations by the Moon of stars which lie in its path across the heavens are common enough and occur daily. Sometimes the Moon occults a planet, which naturally intensifies the interest attaching to the event. In the case of the larger planets and stars brighter than the 6th mag. anticipations of the occurrence will be found stated in the *Nautical Almanac* whence the information is copied into *Whitaker's Almanac* and other almanacs. When an Occultation occurs between the time of New Moon and First Quarter the effect is very striking, because the star occulted is suddenly extinguished at a point where the sky appears uniformly dark, and where there seems no sufficient reason for anything to interfere suddenly with the star. Occultations may be said to be celestial phenomena specially within the reach of amateurs because, when they take place with the Moon young in age, they happen at conveniently early hours in the evening, and are within the reach of telescopes however small.

CHAPTER IX.

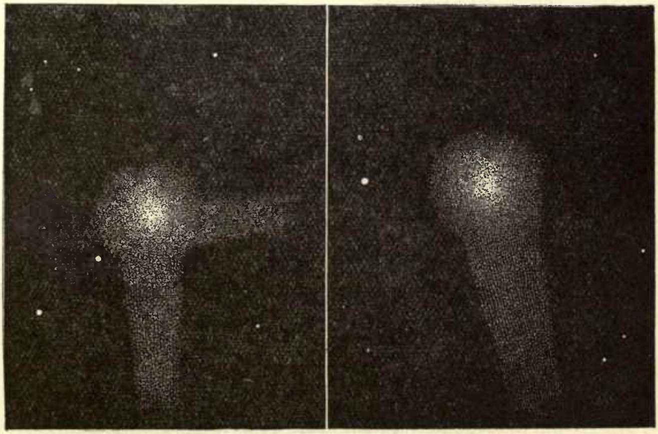
COMETS.

Always objects of popular interest.—Very numerous.—Telescopic comets.—Great comets visible to the naked eye.—Changes in the appearance of a comet after its first discovery.—Often easily mistaken for a nebula.—Usual changes exhibited by a telescopic comet.—Become visible as they approach the Sun.—What is a comet's tail?—Where does it come from?—Why do some comets have tails and not others?—These questions difficult to answer.—Sir J. Herschel's opinion.—General account of tails.—Some tails probably cylindrical.—Bredichen's Types of tails.—The "Light-pressure" theory.—Orbits of comets.—Periodical comets.—Celebrated comets.—Some statistics.

IT may safely be said that the remarkable objects to be dealt with in the present chapter have had a good deal to do with the recent spread of a taste for astronomy, assisted by the increased space devoted to scientific subjects by the ordinary newspaper press, and by the liberal subventions granted in the United States, especially during the last 30 years, by wealthy men there for the establishment and endowment of astronomical observatories.

I name the period of 30 years because that takes us back to the "great comet of 1882," which attracted world-wide attention, much more I think than did the "great comets" of 1858 and 1861, which were in all respects finer objects than the comet of 1882. All these will require notice further on. For the present I must start with some much less attractive details, the true understanding of which is essential if we would get a clear and satisfactory grip of this branch of astronomy.

Comets may be said generally to range themselves in two classes: very small ones, seldom if ever visible to the naked eye, and large ones easily visible to the naked eye, and always exhibiting tails the length of which may vary between two or three diameters of the Moon and half the extent of the visible sky. The last-named sort of comet appears only at long intervals of time, but a naked-eye comet with a tail two or three



Nov. 11. Nov. 15.

Figs. 164–165.—Brooks's Comet of 1898. (X.)

degrees long may be said to present itself every two or three or half a dozen years.

Here we have to face, at the outset, a popular view of things which altogether fails to accommodate itself to the superior knowledge of the professed astronomer. Ask the first person you meet the question, "What is a Comet?" and the answer will always be something like this: "A celestial object which appears unexpectedly and has a tail." Such an explanation and such a limited definition totally fail to represent the facts of the case as brought home to the astronomer working with a duly equipped telescope. He would tell us that, in the course of two or three years, he had seen probably at least half a dozen comets, none of them visible to the naked eye, and none of them possessed of a tail. In point of fact, it may be stated broadly that, in the course of a generation, dozens of comets come within our reach, most of them very diminutive in size and rarely having tails. Such comets are designated in astronomical parlance as "telescopic comets," though it occasionally happens that here and there one, some weeks or months after its first discovery, draws nearer to the Earth, increases greatly in size, puts forth a tail, and becomes to the man in the street alone worthy of the title of "comet."

Donati's Comet of 1858, universally known as the "great comet" of that year, was the one within my own personal recollection which in the most striking manner best illustrates what I have just said. Discovered by Donati at Florence on June 2, 1858, I first saw it in a 7½-inch refractor in August of that year. On one evening in the first week in September I could just manage to see it in a portable 3-inch telescope. It then gradually increased in size, and on October 5 had become one of the largest and most magnificent comets on record, not quite so much from the length of its tail (though that extended to about 50°) as from the wide, fan-like expanse of the tail, and its great brightness.

I have cited Donati's Comet as illustrative, albeit in an extreme degree, of the changes which telescopic comets often undergo, but the ordinary comet of this class occupies a much more humble position in the ken of the astronomer.

Whether such an object is found as the result of systematic search for comets or is picked up by chance in moving a telescope about in the sky, it will usually, when first glimpsed, present the appearance of a little tiny, cloudy patch which may or may not have a sharp, star-like centre. Even when found and presenting such an aspect, the fact of its being truly a comet cannot at first sight be known for a certainty, for there are many nebulæ and small clusters of small stars which can be at first sight, and indeed often have been, regarded as comets, and been publicly announced as such. The discreet astronomer who is jealous of his reputation does not rush at once to the nearest telegraph office or newspaper office and announce his discovery of a comet. He watches for a few hours to see whether the object which he is scrutinising is stationary or in motion with respect to the neighbouring stars. It generally happens that three or four hours will enable him to answer this question one way or the other, but it frequently occurs that the sudden arrival of clouds shuts out the object under scrutiny too soon after its discovery for its motion, if any, to be ascertained, and the observer who thinks and hopes he has found a new comet has to wait till the following night before he can safely announce his success.

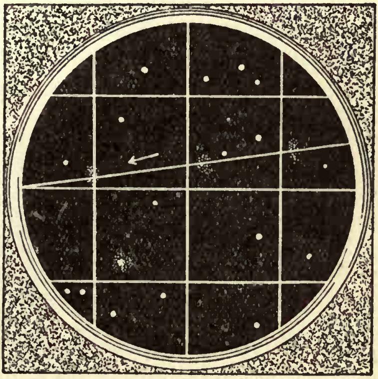


Fig. 166.—Diagram to illustrate the Recognition of a Comet as distinguished from a Nebula.

What I may call an ordinary telescopic comet usually passes through the following stages of developement: when first found it is a mere luminous patch, in or near the centre of which a slight concentration of light either is seen at the very first, or after an interval developes. This, when it acquires something like a distinct central brightness, becomes known as the "nucleus." The general size of the comet and its brilliancy increase, supposing that the comet is approaching both the Earth and the Sun: the hazy, nebulous matter around the nucleus becomes broader and brighter, and is then spoken of as the "coma." That may be the end of the developement, but very likely the coma will go on expanding in one direction, and, after giving the whole object an elongated or oval appearance, the elongation will still go on and become eventually a real tail. These transformations occur during the gradual approach of the comet to the Sun, which will generally be the same as saying its gradual approach to the Earth. Here comes in the question, What will be the time of day, or rather of night, when the comet will be visible? This depends on circumstances which vary in the case of each successive comet.

Bearing in mind that, so far as we on the Earth are concerned, comets only as a rule become visible when approaching the Sun, it may be stated as something like a general rule that, when a comet is discovered in the evening twilight, it will gradually become more and more immersed in the twilight until it is lost in the rays of the setting Sun. After an interval of a few days, or two or three or more weeks, it will reappear on the other side of the Sun in the morning twilight, and gradually recede from the Sun until it becomes lost either in broad daylight, or, if its path takes it amongst the stars with a dark background, it will be lost to view owing to its continuous diminution of apparent size due to its increasing distance from the Sun and the Earth alike.

The foregoing account of what may be called the rise and fall of a comet, so far as its career from a terrestrial point of view is concerned, will suffice to convey a general notion of what happens to these bodies; but, of course, particular comets, by reason of their notorious vagaries in the heavens, may come and go without conforming to the stages of history set forth above. For instance, it often happens that a comet is seen for the first time when its visible career, so far as we are concerned, is coming to an end by reason of the fact that its nearest approach to the Earth and to the Sun happened some weeks previously, when no one saw it, and that when it was first seen it was well on its way on its return journey to the unknown realms from which it came.

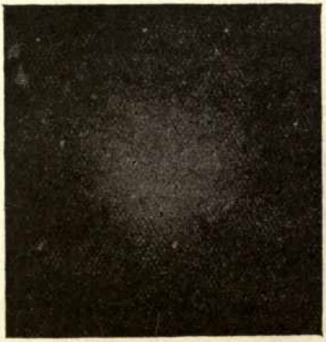


Fig. 167.—Telescopic Comet without a Nucleus.

Fig. 168.—Telescopic Comet with a Nucleus.

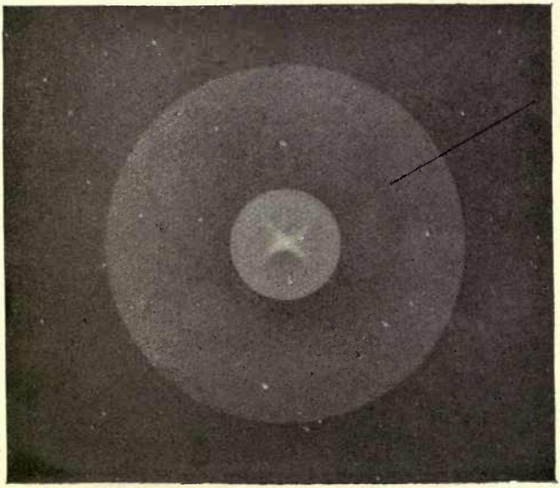
The subject of cometary astronomy is such a very large one that it is not easy to know where to draw the line as regards going into details. The changes which the small telescopic comets usually undergo require, for their proper study, telescopes of considerable power, and it is doubtful whether these changes appeal to the general reader or popular student. It is far otherwise, however, with the tails of comets. The recorded varieties of tail and the changes which have been noted in the tails of particular comets open up a large field both for descriptive writing and for speculation. It must suffice, however, here to state a few general outlines.

Three questions frequently asked are: "What is a comet's tail made of?" "Where does it come from?" and "Why do some comets have tails and not others?"

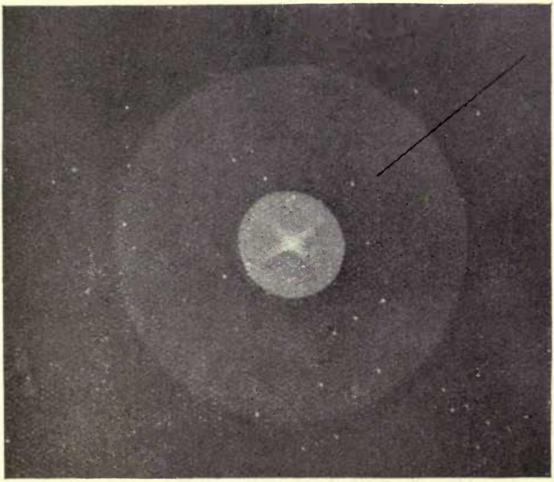
It must be confessed that no very satisfactory answers can be given to any one of these three questions.

The first, especially, is an inscrutable one, and a remark made by the late Sir John Herschel, some three-fourths of a century ago, may be cited as an indirect indication of the uncertainties which confront us. He said, in a famous passage, that the tails of comets probably, as a rule, only weigh a few ounces! This statement may sound, and perhaps is, fanciful; but it is hard to disprove it, and it is equally difficult to prove it, and a contented confession of agnosticism is perhaps the safest attitude to assume.

The second question, "Where does the tail of a comet come from?" is a little more easy to deal with, because we have some evidence of our eyes, which counts for something in this connection. Whilst in a certain number of cases it may be said, with Topsy, that the tails simply "grow" by visible expansion from the comet, yet there are not a few well-established cases in which a tail has been seen to emanate from the bright central head of a comet precisely as a jet of water may be seen to be thrown up from the mouth of a fountain. The third comet of 1862, as sketched by Professor Challis, of Cambridge, was a remarkable instance of what may be called the jet origin of a comet's tail; but there are many other instances on record. The natural idea which the observation of a comet developing a tail from its nucleus suggests is that the nucleus is a source of radiant, luminous matter which is thrown up in the fashion of an Iceland geyser. This is how the matter may be said to come home to the eye of a spectator; but the difficulty is to realise how such a vast mass of luminous matter can be produced in or from the head of a comet, bearing in mind the



Jan. 13.



Jan. 19.

Brooks's Comet of 1884 (I.), (*L. Thollon*).

The black line indicates the direction of the tail.

Encke's Comet, Sept. 22, 1848.

(As seen at the Hartwell Observatory.)

evidence we possess of the ethereal character of these bodies, and their lack of solid substance and weight. On this question of lack of mass it will be necessary, and more convenient, to say something later on.

The question as to why some comets have tails and not others is another of those points connected with cometary astronomy which is inscrutable. Speaking generally, it may be said that very small comets have no tails, and that very large comets always have tails. This, however, brings us no nearer to a solution of the question. At any rate, it may certainly be affirmed that very small comets which are no brighter than the stars of the 10th magnitude or smaller (and there are such), never have tails, whilst, on the other hand, such a thing as a large and compact comet visible to the naked eye and without a tail is unknown. It is true that one or two comets are on record as tailless, and as large in size as a Full Moon, but our knowledge of them depends upon ancient writers whose habitual looseness of language and lack of precision seriously discount their testimony.

It will now be desirable to describe in some detail certain of the features which have been recorded in the case of comets seen in the past. In the first place, when a comet has a tail, the tail is nearly always turned more or less directly away from the Sun; that is to say, it has shot forth in a direction behind the comet rather than in front of it or towards the Sun. This is no more than the common case of the tail of anything, whether it be the train of a queen or the tail of a cow. There are a few instances on record of comets having had not only a normal tail, properly so called, but a short stubby tail on the side of the Sun and pointing towards the Sun. Such a tail is usually spoken of by old writers as a "beard," and the sense of the expression will be obvious from what has just been said as regards tails generally. This fact of tails of comets being usually turned away from the Sun was noted by an observant foreigner named Apian in 1531; but the Chinese seem to have noticed the same fact 700 years previously.

When a comet has a tail, in the majority of cases there is only one such appendage, but two tails are not uncommon, and there have been cases of three, four, and five tails, whilst the celebrated comet of 1744 had six well-defined separate tails. It is important to note that it sometimes happens that, though a comet can only be fairly described as having one tail, yet now and again there may be noticed long, thin, streaks of cometary matter emanating from the same centre as the main tail, and these streaks ought rightly to be numbered as distinct tails. This attribute of subsidiary streamers in the nature of tails was not in the past very much dwelt upon by observers describing comets which they had studied ; but the application of photography to cometary observations has in recent years in several cases brought very distinctly under our notice what must really be spoken of as a multiplicity of tails. Photography grasps undoubtedly a wider range of details than does human vision at the eye-end of a telescope.

Under ordinary circumstances, while a common type of comet has a common type of simple tail, there is nothing in general to catch the eye and lead one to any precise conception of the actual form of the tail ; but in what may be called more perfectly developed tails, one sees the two edges distinctly brighter than the centre, and this compels the conclusion that the real form of such a tail is cylindrical, or, in many cases, conical. That a tail is of this formation is obviously suggested by the fact that, if we look at any luminous cylinder sideways, even if really illuminated evenly all round, it will in projection look brighter at its apparent edges, because the eye will be viewing the edges through a concentrated thickness of material, whereas the portion of the cylinder midway between the illuminated edges will only be of a single thickness, so to speak. This may be tested in several obvious ways in connection with domestic illumination in our houses, and assuredly gives us a clue to the true form of many cometary tails.

Where a comet has evidently two distinct tails (not the appearance of two tails in virtue of the explanation just given) it almost always happens that the two tails are of different length, and that the shorter one is inferior in brilliancy to the longer one.

Except in the case of small comets with short tails, it is seldom that a tail is straight; it is most usual for the tail to

Fig. 172.—Medal distributed by the Monks to avert Misfortune during the Appearance of the Great Comet of 1680.

be curved, and the curvature is the natural result of the comet's head moving forwards, and the tail not being able to keep pace with it because of its more flimsy material. This, at least, seems a fair and proper way of describing the condition of things.

Two astronomers of the present day, working on different lines, have endeavoured to classify the tails of comets on the supposition that there is an individuality about tails, which shows that they are not all formed in the same way or under similar conditions. The most svstematic of these classifications is due to the Russian astronomer Bredichin, who has worked at the matter with great zeal and moderation and discretion of language and conclusions. I lay stress on this description of his labours because there has been of late years a great disposition on the part of astronomers of a certain sort to put forth wild speculations respecting the formation and condition of the tails of comets, with a very limited amount of proof available to support their views. Bredichin's investigations led him to divide the tails of comets into three classes: (1) long, straight tails; (2) curved, plume-like tails; (3) short, stubby, and sharply curved brushes of light.

Bredichin's First Type of tails he considers formed of matter upon which the Sun exercises a repulsive action very much greater than the Sun's attractive action in virtue of the general principles of Gravitation, so that the particles of cometary matter quit their point of origin in the head of the comet with a relative velocity which rapidly increases, and eventually becomes enormous. The long, straight streamers, which I have already alluded to, were well exemplified in Bond's drawings of Donati's comet of 1858, and tails of this type are composed, according to Bredichin, of hydrogen gas. The Second Type of tail is by far the most usual one. Here the repulsive force is much less than in the previous case, and the comet may be said to be more completely and continuously under the attractive control of the Sun. Some kind of hydrocarbon gas is suggested as the constituent of tails of this class. Tails of the Third Type, because they do not seem as a rule capable of much expansion of size, are thought not to be subject to any great amount of repulsive influence, but to be dominated far more definitely by the normal laws of Gravitation. The matter of which they are composed is thought to be in a state indicative of far greater heaviness than obtains in either of the two previous classes, and to consist of the vapour of iron, perhaps also of sodium, and of other substances. It is quite evident that these points are of a very speculative character;

Halley's Comet, Naked-eye View in Mexico (*L. G. Leon*).

Curious Aspect of the Head of Halley's Comet, June 8, 1910.
(*L. G. Leon.*)

but still Bredichin's ideas cannot be condemned as destitute of possibility and probability.

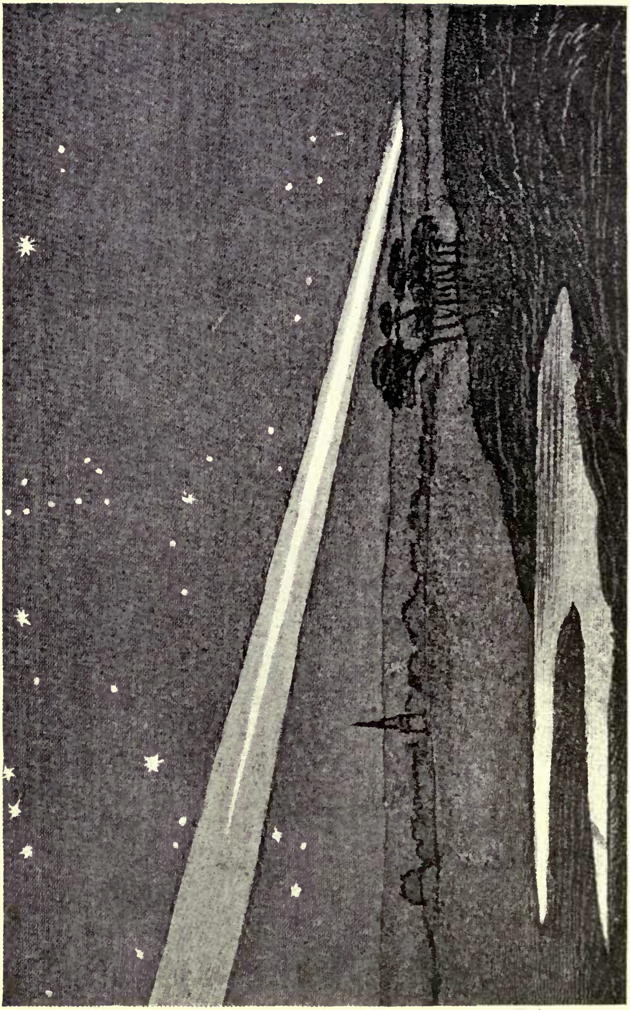
An experienced American astronomer, Professor W. H. Pickering, of Harvard College Observatory, divides the tails of comets into two classes, and sets up a distinction on lines entirely different from those of Bredichin. He seems to consider that, either simultaneously or successively, as the case may be, a tail which we should at the first glance regard as a simple tail, really, when carefully looked into, may comprise either simultaneously or successively a tail which has its origin in the comet's head, surrounding and enveloping which there is another tail (which perhaps rather should be called an envelope), which is of a different and uncertain origin. Pickering says that, "judged by the photographs of recent comets, the former kind is much the more common of the two, and consists usually of a bunch of rays, more or less straight, proceeding from the nucleus directly away from the Sun." He thinks that his second type of tail is well represented in the pictures in existence of the "great comet of 1811," of the "great comet of 1901," and of the first comet of 1910. He considers that Swift's comet, of 1892 (i), was an instance of both types of tail being present at the same time, and that Halley's comet in 1910 was a case of a comet having a tail of a different type after its perihelion passage from what it had before the perihelion passage; that at the earlier period the tail had its origin in the nucleus, but that at the later period the tail was altogether different, and was a large envelope, wrapping up the head, but distinct from it. Pickering goes on to suggest that the enveloping type of tail is much smoother in structure than the type which issues from the nucleus, and that it is the kind which seems to have been present in at least three of the five great comets of the 19th century, namely, those of 1811, 1858, and 1882.

The foregoing classifications, however we may regard them, do not directly help us in coming to a conclusion as to the originating cause of a tail where a comet, when discovered, is tailless, and afterwards becomes furnished with a tail. As to this the theory generally favoured by astronomers nowadays is that what is called "light pressure" is concerned in the creation of cometary tails, probably under impulses which cannot yet be defined or explained, but which are of electrical character. "Light pressure," as a phrase standing by itself, may conveniently be defined as being based on the supposition that all sources of light exercise a sort of repulsive push on all materials on which the light impinges, whatever may be the source of the light or the nature of the material.

Thus far the attention of the reader has only been called to a few general propositions which might throw light upon naked-eye observations of any casual comet which might appear; but much more must be said if we would obtain a comprehensive grasp of cometary astronomy. The question of the number of the comets and of their paths through space opens up a variety of topics which, though in a certain sense subsidiary to what has gone before, are of the greatest intrinsic interest.

In olden times it was not considered that comets, as regards their movements, were subject to any laws, but that they came and went away in a perfectly haphazard fashion. It was not until quite modern times that it was realised that they were subject, to a certain extent, to the same laws of motion as operated in the case of the planets. The situation of things is this: whilst it is true that a large number of comets come to us from whence we know not, and then pass away whither we know not, yet there are a certain, not inconsiderable, number which may be regarded as permanent members of the solar system, and come and go, and after a certain interval come back again. These are termed "periodical comets," and bear a certain analogy to the planets as regards their movements, the principal point of difference being that, whereas the planets all move in orbits not materially differing from

The Great Comet of 1811.



The Great Comet of 1843, March 17.
(As seen from Blackheath, Kent.)

circles, not a single comet moves in an orbit which is anything like a circle. The orbits of the periodical comets are all of them ellipses of great eccentricity. Perhaps this will be better understood by saying that all the periodical comets move in oval orbits, which may be compared roughly to flattened circles.

The orbits of the periodical comets not only differ much in eccentricity, but also in their dimensions. Thus it comes about that Encke's comet, with its period of only a little more than three years, performs its journey round the Sun in an orbit within that of the planet Jupiter, whilst Halley's comet travels so far away from the Sun in the course of its voyage of 75 years that when at its greatest distance it is quite outside what we call the solar system, because it attains a point outside the orbit of Neptune, the most remote of the known planets.

The comets which are not periodic so far as we know, come to us in paths which the mathematician calls "parabolas" and "hyperbolas," though the number of the comets which have been known for a certainty to have pursued hyperbolic orbits are very limited.

Going back to the periodic comets—whilst the known or supposed periods vary between a handful of years and thousands of years, they may be roughly grouped in three classes :

(1) Comets with periods between 3 and 15 years.

(2) Comets with periods averaging 70 years.

(3) Comets with periods of many hundreds of years.

Of only those comets which belong to Classes 1 and 2 can it be positively asserted that they are permanent members of the solar system. This is certain, because they have proved their allegiance to the Sun by having paid him more than one visit ; indeed several of them have paid several visits. Our knowledge of the comets in the third class is much less certain, for the reason that, owing to the length of their periods, no opportunity has yet occurred for them to pay us a return visit. There is indeed one comet of long period which astronomers once hoped might safely be regarded as a permanent member of the system; but the supposition still lacks proof. There appeared in 1556 a brilliant comet which was thought at one time to be a second appearance of the great comet of 1264, one of the grandest on record. Its return about 1860 was confidently reckoned on by many astronomers, but all were disappointed. There have been other comets observed during recent years, which, it has been calculated, move in elliptic orbits, and must therefore be periodic in a literal sense; but, as the periods of some of these amount to thousands of years, it is evident, not only that the world will have to wait for a very long time before seeing them, but also that doubt attaches to the exact characters of their orbits, owing to the vast extent of the same, to say nothing, in some instances, of the lack of a sufficient number of trustworthy observations when they were within our reach.

The following are the names of the short-period comets which may be regarded as well-recognised members of the solar system:—

No.	Name.	Period in years.	Next return.
1.	Encke's	3·29	1914
2.	Tempel's Second (1873, ii.) . .	5·15	1914
3.	Tempel-Swift's	5·53	1914
4.	Winnecke's	5·54	1915
5.	Brorsen's	5·58	1912
6.	Finlay's	6·54	1913
7.	D'Arrest's	6·64	1917
8.	Wolf's	6·76	1918
9.	Holmes's	6·85	1913
10.	Borelly's	7·00	1918
11.	Brooks's Second (1889 v.) . .	7·07	1917
12.	Faye's	7·44	1918
13.	Tuttle's	13·66	1913

Donati's Comet, Oct. 5, 1858 (*Pape*).

June 26.

June 28.

June 30.

July 1.

July 6.

July 8.

The Comet of 1860. (iii.) *(Cappelletti and Rosa).*

With reference to two or three of the comets in the foregoing list, the date of whose next return is suggested, it is

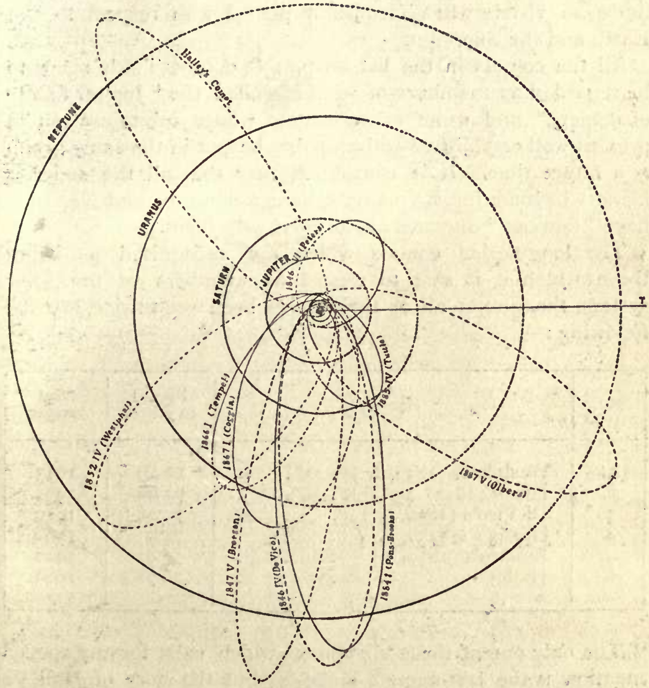


Fig. 184.—The Comet Families of Saturn, Uranus, and Neptune (*Drawn by H. C. Wilson*).

to be understood that, though they have made several returns in the past, they have not been seen very recently, and in some degree a mystery hangs over them, their orbits appearing to have been deranged by the influence of the planet Jupiter. The whole group of 13 consists of small comets not as a rule visible to the naked eye, though some of them are sometimes so visible when favourably placed with respect to the Earth and the Sun.

All the comets in the list on p. 158, except Tuttle's, are to be regarded as members of what is called the "Jupiter family of comets," and some other comets whose orbits are not at present well established will probably be put in the same group at a future time. It is considered now that all the superior planets beyond Jupiter, namely, Saturn, Uranus, and Neptune, have "families" of comets associated with them.

The long-period comets which are recognised as being those which it is safe to regard as members of the solar system, though not all of them have been seen twice, are the following:—

No.	Name.	Period in years.	Next return.
1.	Westphal's (1852, iv.)	60 (?)	1913
2.	Pons's (1812)	70·68	1955
3.	Di Vico's (1846, iv.)	73·25	1919
4.	Olbers's (1815)	74·5	1960
5.	Brorsen's (1847, v.)	74·97	1922
6.	Halley's	76·78	1986

The only one of these six comets which calls for any special mention is the last-named, Halley's; but the story of Halley's comet is now so well known that it would be tedious to give it at any length.

Sir Isaac Newton and Edmund Halley share between them the honours of the comet which now bears the name of the latter, and even in a skeleton form its story is very interesting. Sir Isaac Newton gave to the world in 1687 his celebrated treatise on Universal Gravitation which is best known by the simple name *Principia*, but of which the full title is *Philosophiæ Naturalis Principia Mathematica.* The cost of publishing this book appears to have been borne by Halley, and, after studying his venture, the idea came into his head to try and see whether Newton's labours could be utilised for obtaining some insight into the movements of comets. A comet seen by Halley himself in 1682, though not discovered by him, seemed to offer the desired opportunity, and he calculated its orbit on Newton's principles. One thing led to another, and, after finishing his calculations with regard to the comet of 1682, he turned his attention to the recorded observations of comets which had appeared in 1607 and 1531. The results as to the nature of their orbits were so nearly identical in all particulars that he did not long hesitate in coming to the conclusion that the three comets were really one comet, and that therefore it was a periodical member of the solar system. He had sufficient confidence in his own work to venture on the prediction that the comet would return again about 1758 ; and so it did. The story of its discovery on the night of Christmas Day of that year by a Saxon farmer named Palitzsch, living near Dresden, and of the calculations made in anticipation of its return, is a thrice-told tale. Halley died in 1742, and left behind him a plaintive record of his hopes that "impartial posterity will not refuse to acknowledge that this [periodicity] was first discovered by an Englishman."

Halley's Comet paid another visit to these parts of Space in 1835, and the whole subject of mathematics as applied to orbits had made such progress between 1758 and 1835 that the comet's perihelion passage, as calculated, was found to be wrong only to the extent of about 4 days.

The last return of Halley's Comet to perihelion in the spring of 1910 will be fresh in the minds of all my readers—how it was for the inhabitants of the northern hemisphere a great disappointment, whilst dwellers on the opposite side of the world enjoyed a magnificent sight. The pictures annexed will give its appearance at various times, and as seen in various places. In England it showed itself as quite an ordinary comet, just visible to the naked eye, and not very conveniently placed, being near the Sun in the evening twilight. But, after its perihelion passage on April 19, when it had passed round to the other side of the Sun, and was visible in the early morning, those who had that opportunity by reason of their being in Africa, Australia, or New Zealand, saw the comet as a magnificent object with a tail extending half over the celestial vault.

The world-wide interest felt in Halley's Comet in 1910 is well shown by the following account of it which came from the far-off island of New Guinea:

"On May 9 the comet, looking like a muffled star, was seen in the East, and its tail, a broad beam of brilliant light, extended upwards through about 30°. Below the comet and a little to the South of it Venus shone like a little moon, appearing far bigger than any planet I have ever seen. The comet grew enormously, and in the early morning of May 14, the last time that we saw it completely before it had passed the Earth,[1] the tail blazed across the heavens like an immense searchlight beam to the zenith and beyond. On May 26 it appeared again in the evening reduced in size to about 45°, and several nights we watched it growing always smaller, until it vanished from our sight. Superlative expressions will not describe Halley's Comet as we saw it in New Guinea; it was a wonderful appearance and one never to be forgotten. Our coolies and the Javanese declared that it portended much sickness and death. Though we tried to question them about it, we never learnt how it impressed the minds of the natives."[2]

A matter which caused much discussion, both as a matter of prophecy and fulfilment (or non-fulfilment), was whether the comet had crossed the Sun as seen from the Earth, and whether it had been detected whilst doing so. The conclusions

[1] A probable mistake for Sun.

[2] WOLLASTON, *Pigmies and Papuans.*

Halley's Comet, May 1, 1910.

Photographed at the Transvaal Observatory.

May 5, 3.15–3.45 a.m. C.T.S.

May 13, 3.10–3.37 a.m. C.T.S.

May 25, 9.05–9.35 p.m. C.T.S.

May 29, 9.17–9.55 p.m. C.T.S.

May 30, 9.20–9.60 p.m. C.T.S.

June 5, 10.00–10.30 p.m. C.T.S.

Halley's Comet, 1910 (*D. W. Morehouse*).

arrived at were indeterminate : it is probable that the comet did cross the Sun's disc, and ought to have been seen, but it was not seen. On the other hand, it appears quite certain that the Earth passed through some part of the comet's tail, though nothing inconvenient happened.

It may be stated, by the way, that the question of a collision

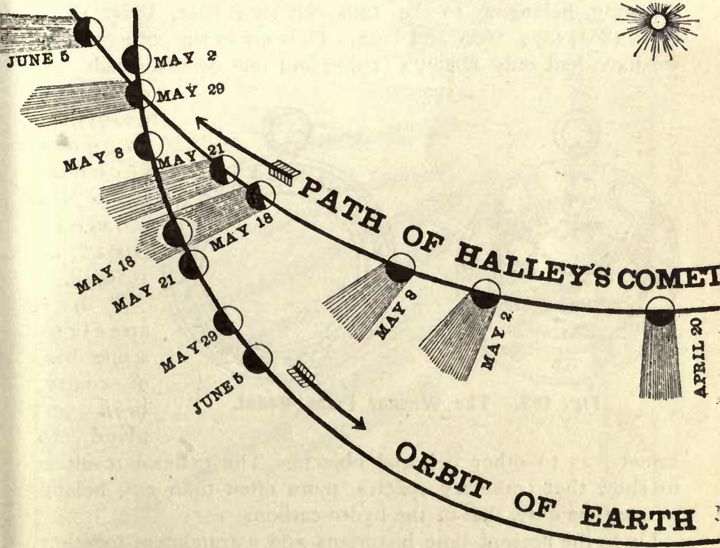


Fig. 192.—Path of Halley's Comet, 1910.

between a comet and the Earth has often occupied men's minds in past times, and given rise to panics ; but there never has been the slightest justification for alarm. It is quite certain that in 1861 the Earth passed through a very thick part of the tail of the great comet of that year, but nothing happened beyond a sensation of fogginess which impaired the light of the Sun, shining at the time, and led in one case, at least, to a demand for artificial light at the early hour of 7 p.m. on June 30, when it was also noted that the sky had a yellow auroral glare, the Sun shining, but not as usual.

To give a list of all the comets to which might be applied the adjective "celebrated," and still more to describe them, would run into many pages. Let it suffice, then, to mention the following, belonging to the 19th century: 1811, 1825, 1843, 1858, 1861, 1874, 1880, and 1882. Thus far in the 20th century we have had only Halley's (1910), and one or two which can only be described as good second-class comets (1902, i.; 1910, i.).

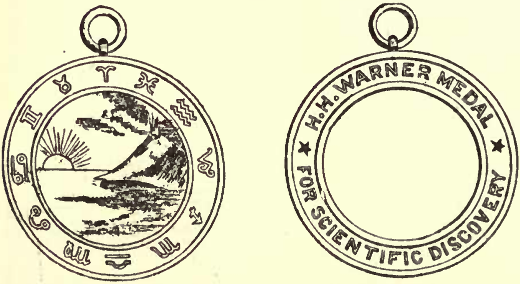


Fig. 193.—The Warner Prize Medal.

The spectroscope has, of course, been applied to comets, as to other celestial objects. The general result is to show that cometary spectra, more often than not, belong to one type only, that of the hydro-carbons.

Up to the present time historians and astronomers together have recorded a total of about 1100 comets. Of course down to the 17th century the comets noted were all naked-eye ones; but, seeing how nowadays the naked-eye comets fall short in number of the telescopic comets, it is safe to assert that, since the Christian era, several thousand comets have visited our system.

In case a reader may be surprised at the number of comets

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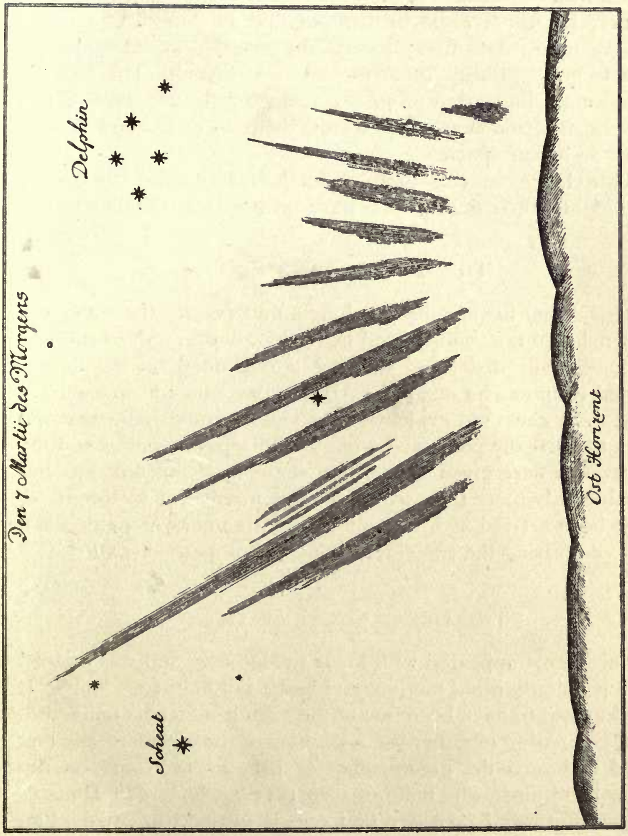


Fig. 194.—The Tail of the Great Comet of 1744.
According to a contemporary sketch.

discovered in America of late years having been so large compared with the number discovered in all other parts of the world, it may be worth while to mention that in America prizes in money and medals are systematically awarded to those who are able to prove priority in picking up new comets. The Warner gold medal, illustrated on p. 164, is one of the stimulants which American astronomers have before them to encourage zealous work on behalf of science.

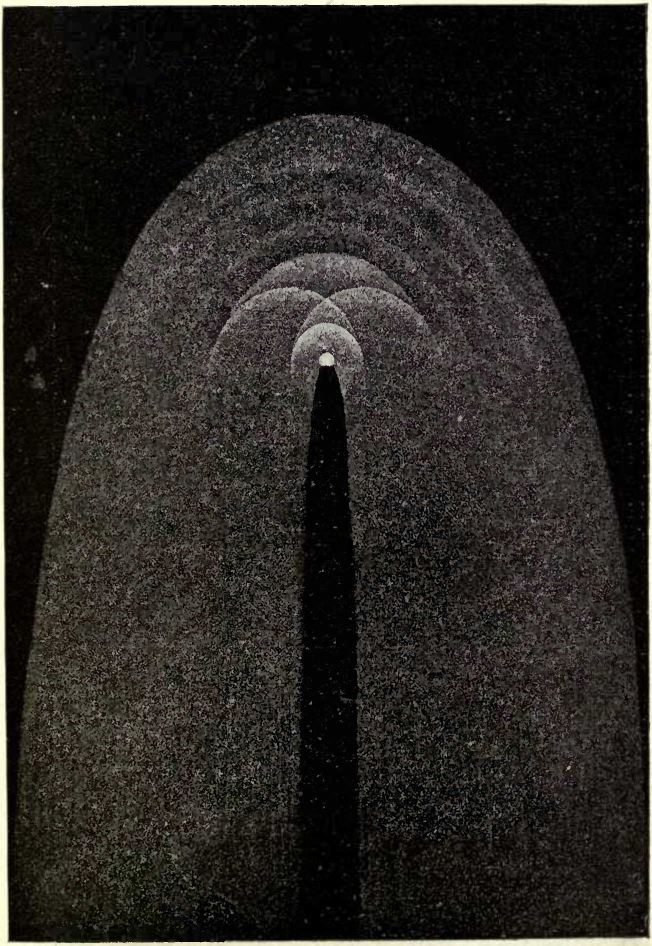
This chapter may be usefully concluded by some brief notes in detail on the comets which have been selected to illustrate it.

THE GREAT COMET OF 1744.

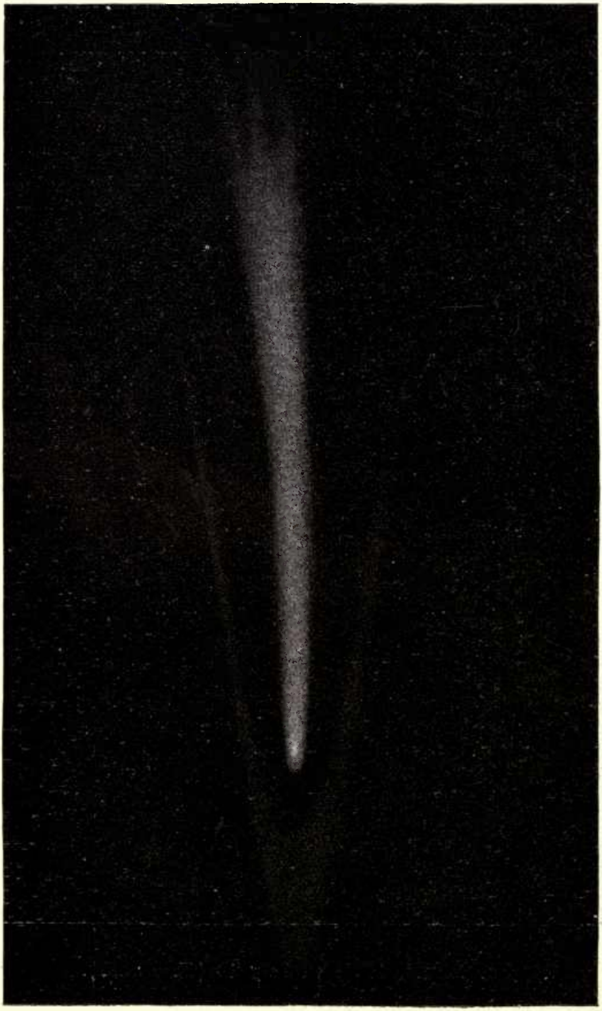
This comet historically was long a mystery, for the statement that it had 6 tails, announced in books all over the world, was very generally distrusted because it depended on the unsupported testimony of one man. But some years ago, in a curious way, there came out evidence of a contemporary writer that the comet had really possessed a number of separate tails ; and the illustration here given shows that there were not only six, but considerably more than six tails. The number of six seems to have been arrived at by counting the streamers in pairs, each pair comprising the two sides of one tail properly so-called.

THE GREAT COMET OF 1843 (i.).

This comet appeared with great suddenness, and was endued with peculiarly rapid motion, and had a tail fully 100° long. It would seem to have been one of the grandest comets on record, and, comparing together the testimony of those who on the one hand had seen the great comet of 1811 as well, and on the other hand those who had not seen 1811 but had seen Donati's Comet of 1858, I consider that one is justified in saying that the 1843 comet was the grandest of the 19th century in point of size and brilliancy.



Coggia's Comet, 1874, on July 13 (*F. Brodie*).

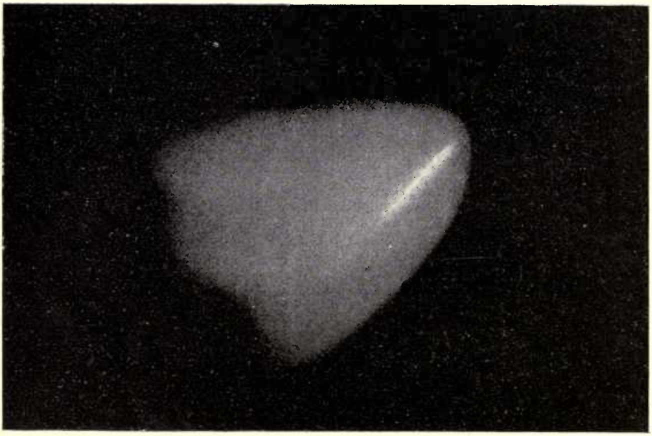


The Great Comet of 1882 (*Charlois*).

Nov. 13.

Nov. 7.

The Great Comet of 1882.



Nov. 13.

Nov. 21.

The Head and Nucleus of the Great Comet of 1882. [I66c

Feb. 23, 1883.

[Feb. 1, 1883.

The Nucleus of the Great Comet of 1882.

March 3, 1883.

Feb. 27, 1883.

The Nucleus of the Great Comet of 1882.

DONATI'S COMET, 1858 (vi.).

This comet, though inferior in size, as just stated, to the great comet of 1843, may be regarded as having been the most beautiful comet of the 19th century, owing to its plume-like shape, and to its possession of certain long, straight streamers not reproduced in the engraving. The star visible near the comet's head is Arcturus.

THE COMET OF 1860 (iii.).

This comet was not one of very remarkable size, but the pictures are given for the reason that they exemplify in a striking degree the jet-shaped emanations which occasionally are noticed to proceed from the head of a comet. This feature was also brought out in a very marked manner in the comet of 1862 (ii.).

COGGIA'S COMET, 1874 (iv.).

Coggia's Comet of 1874 may be described as a good specimen of a second-class fine comet. It was a striking object in the evening sky during the month of July, but it is engraved in this book as being a good example of the way in which some comets seem to shed off independent envelopes, or shells of matter, one after another.

THE GREAT COMET OF 1882 (iii.).

This was a fine naked-eye comet, with a tail very much in the shape of a Turkish scimitar. The main tail gave one the impression of being inside a long and wide, but very ethereal or flimsy, envelope. But the special feature of this comet was its nucleus, which was and still is unique in its form. It was elliptical, and of great length in proportion to its breadth ; it was placed longitudinally with regard to the general direction of the tail ; and, to crown all, instead of having the usual one special bright centre, it was always seen to have three bright centres, sometimes four, and on one occasion a fifth was suspected, all of them a little distance from one another.

SWIFT'S COMET, 1892 (i.).

We have passed now from the epoch of hand-drawn pictures of comets to representations based upon photography. Whilst it is, of course, a truism that the Sun is a more accurate draftsman than the human eye and hand together, it must be confessed that photography often fails to bring home to the eye many details which sometimes strike even the most inattentive observer.

But this cuts both ways, because not only in the case of comets, but also in the case of nebulæ, photography frequently catches features which are invisible, not only in the telescope used by a particular observer, but in all telescopes, whatever may be their size. It was owing to photography that Swift's Comet was the first to bring out features connected with the tails of comets which may be said to have revolutionised our ideas as to the physical condition of those bodies. Barnard well remarks that this "has occurred in the case of comets with which the older method of observing would have promised little or nothing of interest." Swift's comet may be mentioned as one of those which seemed to be endued with a rotation of the head and tail about an axis passing lengthwise through the tail.

RORDAME'S COMET, 1893 (ii.),

illustrates a remark in the last paragraph about photography, bringing out details not readily grasped by the naked eye, for some of its peculiarities are of the same sort as those of Swift's Comet.

April 5.

April 7.

March 30.

April 6.

Swift's Comet of 1892 (i.).

April 21.

April 23.

April 14.

April 22.

Swift's Comet of 1892 (i.).

July 13, 1893.

July 8, 1893.

Rordame's Comet of 1893 (ii.), (*W. J. Hussey*).

Oct. 21.

Oct. 22.

Brooks's Comet of 1893 (iv.).

Borelly's Comet of 1903 (iv.), (*R. J. Wallace*).

Dec. 29, 1905.

Giacobini's Comet of 1906 (i.), (*E. E. Barnard*).

Dec. 29, 1905.

Jan. 5, 1906.

168*f*] **Giacobini's Comet of 1906 (i.), (*E. E. Barnard*).**

Daniel's Comet, 1907 (iv.), on Aug. 18.

The black dot near the end of the tail is γ Geminorum

BROOKS'S COMET OF 1893 (iv.).

This seems to have been a comet damaged by some external violence, strange as the idea may seem. Barnard wrote thus about it :—

"Indeed, the singular freaks of that comet's tail compel us to seek an explanation in some outside cause—inherent neither in the comet nor in the Sun. The tail, which one day was in a normal condition, was on the next broken and disturbed, as if it had encountered some resisting medium in its flight through space. The disturbance seemed to come from the direction towards which the comet was moving. On the succeeding morning it was badly broken, and hung in cloud-like masses, some of which were entirely torn off from the tail and appeared to be drifting away in space. On another occasion the tail was concave towards the direction of motion, and had the appearance of beating against a current of resistance. It was disjointed in places, and near the end was abruptly bent at nearly a right angle, as if at that point it had encountered a stronger current of resistance. If one examines these pictures there seems no escape from the conclusion that this comet's tail did actually encounter some resisting or disturbing medium about October 21, 1893, and for several days subsequent to that date ; whether this was a swarm of meteors—such as we know exist in space near the Sun, or some sort of resisting matter, of which we as yet know nothing, is a subject for time to settle."

BORELLY'S COMET, 1903 (iv.).

This comet manifested signs of disintegration of a curious nature—that is to say, signs of a part of its tail having actually broken off from the main tail ; which latter, after losing the aforesaid fragment, began to grow again in consequence of a new supply of matter being forthcoming from the nucleus.

GIACOBINI'S COMET, 1906 (i.).

Observations of this comet were unfortunately much interfered with owing to the prevalence of bad weather ; but, notwithstanding this, Barnard got some good photographs of it, and was also able to make some striking notes. He says that the comet's appearance on December 29, 1905, was—

"in some respects quite unique. From a rather large head and a slender neck, the tail widens out on each side in a graceful curve, which partly closes in again and gives a strong convexity to the tail. The edges of these convexities are sharply defined, and are outlined by a rather narrow bright rim or border. The appearance of the tail strongly suggests a hollow, convex, transparent cone with a sensible thickness. A straight-edge placed along the sides of the tail shows this convexity strikingly, as may be seen on an examination of the plate. I have not noticed quite this appearance before in a comet's tail."

DANIEL'S COMET, 1907 (iv.).

The original negative of this comet showed the tail to have six branches, but, owing to the extreme faintness of two of them, only four are depicted in the illustration. The star near the end of the tail with a black dot in it was γ Geminorum.

MOREHOUSE'S COMET, 1908 (iii.).

This comet, though not in itself a very large one, attracted considerable notice in the astronomical world owing to the transformations which it underwent. The two pictures, both dated October 15, taken, one in England and the other in America, within a few hours of one another, will give a clue to the cause of this excitement. Barnard's photograph vividly brings out the fact that the tail of the comet underwent a serious and real disruption.

HALLEY'S COMET, 1910 (ii.).

So much has been said already about Halley's Comet that it seems only necessary here to remind the reader that it was only in the Southern Hemisphere, and after the comet had

On Oct. 15, at 14 h. 31¾m.

Morehouse's Comet of 1908 (iii.), (*E. E. Barnard*).

Oct. 15, 14 h. 34 m. G.M.T.

Nov. 15, 12 h. 6 m. G.M.T.

Morehouse's Comet of 1908 (iii.), (*Yerkes Observatory*).

Morehouse's Comet of 1908 (iii.), on Nov. 13.

May 25.

May 27.

May 28.

June 2.

Halley's Comet, 1910 (*C. H. Gingrich*).

The Daylight Comet of 1911 (*W. B. Gibbs*).

As seen in North Africa.

Sept. 24.

Sept. 21.

Brooks's Comet of 1911 (*F. W. Longbottom*).

passed its perihelion, that the most striking views of it were obtained. Hence it comes about that the pictures here given may excite distrust as to their accuracy on the part of dwellers in the Northern Hemisphere.

Brooks's Comet, 1911 (*c*).

The picture dated Sept. 24 [Plate LXXVIII.] brings out the case of a comet with a very large head having a very slender tail proceeding from it. The photograph vividly recalls to my mind one of the earliest comets I ever saw. I am not certain of the exact name and date, though I think it was one of three visible in the summer of 1857, discovered by Klinkerfues at Göttingen on August 20.

By way of a last word, it may be well to explain why, in nearly all cases, the stars which appear in the comet-pictures given in this volume show as streaks and not as points. It is because the several comets being themselves in motion, it is always necessary, when long exposures are desired (in order to get good views of the comets), that the driving-clocks of the telescopes employed should be timed to keep pace with the comets rather than with the diurnal movement of the stars.

CHAPTER X.

SHOOTING-STARS.

Various classes of luminous meteors.—Shooting-stars.—Fireballs.—Aërolites.—Radiant points of shooting-stars.—Account of the most important showers.—Position in the heavens of some of the chief radiant points.—Historical allusions.—Celebrated great showers.—Fireballs.—Their general resemblance to one another.—Remarkable fireballs described by Webb and Brodie.—Their sizes, distances, and movements.—Computation of their paths.—Connection between meteors and comets.—Shooting-stars, fireballs, and aërolites all of the same nature.—Circumstances attending the fall of aërolites.

"SHOOTING-STAR" is the popular name for a celestial object which is scientifically spoken of as a "luminous meteor," and luminous meteors are subdivided into small luminous meteors and fireballs, with what are called aërolites thrown in. Though the first two subdivisions are visually closely allied, the third may seem to be somewhat detached, though it is not so in reality. A simple shooting-star is just exactly what its name imports at first sight—a star which shoots; yet it is not a star, and it does not shoot.

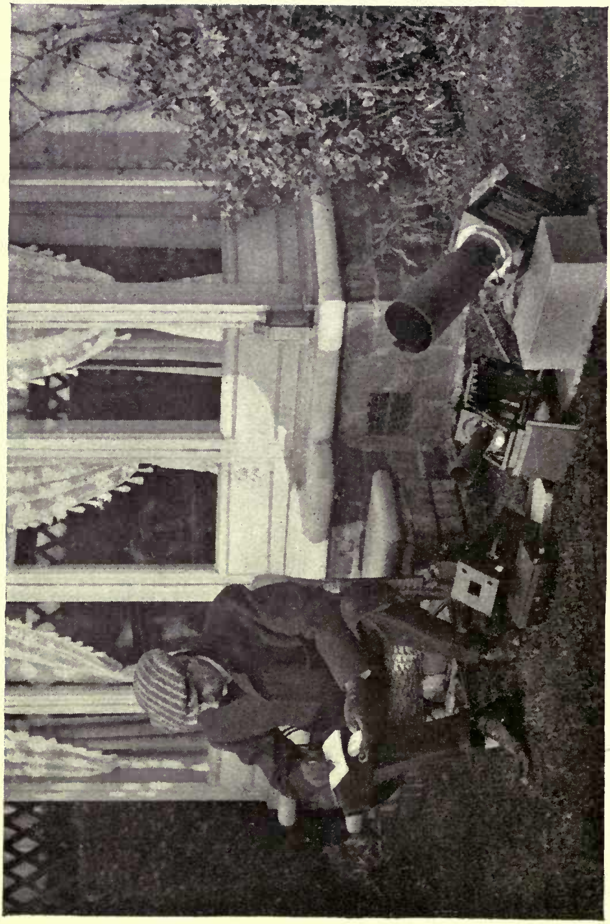
Postponing for a while a consideration of the nature of all these bodies, we will first of all consider how and when they show themselves. It is safe to say that several shooting-stars may be seen on any clear night throughout the year when the air is transparent and the Moon is absent. Thoughtlessly looked at, the observer will fancy that they dart forth casually in the sky, first at one point and then at another point; but such is not the case. It is true that these isolated meteors

A Meteor in Flight (*E. E. Barnard*).

("The object gradually increased in brilliancy, and as gradually faded out, ending in two short flashes of light.")

FIG. 234

PLATE LXXX.



Fishing for Meteors without an Equatorial (*F. W. Longbottom*).

used to be thought independent of one another, and they were formerly called "sporadic" meteors, which meant that they were haphazard outbursts of light. The designation has, however, now lost nearly all its importance and significance, because the prolonged observation which has been given to these bodies during recent years has enabled astronomers to realise that they belong to families, each with its own centre in the heavens, which is called its "radiant point." The recognised radiant points are now very numerous, indeed, several hundred in number; but of these the majority would not readily attract notice except after prolonged and patient attention. On the other hand, there are a certain few radiant points from which, at definite dates, and in great numbers, shooting-stars emanate; and it is to these that I will in the first instance direct the reader's attention.

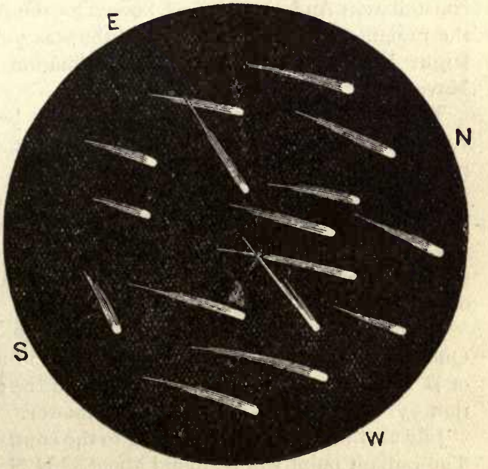


Fig. 235.—Flight of Telescopic Meteors (*Brooks*).

The most important shower of shooting-stars is undoubtedly that named the Perseids, because they belong to the constellation Perseus and show themselves on or about August 10.

Meteors may be noticed some days before and some days after the precise date just mentioned. They constitute a very rich annual shower of swift and bright meteors, which leave streaks behind them. The approximate centre of the shower may be taken to be a point 4° N.E. of the star η Persei; say, Right Ascension 3 h. 4 m., and Declination 57° N.

The next most important shower is that appertaining to the constellation Andromeda, and known as the Andromedes, with the radiant point about 4° N.W. of the star γ Andromedæ; say, Right Ascension 1 h. 40 m., and Declination 44° N. Date :—November 27.

The third most important shower may be said to be the Lyrids, belonging to the constellation Lyra, with the radiant point about 8½° S.W. of α Lyræ; say, Right Ascension 18 h., Declination 33° N. These meteors move swiftly, and the brighter ones leave streaks. Date :—April 20.

The next few paragraphs will give some of the more important showers, arranged in the order of dates from January onwards.

January 2, the Quadrantids, belonging to the constellation Quadrans. The radiant point will be found about 12° N.N.E. of β Boötis; say, Right Ascension 15 h. 29 m., and Declination 53° N. This is a rich annual shower.

July 28, the Aquarids, belonging to the constellation Aquarius. The radiant point will be found about 5° N.N.W. of δ Aquarii; say, Right Ascension 22 h. 36 m., and Declination 12° S. This is an active display of slow and enduring meteors which may be depended upon to recur annually.

October 18, the Orionids, belonging to the constellation Orion. The radiant point will be found 2° E. of ν Orionis; say, Right Ascension 6 h. 8 m., and Declination 15° N. This is a very rich shower, which occurs every year, and, though dated for October 18, watch for it should begin on October 9, and be continued till October 29.

November 13, the Leonids, belonging to the constellation

Leo. The radiant point will be found 3° W.N.W. of γ Leonis; say, Right Ascension 10 h., and Declination 22° N. This is a great historic shower, which manifested sensational displays in 1799, 1833, and 1866, and did not reappear in its pristine splendour, as was confidently expected, in 1899. A slight display certainly belonging to this shower may be expected every year between November 9 and 17.

November 20, the Taurids, belonging to the constellation Taurus. The radiant point will be found 5° N.N.W. of υ Tauri; say, Right Ascension 4 h. 8 m., and Declination 23° N. This is a well-known shower of slow meteors.

December 10, the Geminids, belonging to the constellation Gemini. The radiant point will be found 3° W.N.W. of α Geminorum; say, Right Ascension 7 h. 22 m., and Declination 33° N.

It will be understood that the showers enumerated in the preceding paragraphs are those which may be regarded as the most notable; but, as has already been stated, shooting-stars belonging to many other groups may be noticed almost every night in the year. It would take up too much space in these pages to specify, and state the positions of, even a tithe of the other recognised radiant points; but observations of luminous meteors, small as well as large, may be suggested to amateurs as a very interesting study, the fruits of which, if collected and tabulated with care, will be very useful in promoting the progress of meteoric astronomy. Denning has remarked that brilliant meteors often emanate from the constellation Scorpio in the month of June. This might be a suggestion worth following up.

Shooting-stars often appear in the pages of history, and have done so from ancient times. One of the earliest allusions to them dates from A.D. 472, when we are told by Theophanes, the Byzantine historian, that the sky at Constantinople appeared to be on fire with flying meteors. A remarkable display took place in England and France on April 4, 1095, when the stars seemed to be "falling like a shower of rain from heaven upon the Earth."

There was a great display on November 13, 1799, visible throughout America, and of which Alexander Humboldt has left a thrilling narrative; but the greatest display on record appears to have been that of November 13, 1833, following fine displays in 1831 and 1832. The 1833 shower was visible over nearly the whole of North America, and, from the accounts which have reached us, it must have been one of imposing grandeur. In many parts of the country the population, especially the Negro population, were terror-stricken, such was the beauty and magnificence of the spectacle presented. The following account is from the pen of a planter in South Carolina:—

"I was suddenly awakened by the most distressing cries that ever fell on my ears. Shrieks of horror and cries for mercy I could hear from most of the Negroes of the three plantations, amounting in all to about six or eight hundred. While earnestly listening for the cause I heard a faint voice near the door calling my name. I arose, and, taking my sword, stood at the door. At this moment I heard the same voice still beseeching me to rise, and saying, 'O my God, the world is on fire!' I then opened the door, and it is difficult to say which excited me the most—the awfulness of the scene or the distressed cries of the Negroes. Upwards of one hundred lay prostrate on the ground—some speechless, and some with the bitterest cries, but with their hands raised, imploring God to save the world and them. The scene was truly awful; for never did rain fall much thicker towards the Earth. East, west, north, and south it was the same."

Though I have spoken of shooting-stars as being visible almost always everywhere, this statement must not be taken to imply a uniform distribution over the heavens, because it is evident that in certain hours of Right Ascension (that is, in the constellations occupying those hours) there are more centres of meteor-radiation than in others. In other words, that meteor-centres are most abundant in the first 4 hours of R.A., whilst they are fewest in the hours between X and XIV hours. A somewhat similar disparity may be traced in the declinations, there being an obvious maximum between 41° and 60° of North Declination. These results are due to the untiring industry of Denning, who is our principal meteor observer. Unfortunately, no corresponding statistics are available for the Southern Hemisphere, because luminous meteors have never been catalogued and studied there as they have been in the Northern Hemisphere. Dissecting the year by months, it has been found that an overwhelming preponderance of meteors are associated with the month of August; indeed, the two months of July and August together provide 50 per cent. of the total number of meteors catalogued during the

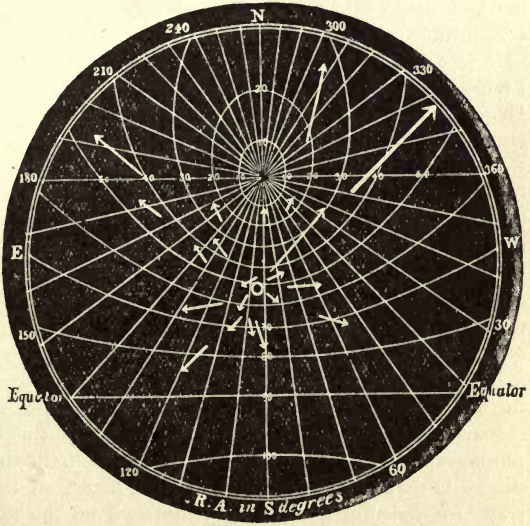


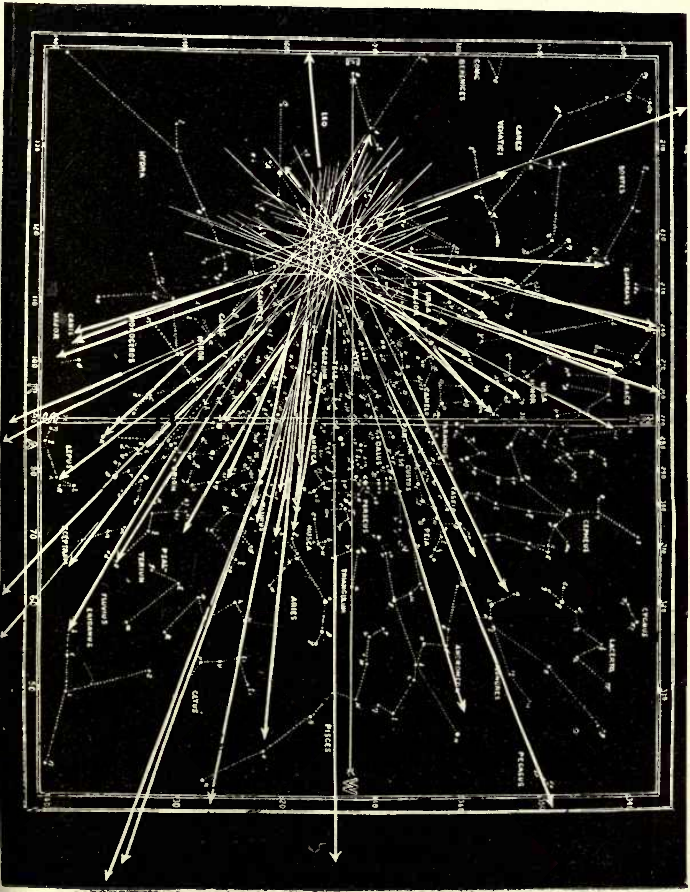
Fig. 236.—Meteor Radiant Point in Gemini (Dec. 12) on Nov. 28—Dec. 9, 1864.

past half-century that systematic observation of luminous meteors has been carried on.

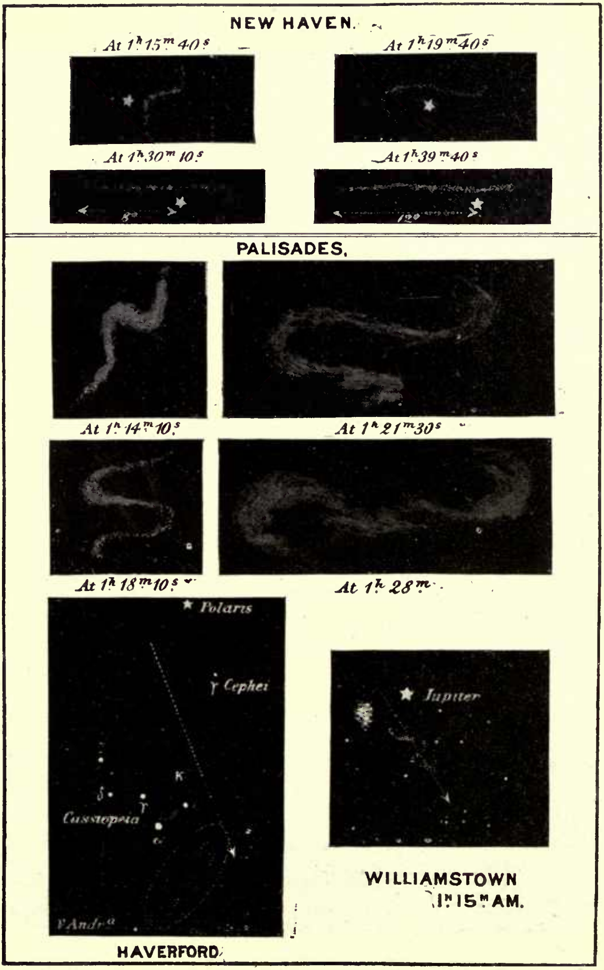
The character of a radiant point, and in some sense the details of the observations which, under ordinary circumstances, can be carried out in connection with it, will be better realised by an examination of a plan (Fig. 236) showing the meteors marked down on some particular night as having been seen emanating from the radiant point in question.

Fig. 234 represents an arrangement devised by Mr. F. W. Longbottom for doing what he calls "fishing for meteors." He arranges in a row several rapid cameras and takes his chance of their being able to catch any meteors which may show themselves in the regions of the sky towards which the cameras point. The stars, of course, are shown by streaks, but that does not matter, as their streaks can never be mistaken for the streak which a meteor would leave, the difference between the two being always very marked. If the time of commencing and finishing the exposure is noted, a map of the stars recorded on the plate can be made by pricking off their position on the trail at any desired moment. It is a good plan to stop exposure when a meteor is seen to cross the field covered by the camera-lens; then the end of each star-trail shows the position of the stars at the moment the photograph was taken, just before the actual attempt. It is desirable that the exposures should be made so that the star-trails (or most of them) begin and end on the plate, though, of course, near the Pole the exposure would be long. The time at which the meteor is seen should be noted, and also, of course, any other particulars deserving to be recorded.

We will now proceed to consider the question of Fireballs. It is doubtful whether any distinction of either origin or nature can properly be drawn between shooting-stars and fireballs, or that there is any distinction at all between them excepting that of size, to which perhaps may be added that of duration of visibility. The grounds for this assumption of identity of



The Meteor Radiant Point in Leo.
(Tracks of Meteors seen at Greenwich, Nov. 13, 1866.)



Meteor as seen at New Haven, Conn.; Palisades, N.Y.; Haverford, Pa.; and Williamstown, Mass., Nov. 14, 1868.

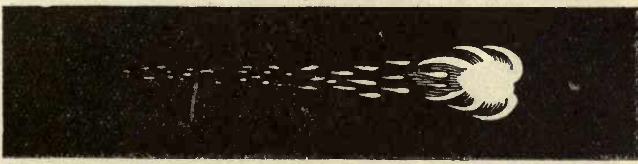
Fig. 248.

First View.

Fig. 249.

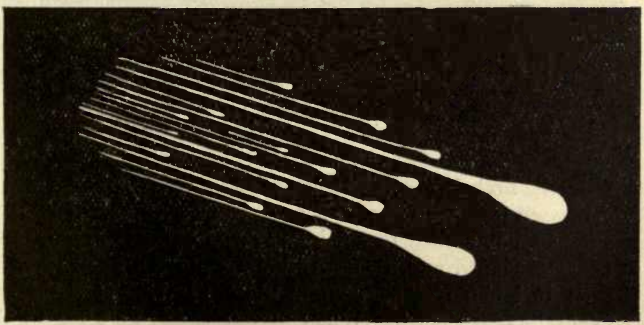
Second View: 1783, Aug. 18 (*Sanby and Robinson*).

Fig. 250.



1878, June 7 (*Denning*).

Fig. 251.



1863, Oct. 19 (*Schmidt*).

Fireballs.

origin and nature between the two classes of bodies now under consideration depend on the fact that various meteor-showers, such as the Perseids and the Leonids, and many others, whilst mainly consisting of star-like points of light, yet now and again yield meteors of great brilliancy, comparable alike in size and brilliancy to the isolated objects which are specifically

1. 2.

Figs. 252, 253.—Curious Form of Trail left by the Fireball of Oct. 19, 1877.

1. First effect. 2. Second effect (10 min. later).

termed "fireballs." Speaking generally, of course, it must be confessed that the large and conspicuous fireballs of sufficient size and importance to get into the newspapers appear in the heavens singly, and, though usually noiseless, sometimes are seen to burst, making a great noise. In this case they are generally pear-shaped. When moving slowly they usually give forth trains of sparks, which either disappear promptly or sometimes linger for many minutes, and drift slowly away, apparently under the influence of currents of wind high up in the atmosphere.

There is a strong family resemblance between all fireballs, and a drawing of one would be typical of a large number, as will be realised by an examination of the illustrations here

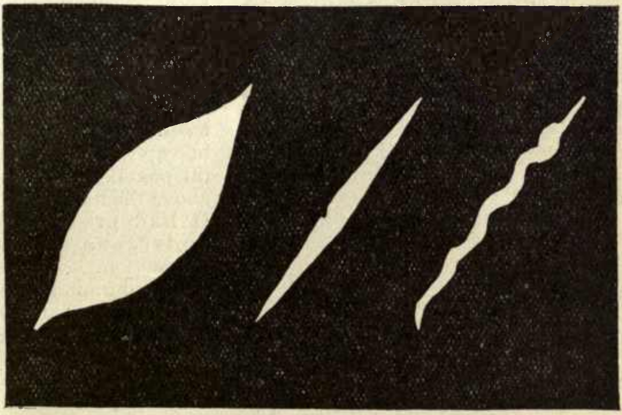


Fig. 254.—Successive Changes in a Fireball during its Visibility.

given. As good a description as could be had of an average fireball will be found in the following account of one seen by the Rev. T. W. Webb on November 12, 1861. He said:—

"We were walking, a party of three persons, along a wide turnpike road, fully lighted by a Moon 10 days old, when we were surrounded and startled by an instantaneous illumination, not like lightning, but rather resembling the effect of moonlight suddenly coming out from behind a dark cloud on a windy night. It faded very speedily, but on looking up we all perceived, at a considerable altitude, perhaps 60° or 70°, a superb mass of fire sweeping onwards and falling slowly in a curved path down the W.S.W. sky. . . . Ruddy sparks, of the colour of glowing coals, were left behind at its smaller end, and its path was marked by a long pale streak of little permanency. Its termination, unfortunately, was concealed by boughs of trees, among which, however, it was traced till possibly some 10° above the horizon, but it had previously undergone a great diminution. . . . The whole duration may have been as much as five seconds. Its aspect was decidedly that of a lignefied and inflamed mass, and the immediate impression was that of rapid descent."

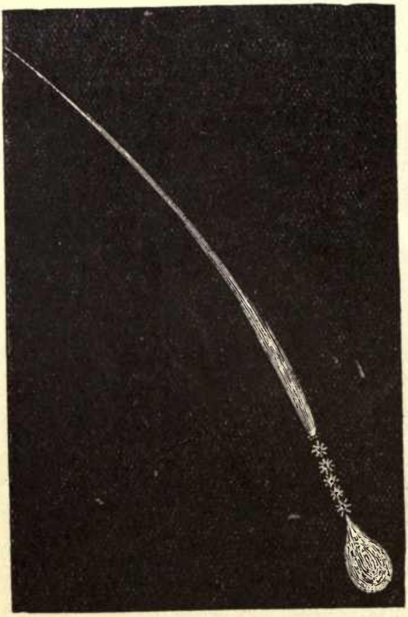


Fig. 255.—Meteor of Nov. 12, 1861 (*Webb*).

The following description of the luminous track of a large meteor, seen on February 22, 1909 (which seems to have been indeed a fireball), and was widely observed along the S. coast of England, is from the pen of Mr. C. G. Brodie. The meteor was quite unique, I think, in the astonishing length and

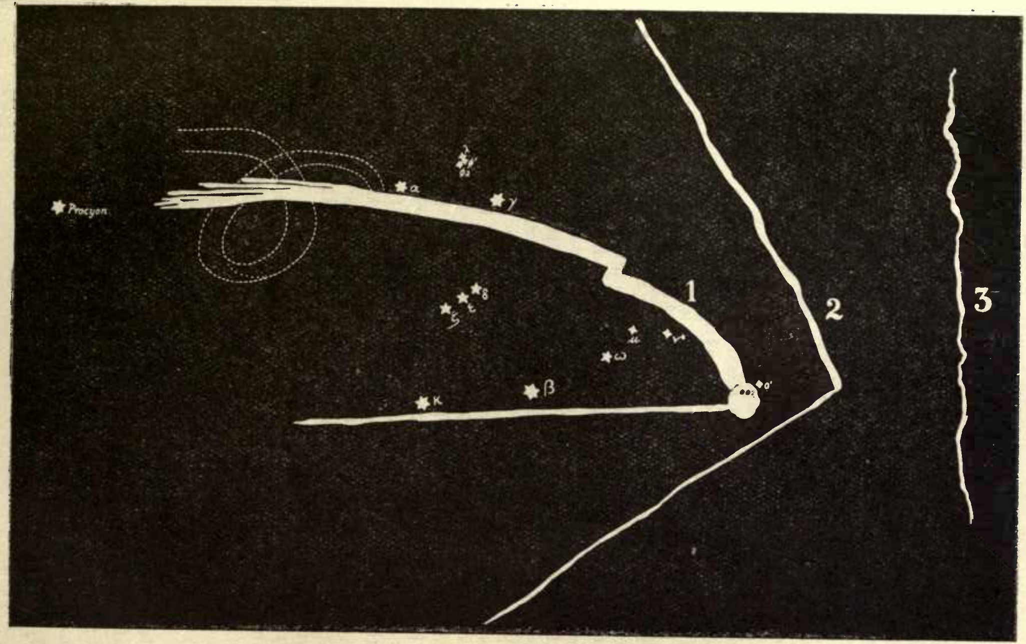


Fig. 256.—Path of a Fireball observed in the Isle of Wight, Feb. 22, 1909 (*C. G. Brodie*).

vagaries of the trail which it left behind. He says that on the day in question—

"While crossing to the Isle of Wight from Portsmouth, my attention was called to a luminous streak in the southern sky. I did not actually see the meteor, but this must have fallen about 7.30 p.m., as we were leaving the harbour. The trail, when I first saw it, extended from near Procyon, passing west under α and γ Orionis as a plain luminous streak somewhat laminated in structure. Passing from W. to S., it entered Eridanus, zigzagging in a curious fashion, exhibiting a shoulder reminding one of a bayonet, above μ Eridani; and then passing S. and W. to about o^2 Eridani, where it ended in a bluish-white, round, luminous nucleus. From this another streak stretched directly eastwards, passing under the two lower stars of Orion (β and κ) into Canis Major; this streak was very thin. The commencement of the upper streak between Procyon and Orion next became curved upon itself, forming a large loop, the cusp being downwards. Before we reached Ryde (say 7.55 p.m. to 8 p.m.), the upper limb had drifted round westwards into an almost vertical position, the angle became less acute, and the nucleus disappeared, the lower streak drifting southwards. The whole trail had become narrower and less distinct. As late as 8.40, while driving from the Wootton station, there was still a trace of the upright limb in the western sky in the form of an irregular narrow streak. Several people told me that the fireball was so brilliant as to resemble the sudden turning on of an acetylene lamp behind them. This shows that the meteor must have been exceptionally bright, as the sky was clear and there was a young Moon. The way in which the luminous track altered its position suggested to my mind that it was drifting by the action of the wind, which on that day was registered as S.-E., and the day following was still easterly."

It has been found that certain dates may be stated at which fireballs may specially be looked for. The following are some of these dates: January 2, February 7, April 11–12, 19–20, June 6, July 25–30, August 7–13, September 1–2, 6–7, November 1–2, 6–9, 11–15, 19, 27, December 8, 11–12, 21.

Attempts have often been made to subject particular fire-balls to computation as regards their distances, sizes, and velocities; but the suddenness of their appearance, and the rapidity of their movements and of the changes which they undergo render the results in all cases very uncertain. Subject to this view it may be stated that their height above the Earth's surface commonly varies between a few miles up to 80 miles or more; their absolute diameter between perhaps 50 yards and 2 miles; and their velocity between 2 miles and 40 miles per second. The foregoing figures are actual results in the case of particular fireballs. It may be remarked, however, that one is apt to exaggerate estimates of diameter, and also of velocity, measured in the first instance as so many degrees in the sky in so many minutes. The only cases in which trustworthy results can be assured are in the instances, naturally very rare, in which two trained observers in widely separated parts of the country may each have the good fortune to see the same fireball start on its career and be able to follow it to the end. There are a few instances of this on record, and the calculated results may in such cases be, to a large extent, depended upon.

There must now be mentioned a matter connected with celestial mechanics, which might with equal propriety be attached to the chapter on comets or to this one on meteors. I allude to the modern discovery of the association between certain comets and certain displays of luminous meteors. This may now be regarded as a clearly ascertained fact, though it is far from easy to pronounce dogmatically on the circumstances so far as they are yet known. The simple fact, concisely expressed, is that there are meteor-showers revolving round the Sun in orbits so closely resembling the orbits of certain comets that we are driven to the startling conclusion that some of the recognised meteor-showers are either off-shoots from comets or are the actual materials of disintegrated comets. There is, at any rate, one instance of this which is hardly open to serious question. The former well-known Comet of Biela has absolutely disappeared, but there exists a swarm of meteors travelling round the Sun which present themselves every November, radiating from the constellation Andromeda, which pursue a path practically identical with that which used to be followed by Biela's Comet, so long as we knew it as a comet ; and the conclusion is inevitable that the comet, as it originally was, has been broken up and become a swarm of meteors.

Whilst it is obvious that such a conclusion sets us all thinking, it is not easy to say how far, or in what direction, our thoughts ought to go.

The following is a summary statement of the association of certain comets with certain meteor-showers :

Comet.	Meteors.	Radiant Point.	Date.
Tebbutt's	Lyrids	Lyra	April 20
Halley's	Aquarids	Aquarius	May 1–6
1862 (iii.)	Perseids	Perseus	Aug. 10–12
Tempel's 1866 (i.)	Leonids	Leo	Nov. 13
Biela's	Andromedes	Andromeda	Nov. 27

The circumstances of Tempel's Comet are specially remarkable, and, as they have been investigated very fully by Kirkwood, some details will interest the reader. It has already been stated in an earlier part of this chapter that the Leonid meteors first attracted the attention of a scientific observer in 1799, and that at a subsequent date it was clearly ascertained that the shooting-stars seen in 1799, 1833, and 1866 were periodic manifestations of the same shower ; but it was not till near the last-named date that the association of a certain comet with this shower became fully understood.

The subject was started in its first developement by the discovery, on December 19, 1865, of a small comet by Tempel, then at Marseilles. It was generally observed for 7 weeks, and, although not a very conspicuous object, its relations to the

Earth and Uranus may be said to have given it an importance surpassed by very few comets. The final computation of its orbit showed that it was a periodical comet revolving round the Sun in 33·28 years. This comparatively short period led to catalogues of comets being searched, and it was found that, reckoning backwards 33·28 years a good many times, there were coincidences (with breaks) back to the year 465 B.C. of comets which might be identical. If one can assume that such a date may be safely taken as a *terminus a*

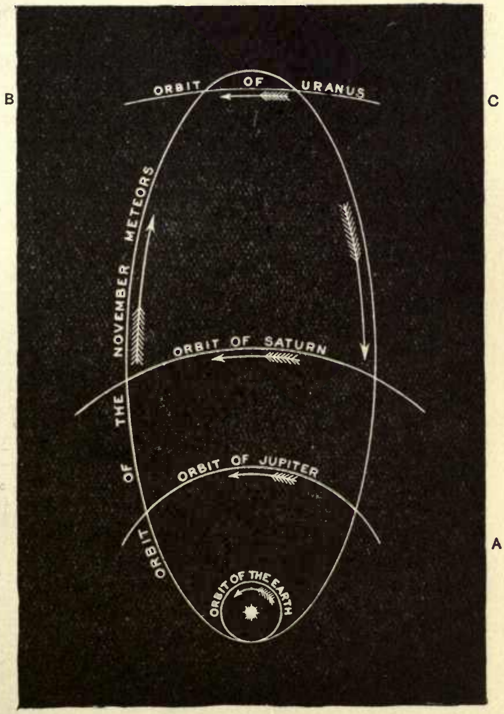


Fig. 257.—Orbit of the Leonids of Nov. 13 and of the Comet of 1866 (i) relatively to the Orbit of Certain Planets.

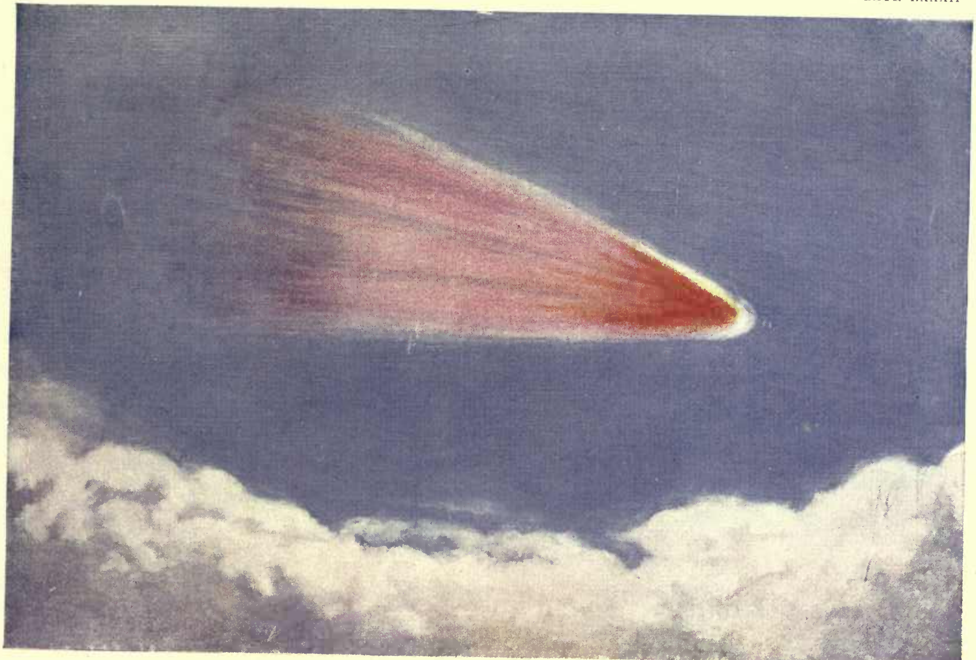
Points on the orbit opposite to the letters A, B, C are the positions of the 3 detached swarms, according to Kirkwood.

quo, we have, as a result, 72 periods of 33·28 years down to A.D. 1366. A comet in 1366 is regarded as another absolutely certain *terminus a quo* for later centuries. From 1366 to 1866 is 499·3 years, or fifteen periods of 33·28 years.

Professor H. A. Newton, working on independent lines, traced back the great showers of 1866 and 1833 to A.D. 902. He showed that there were five possible periods for the revolution of the swarm round the Sun, namely, 180 days, 185 days, 355 days, 377 days, or 33¼ years. This important uncertainty was, however, first definitely solved by Professor J. C. Adams in 1867, who, by working on Newton's labours, found definitely that the periodic time was about 33·25 years.

The conclusion that Tempel's Comet and the great meteoric swarm of 1866 and previous dates move in the same orbit, and that the swarm of meteors was in fact derived from the comet, was reached almost simultaneously by Peters, Le Verrier, and Schiaparelli; but the matter was carried a good deal farther by Kirkwood, who found very clear proofs not only of a second, but also of a third cluster belonging to the same family, moving in orbits clearly identical in form with those of the comet and the 1866 meteors. It need hardly be pointed out what an interesting series of coincidences have thus been brought to light. I have not space to go into further details, but Kirkwood gathered up from a long series of observations of meteor-showers, spread over several centuries in each case, materials which furnished him with the information on which he based his conclusions.

We will pass now to the consideration of aërolites, and this brings us face to face with the important questions which I have not yet broached: What is a shooting-star? What is a fireball? Whence comes an aërolite? I think it must be said that these questions must be answered together, and that



Daylight meteor seen at Penshurst, Kent, June 20, 1866. (*J. Nasmyth*)
Length of coloured portion 1°; space traversed in 2 seconds, 30°

the conjoint answer must be that all these bodies are, or have been, masses of solid matter floating about in space, coming from whence we know not, but which, when they reach the Earth's atmosphere at about 80 miles above the Earth's surface, (1) take fire and fizzle away, or (2) take fire and burst, or (3) fall to the ground as solid masses of stony matter, which are either in their original form and of their original size, or which, when we see them on the ground, are the broken-up fragments of some larger mass, which has become disintegrated, either in the upper regions of our atmosphere or farther off in Space.

With aërolites we rather pass from the domain of astronomy into that of chemistry, geology, mineralogy, and geography, and therefore my treatment of the subject in these pages must be brought into somewhat narrow limits. The crucial fact which we have to bear in mind is that now and again stony or semi-metallic masses, composed of many diverse materials, fall on the Earth, from whence coming we know not.

The number of such falls, recognised as such, has now reached a considerable total, and covers a large field both in time and area; that is to say, that instances of such falls have been recorded at many dates, beginning with more than 2000 years ago; and the produce of such falls may be found in every part of the habitable globe. But many aërolites have been transported by the hand of man from the place where they fell to some neighbouring or distant public museum. Hence it comes about that specimens of aërolites are to be found alike in the British Museum and in many other public museums in different parts of the world. Naturally, most of the aërolites which have been found were in the stone-cold condition, and their extra-terrestrial origin had to be inferred from analogy and chemical analysis; but a few cases are on record in which the aërolite was seen to fall, and was examined by an eye-witness and found to be still warm. The following is a typical case in point. On April 20, 1876, a mass of meteoric iron weighing about 7 lbs. fell at Rowton, in Shropshire. We are told that shortly before 4 p.m. a sound like that of thunder, followed by reports as of cannon, shook the air, and was heard during rain-showers for many miles round in that neighbourhood. No fireball was observed. The iron was found about an hour afterwards in a meadow, where it had sunk into the earth to a depth of 18 inches. When dug out it was still quite hot.

In the foregoing case the material was metallic, more or less. But in other cases, and the majority, the material has been generally stone of sorts, either a conglomerate mass of mixed composition or a mass somewhat basaltic in its nature. It is obvious that opportunities for actually observing the fall of an aërolite are few and far between, and that the most which we can do is to study their appearance and investigate their chemical composition in the light of the facts gathered up for us as regards the time and place of their fall.

CHAPTER XI.

THE STARS.

The apparent movement of the stars on a starlight night.—The stars in magnitudes.—Diurnal movement of the Earth.—Its consequences.—The stars visible vary with the latitude.—The expression "fixed stars."—Stars that are visible to the naked eye.—The identification of the stars.—Bayer's system of lettering stars.—Flamsteed's numbers.—Sir J. Herschel's striking remarks.—Total number of naked-eye stars.—Amount of star-light.—Twinkling.—Double stars.—Binary stars.—Coloured stars.—Complementary colours.—Triple and multiple stars.—Variable stars.—Notable variable stars.—Temporary stars.—Tycho Brahe's Star.—Recent temporary stars.

WE are now starting on what is obviously a very large subject, and one which has numerous ramifications, and I propose to treat the sequence of the different branches somewhat in the order in which the student of the stars would be likely to approach the subject, first of all as an observer using only his eyes, and then proceeding to employ an opera-glass, a small telescope, and a larger telescope all in succession. The dominant idea which will run as a thread through this and the later chapters dealing with the constellations will be that the reader will wish to make himself acquainted with the actual geography (though this is not the proper word [1]) of the heavens, with the view of knowing what interesting objects to look for and where to find them.

[1] It should be "uranography," from Ουράνος heaven, and γραφω, I write.

I will now proceed to deal with a variety of general considerations relating to the stars, individually and collectively, including their apparent movements through the different seasons of the year. Some of these topics may seem to be dry, but clear conceptions as to many of them are of prime importance.

Everybody, I suppose, knows that the Earth turns on its axis as a wheel turns on its axle. The visible consequences of this act should be thoroughly realised, and this will best be done by the reader taking his station on a clear, starlight night in some high and fairly open position facing the N., but with a tolerably wide range of view all round. Let him, in the first instance, try and fix in his mind the grouping of the stars in the W., somewhere about the point where the Sun has set. Next let him turn his eyes and take note of the stars immediately overhead. Finally, let him examine the stars due E. of his position, and fix in his mind their general appearance.

Having taken stock, as it were, of these three portions of the heavens, let him go indoors for an hour, or, better still, for a couple of hours, and then come out again and refresh his memory by trying to regain the conceptions of two hours ago; and he will find some difficulty in doing so. Several of the principal stars which he had previously noted as low down in the western horizon will have disappeared. Those which had been overhead will have appreciably moved on towards the W., whilst, when he directs his eyes to the eastern horizon, he will discover a fresh set of stars which he had not seen before, those which he had seen having visibly risen higher up towards the zenith.

If, instead of coming out a second time the same evening, the reader had postponed for a week his second inspection of the heavens, he would have noticed very material changes in the aspect of affairs. Every group of stars would have moved on; those which had been in the W. would have disappeared, and a new assortment would have started up in the east. If, instead of resuming his work in a week, he had waited a month, the changes in the aspect of the sky would have been still more radically different; and, to cut a long story short, if he had prolonged his study of the sky by only looking at it once a month for 12 months, he would, at the end of the twelfth month, have seen all the stars, and in identically

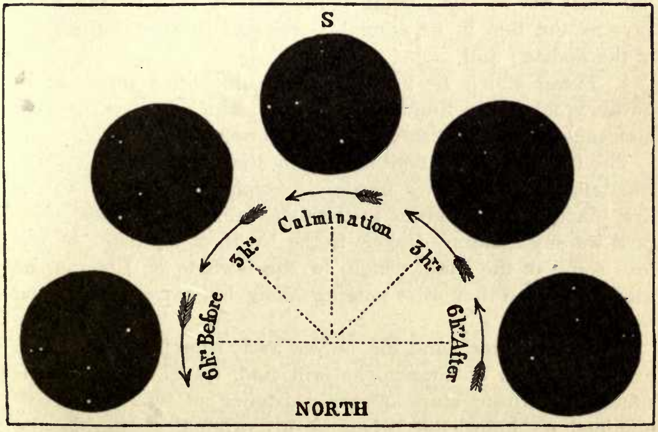


Fig. 259.—Apparent Changes in a Group of Stars in the Course of 12 hours between Rising and Setting.

the same positions in which they had been on the night of his first view one year previously. Otherwise expressed, what would have happened would have been this: he would have had under notice all the constellations, and therefore all the stars, which under any possible circumstances could be seen in the latitude of his place of observation.

This mention of the word "latitude" opens up a subsidiary matter of great practical importance. In consequence of the axis of the Earth being inclined about 23° to the Ecliptic (the apparent annual path of the Sun), the whole body of stars need to be considered under three heads :—

1. Those in the neighbourhood of the Poles which never go below the horizon, but which are visible on every clear night throughout the year.

2. Those which I have first described, which come into view and pass out of view, being obliterated in turn by the Sun's rays as the Sun in its annual course passes through the signs of the Zodiac ; and,

3. Those which lie towards the S., including those which gather round the South Pole, all of which are perpetually concealed from the observer in a given northern latitude.

The foregoing statement respecting the visibility of particular constellations and stars needs a twofold extension. In the first place, if the observer in the first-mentioned latitude—suppose we say London—travels to the North of Scotland, he will lose some of the stars which, in the latitude of London, he glimpsed when they were passing along his extreme southern horizon.

If, on the other hand, he moves away from London to the extreme South of France, he will find, travelling along his southern horizon, stars of the existence of which he had obtained no knowledge when at his original station in the latitude of London. If he should proceed farther S., right away 6000 miles to the Cape of Good Hope, or on to Australia, he will come face to face with an entire reversal of everything which he had seen when in the latitude of London. The North Pole, the Great Bear, the Little Bear, and all the constellations in their neighbourhood would have disappeared irrecoverably. The constellations which had passed over the zenith in London will be low down in the northern horizon, the previously visible North Pole, and its Pole-star, will have disappeared, and been replaced by another Pole, and another

Pole-star,[1] and an entirely new set of constellations will pass over the zenith at the Cape and in Australia, so that in point of fact the aspect of the nocturnal heavens will have become completely revolutionised.

The statement just made as regards the consequences of an observer transferring himself from London, in the North latitude of 51°, to a place in the corresponding latitude in the Southern Hemisphere, which would be somewhat to the S. of New Zealand, may be otherwise expressed thus: that the stars which are within the "circle of perpetual apparition," otherwise known as "circumpolar stars," and are therefore perpetually visible in England, will be perpetually invisible in New Zealand, and the stars which are perpetually out of view in England will be perpetually in view in New Zealand. It must be understood that this statement, to be literally true in substance, depends on identical latitudes being compared, and that the latitude of 51°, which is assumed to be that of London, finds its literal counterpart not actually in New Zealand, but a little distance S. of the most southerly point of New Zealand.

I hope that the foregoing statements as to the changes in the aspects of the heavens which will be noticed by an observer watching the stars from night to night throughout a period of one year will be sufficiently intelligible; and that what is meant is that the whole vault of heaven with its myriads of fixed stars is in constant movement as an unchanging whole. But this presentation of the matter, though convenient and indeed necessary to convey general ideas, is not quite literally true; it is one of those conventional untruths which are often useful in astronomy as a preliminary to pave the way to precise

[1] Whilst the Northern Hemisphere has, as its representative Pole-star, a fairly bright star (α Ursa Minoris), which is very close to the exact polar point, it is to be regretted that the South Pole has no sufficient Pole-star, the nearest star to the South Pole (σ Octantis) being only of magnitude 5, and some distance from the polar point.

accuracy. The term "fixed stars" is so old and so universally used that I think it may be said to deceive nobody. Moreover, it is perfectly well known that certain objects which are often colloquially included under the name of "stars" are not fixed, but wander hither and thither, and are known as "planets," which very word itself implies that they do not occupy fixed positions.[1] Furthermore, precise modern observations, conducted with special skill and care, have brought to light the fact that a very considerable number of stars are endued with actual proper motion of their own, so that they move relatively to one another, though by amounts which are entirely beyond the grasp of the naked eye.

The stars being of different apparent size, which for our present purpose means brilliancy, have been classified in magnitudes which range from the 1st to the 18th, though the higher figures which one meets with in various astronomical publications are very uncertain and fanciful.

It is usually considered that the range of naked-eye vision ends with the 6th magnitude inclusive; but with many persons the limit must be put at 5½, whilst with a few other people it may be extended to 6½. Beyond this the range goes to 7, 8, 9, 10, 11, and 12; and there all accurate values may be deemed to cease, though one often comes upon higher figures. All the recognised figures began with eye estimations in bygone times. It is obvious that this is a most unsatisfactory and unbusiness-like way of estimating the brightness of a star, and, though organised photometric methods have often been proposed, they have only, up till now, been carried out to a limited extent. The observers at Harvard College, United States, have published catalogues of naked-eye stars estimated in brightness by means of an instrument called a photometer,[2] and the value of their labours is very great indeed.

Independently of instrumental values of star-magnitudes, it

[1] Gr. πλανήτης, a wanderer.

[2] Gr. φῶς, light, and μέτρον, a measure.

is customary to subdivide magnitudes decimally from 0 to 9, which gives an air of exactitude to the figures assigned, which can only be regarded as, in many cases, a sham.

When we come to deal with the stars in detail it will be seen that other classifications besides those depending on brilliancy have to be resorted to ; so that we shall have to put into separate sections "coloured stars," "double stars," "temporary stars," "variable stars," and "moving stars." Next will follow, as a complement to double stars, "triple," "quadruple," and "multiple stars," clusters of stars, and nebulæ, and last, but not least, the Milky Way. But, before entering on such details, there are several other matters which must be brought under the notice of the reader.

Postponing a consideration of the constellations to the chapter specially dedicated to them it will yet be convenient in this chapter to say something about the identification of the stars. In early times, after a large number of the important constellations had been named (and the origin of most of these names is lost in antiquity), it soon came into men's minds that some means of distinguishing one star from another in the same constellation was urgently necessary. This was a matter taken in hand by the Arabian astronomers during the centuries following the Christian era. Most of the names of particular stars now in use (Aldebaran, Altair, etc.) are of Arabic origin, with additions of Greek and Latin origin (Arcturus, Spica Virginis, etc.). These names served their purpose in a certain way, and for a certain time, but the need of more precise names was soon felt, hence Aldebaran came to be called Oculus Tauri, the "eye of the bull," a phrase supposed to give some indication of where the star was to be found.

It requires no great amount of acuteness to realise that such methods to indicate stars as these were so rough and vague as to be practically useless ; but a very marked advance in the direction of scientific exactness was made in 1603 by a German astronomer named Bayer, who in that year published the first Celestial Atlas, the title of which was *Vranometria, Omnium Asterismorum continens Schemata Novâ Methodo delineata.* In this work the stars of each constellation were distinguished by having attached to them the letters of the Greek alphabet, and these have been used ever since. It would seem that Bayer started with the idea that he would label the stars in the order of brightness from α and β, and so downwards as far as might be necessary till the alphabet was exhausted. The common idea is that the order of the alphabet, as we know it, did and does represent the order of the stars so estimated; and occasionally it has been argued that the brightness of a star must have varied, because it does not occupy its proper position in brightness according to its position in the Greek alphabet. There is, however, no doubt that such an argument is worthless, and that the idea of accurate sequence cannot be carried further than to say that the brightest star in every constellation always had α allotted to it, and perhaps the second brightest β, but that all the rest followed somewhat, but perhaps not altogether, at haphazard.

The next worker in this field was our own John Flamsteed, once Astronomer Royal. He prepared and in 1725 published his *Catalogus Britannicus*, which contained 3310 stars observed at Greenwich, and reduced to 1690, all the stars of which were numbered by his modern editor, Francis Baily, from No. 1 onwards in each constellation. Flamsteed's numbers are still in general use, and they, together with Bayer's Greek letters, are to be found engraved in almost every star-atlas in existence. When Bayer's letters are used they are prefixed to the genitive case of the Latin name of the constellation, thus: α Ursæ Majoris, β Canis Minoris, and so on. In addition to Bayer's Greek letters and Flamsteed's numbers there are a few stars indicated by Roman letters. The use of these letters, but to a very limited extent, was really started before Bayer's time by an Italian, Piccolomini of Siena, but his use of them was limited. A long time elapsed after the invention of the telescope, and the commencement of methodical observations of stars as regards their exact places in the heavens, before the constellations and stars of the Southern Hemisphere were submitted to critical instrumental measurement.

This did not come about till Lacaille published, in 1763, his *Cœlum Australe Stelliferum*, which contains 1943 southern Stars, observed by him at the Cape. Lacaille had the whole Southern Hemisphere to himself, so to speak, and he turned his opportunities to account not only by observing its stars but also by attaching letters, Greek and Roman, to them, at the same time creating 14 new southern constellations. In the particular case of the constellation Argo, one of vast extent and with many large stars, Lacaille got into a good deal of difficulty in the lettering—that is to say in finding letters for the 180 stars to which he deemed it desirable to attach letters. Thus it came about that, besides using up the Greek alphabet, he employed the whole of the Roman alphabet, both in capital and small letters, repeating indeed each several times, and so, of course, paving the way for a good deal of confusion.

Sir John Herschel once made some remarks on the subject of the stars which are so very striking as to deserve quotation, the more so as they help to indicate the utilitarian side of astronomy, and moreover constitute what the French call politely a *démenti* to the absurd statement once made by the late Sir George Cornwall Lewis that astronomy is only a science of "pure curiosity." These are Sir John's words :—

"The stars are the land-marks of the universe, and, amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in His works. It is indeed hardly possible to over-appreciate their value in this point of view. Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him, the same for ever and in all places, of a delicacy so extreme as to be a test for every instrument yet invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock as for conducting a navy to the Indies; as effective for mapping down the intricacies of a petty barony as for adjusting the boundaries of transatlantic empires. When once its place has been thoroughly ascertained and carefully recorded, the brazen circle on which that useful work was done may moulder, the marble pillar totter on its base, and the astronomer himself survive only in the gratitude of his posterity; but the record remains, and transfuses all its own exactness into every determination which takes it for a groundwork, giving to inferior instruments, nay, even to temporary contrivances, and to the observations of a few weeks or days, all the precision attained originally at the cost of so much time, labour, and expense."

As regards the number of the stars there is great misapprehension in the minds of many people. One's natural impulse is to exaggerate the numbers. Bearing in mind the difficulty of drawing precise lines of demarcation between the different magnitudes (the difference between the 1st and the 2nd not excepted), the following may be stated as approximately the numbers for the several magnitudes:—

Magnitudes.	No. of Stars.
1st	21
2nd	65
3rd	190
4th	425
5th	1100
6th	3200

Below the 6th magnitude the uncertainties are too great to make exact estimates justifiable, and it is not safe to say more than that the visible stars, from the 1st magnitude down to the 9th inclusive, have been estimated by experienced observers to be about 130,000 in number, though Argelander raised this figure to 200,000.

It is generally considered that the total number of stars visible to the naked eye in England on any given night must not be put higher than 2500, whilst the grand total of all the stars which could be counted in England, all the months lumped together, may be said to be no more than about 4000, though Heis, of Münster, turned this into 5000.

Such statistics as these are not very profitable, because different enumerators are certain to do their work of taking a census of the stars on different principles : still, the subject could not be entirely passed over.

A question which has been raised, though it can hardly be said to have been settled, on any sure basis, is the question whether the stars, or any of them, transmit any measurable quantity of heat. Experiments carried out many years ago at the Greenwich Observatory and elsewhere seem to suggest an affirmative answer, but when I quote one of the results in the form in which it was announced, scepticism on the subject will not be deemed unreasonable. Here is this result : That Arcturus, at an altitude of 25° above the horizon, was found to emit the same amount of heat as that which would be felt from 3 cubic inches of boiling water at a distance of 400 yards ! An analogous difficulty—I had almost said impossibility—arises in connection with the question, What is the amount of light given out by the stars ? All attempts to express this in figures seem to me perfectly futile, and that we cannot safely do more than say that, contrasting a starless night with a night on which the stars are shining brightly, there is in the latter case a sensation of less darkness than in the former case. Beyond this I do not deem it safe to particularise.

Fabry, at Marseilles, published in 1910 the results of certain efforts made by him by way of developing previous attempts by Newcomb, Burns, and Yntema, a Dutchman, to determine the intrinsic brightness of the sky so far as star-light was concerned. It need hardly be said that the task to be performed proved a very difficult one and the results very contradictory all round ; so much so that I hesitate to attempt to summarise them, beyond saying, what is an evident truism, that the stars collectively do afford some light to the Earth.

We must not pass away from the consideration of the stars as isolated or single objects without saying something on the interesting and time-honoured question of their twinkling. This optical phenomenon came before all of us in our earliest years. Who has forgotten :—

"Twinkle, twinkle, little star ;
How I wonder what you are !
Up above the world so high,
Like a diamond in the sky"?

This has been in part replaced by the advance of modern science, and accordingly we have the following revised version in circulation :—

"Twinkle, twinkle, little star ;
Now I've found out what you are,
When unto the midnight sky
I the spectroscope apply."

Familiar as the phenomenon is to all of us, full scientific explanations of it are lacking. In its effects it is evidently largely dependent upon the condition of the Earth's atmosphere, the varying influence of which undoubtedly affects the extent of the twinkling noticed on any given night. The weather indications which twinkling bespeaks seem uncertain when it is a question of excessive twinkling, which may indicate fine weather or the approach of weather of the contrary character ; but it seems quite certain that the absence of twinkling (that is to say, if the stars are dull and devoid of rays) renders the approach of rain a certainty. Bright stars twinkle much more than faint ones ; indeed, it may be said that faint stars do not twinkle at all. Again, stars low down near the horizon twinkle more than those high up towards the zenith ; and an observer in a low-lying position on the Earth will notice the twinkling to be more marked than when he looks at the same stars from a mountainous or considerably elevated level above the surrounding country—in other words sees the stars through a comparatively rarefied atmosphere. These facts accentuate the certainty that twinkling is a matter largely, one might perhaps almost say wholly, dependent on atmospheric conditions. It has been suggested, however, that this question of the density or rarefaction of the air, dependent on a star's position above the horizon, must not be pushed too far because (as is supposed) several of the principal fixed stars, presumably on account of the nature and peculiarity of their light, vary considerably in their display of twinkling, independently of their position in the heavens. For instance, Procyon (α Canis Minoris) and Arcturus (α Boötis) twinkle much less, under all circumstances, than Vega (α Lyræ), a notable bluish-white star. A French observer, Dufour, has laid it down that red stars twinkle less than white ones and that twinkling is more visible during twilight than later on.

The subject of twinkling was very exhaustively studied by the late C. Montigny, an amateur, who lived at Brussels, where I had many interesting conversations with him in 188—. He arrived at some very striking conclusions. He found that twinkling is more pronounced when rainy weather is impending, and also more pronounced in winter than in summer. Dry weather in spring and autumn stands on about the same footing, but autumnal wet weather developes the phenomenon in a much more marked manner than does spring wet weather. Variations in the barometer and in the humidity of the atmosphere, as indicated by the hygrometer, also affect the amount of twinkling ; it is also more developed when a rainy period likely to last two or three days is approaching, than merely before a single casual rainy day; it also varies with the aggregate total rainfall of a group of days, being greater as the rainfall is greater, suddenly and considerably decreasing directly the rain has passed away.

Montigny's observations and conclusions were not based on crude, haphazard eye-observations, but on an instrument of his own invention, which he called a *scintilometer*, using the French word for twinkling as the basis of the name of his appliance. He found the number of scintillations (*anglicé*, twinkles) observable per second to vary from a minimum of 50 during June to July to 97 in January and 101 in February, increasing or decreasing month by month in regular gradation. He also found that a display of Aurora Borealis exercised a marked influence in increasing the twinkling. But this was not all in regard to his discoveries. It came into his head that possibly the different classes of stars as classed by Secchi with respect to their spectra might yield some definite results in regard to twinkling; and he was not disappointed. Anticipating here what belongs to a later part of this volume, a proper account of Secchi's classes of stars, I may state that Montigny, as the result of some hundreds of observations of 41 bright stars belonging to Secchi's first 3 classes, was led to the following conclusions: that stars of the first class yielded an average number of 86 scintillations per second, stars of the second class 69, and stars of the third class only 56. The more perfectly any star possesses the distinguishing characteristics of its class the more nearly does the number of its scintillations agree with the law indicated by the above statement. This law may be stated thus: The more considerably the spectrum of a star is interrupted by dark lines, the less frequent are its scintillations; from which it follows that on the characteristic of each star depends its twinkling, both as regards its frequency and the colours which it displays.

Sufficient has now been said by way of treating the stars as isolated objects in the heavens, and we must now proceed to consider the stars in combination, beginning with pairs of stars, and leading up to clusters of indescribable multitudes. I pass over such recundite matters as the "proper motions" of stars, "star-drift," and the "motion of the Solar System in space," as involving difficult technical details not likely to interest the readers for whom this volume is primarily intended.

Fig. 260.—Two Stars at Different Distances seen as a "Double Star."

DOUBLE STARS.

A very large number of stars, including some of the largest and some of the smallest visible, though they appear to the naked eye, or through an opera-glass or a small telescope, to be single stars, yet, with increased optical assistance, are found to consist of two stars so close together as previously to have been regarded as only one star. Other stars seeming to be single are eventually found to comprise three stars, and so on, four stars, or five stars, until the word "multiple" has to be used. We will start with a common form of double star, though in numerous cases greatly increased optical assistance shows that one or other member of a pair, regarded only as a pair, is itself double again. Up to the time of Sir W. Herschel very few double stars were known. His powerful telescopes enabled him to convert 500 stars apparently single into doubles; and now the researches and perseverance of modern observers have resulted in the number of recognised double stars being increased to many thousands.

The mere fact of looking at a star and finding it in a small telescope to be single, whilst a larger telescope, or more power on the small one, reveals its duplicity, though a thing interesting in itself, falls far short of the great interest which attaches to many of these objects after prolonged study of them. Herschel at first merely supposed that he was looking at 2 stars either stationary side by side at the same distance from the Earth or at 2 stars in nearly the same line of sight at distances altogether different. The annexed diagram (Fig. 260) will make clear what is involved in this simple statement regarding a star only optically double. Herschel, however, was led by the force of circumstances into a discovery which both astonished and captivated him. In the early stages of his work as a double-star observer he recorded the angular position of all his double stars with respect to the N. and S. points of the heavens, and their distances from one another. He continued observations of this character for the sole purpose of trying to discover whether observations at different periods of the year gave indications of his stars being subject to displacement by way of parallax in consequence of the Earth's annual motion round the Sun.

Instead, however, of obtaining any information to help him as regards parallax, he found in a very large number of cases that these pairs of stars were experiencing relative change, and that their distances were varying; as also the angle with the meridian of a line joining the centres of the 2 stars. In other words, he found that there were in existence systems consisting of 2 stars revolving about each other in elliptic orbits, and evidently linked together. The interest attaching to this discovery is of a twofold nature. ~~First~~ of all, there was the unforeseen and captivating novelty of it, and then there was the important fact that it was ultimately found that the Newtonian Law of Gravitation was in operation far beyond the confines of the solar system to which it had been previously supposed to be limited.

The actual application of the law to Herschel's discoveries did not take place till many years after those discoveries, when

Savary, in 1830, computed an orbit for the star ξ Ursa Majoris which is now recognised as a binary, the smaller star of which steadily circulates round the larger one in a period of

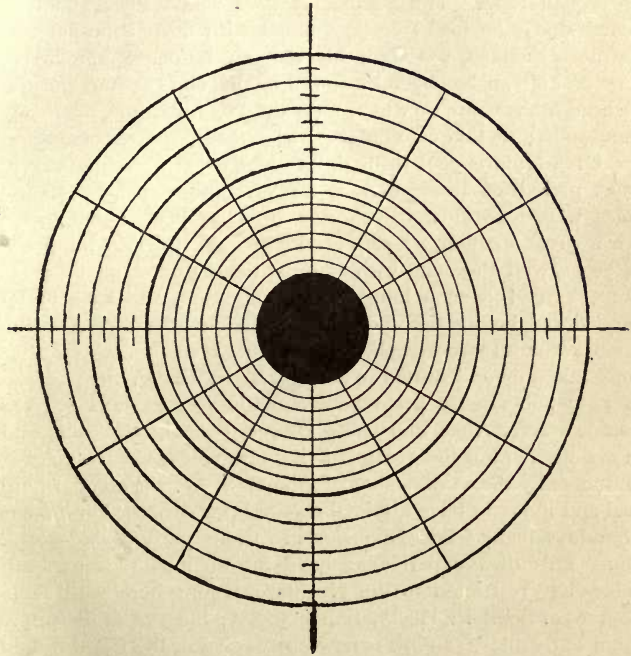


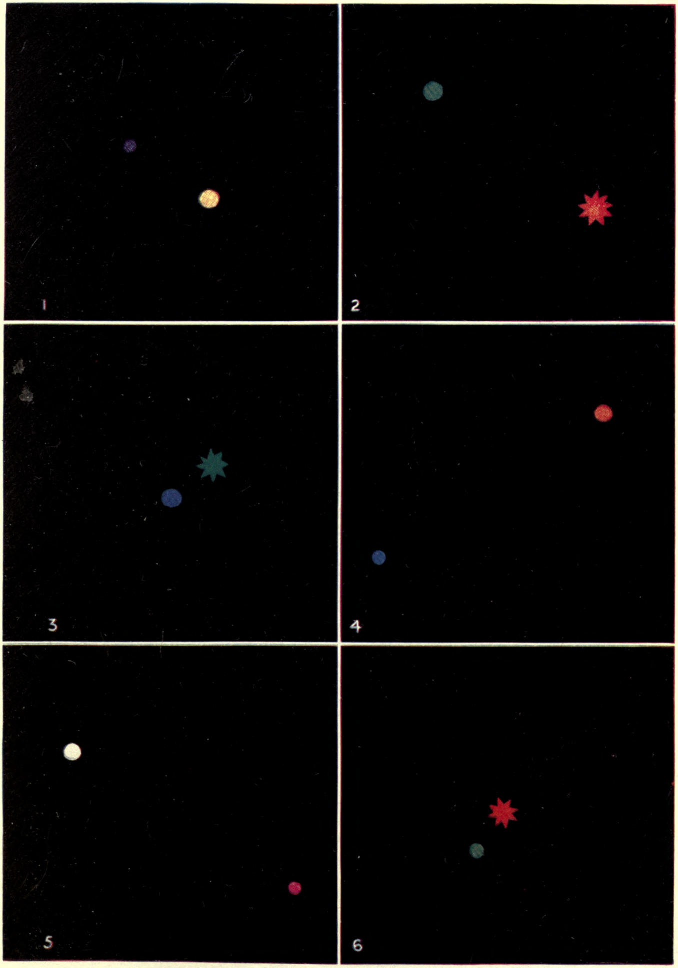
Fig. 261.—Diagram for sketching of the Corona in Total Eclipses of the Sun.

Devised by E. J. Stone, and available for plotting measurements of Double Stars.

about 60 years. This star may be well commended to the notice of amateurs for the reason that both components are large, the larger one being of magnitude 4, and the smaller one of magnitude $5\frac{1}{2}$, and the distance between them generally being about 2″ of arc, more or less. Herschel made his discovery known in a memorable paper presented to the Royal Society in 1802. The number of stars which, after about 25 years' study, he found to be endued with orbital motion was no more than 50, but since his day an immense amount of time and labour has been bestowed on that class of star, and the assured binaries are now to be numbered by hundreds, not to say thousands, if we take count of those which are suspected of motion.

ξ Ursa Majoris goes through its changes in a comparatively short period of time—that is to say, there are not many stars whose periods are shorter than 60 years; but there are a great number whose certain periods run into hundreds of years, and therefore with many of them prolonged observations, spread over a long expanse of years, will have to be carried out before the certainty of their movements and the precise details thereof can be established. Herschel's discoveries were taken up and turned to account by F. G. W. Struve, who in 1837 published a great book containing measures of 3112 double stars. After him came Dawes, Secchi, Seabroke, and many others; but the greatest living observer of double stars is undoubtedly the American astronomer S. W. Burnham, whose zeal and industry have attained colossal proportions, but he has nowadays many fellow-labourers in various parts of the world. Burnham's own experiences have for obvious reasons been somewhat restricted to the Northern Hemisphere with some degrees of Southern Declination included; but a great developement of double-star work is now proceeding at the Cape and in Australia. At the Cape the lead is being taken by R. T. A. Innes, the Director of the recently established Observatory at Johannesburg, in the Transvaal; and, as time goes on, we may expect a large output of work from that centre.

At the end of this volume a list will be given of some of the more interesting and easy double stars adapted for observation by small telescopes.



COLOURED STARS.

1. η Cassiopeiæ, yellow purple; 2. γ Andromedæ, orange, green; 3. α Piscium, pale green, blue: 4. ι Cancri, orange, blue; 5. α Circini, white, brick red; 6. ϵ Bootis, pale orange, pale green.

Many double stars exhibit the curious and beautiful phenomenon of complementary colours. In such cases the larger star is usually more or less reddish or orange, and the smaller one bluish-green or greenish-blue. If complementary colours are noticed in the components of a double star of very unequal size the circumstance may be attributed often to the effect of contrast. Perhaps it may be useful to put on record here a table of the complementary colours, though somewhat of a digression, for the subject is one that belongs to the science of optics rather than to astronomy proper.

Red	is complementary	to	bluish-green.
Orange	,,	,,	sky-blue.
Yellow	,,	,,	violet-blue.
Greenish-yellow		,,	violet.
Green	,,	,,	pink.

The meaning of the foregoing table is this: that if any two colours which are complementary, as above, are put upon a rapidly revolving disc in proper proportions, when the disc is set in motion on its axis a composite tint, almost white, is exhibited to the spectator's eye.

As regards this question of the colours of double stars, an examination made many years ago of the colours assigned, in Struve's catalogue, to 596 of his bright stars, yielded the following results: 375 pairs were of the same colour and intensity; 101 pairs were of the same colour but of different intensity, whilst 120 pairs were of totally different colours.

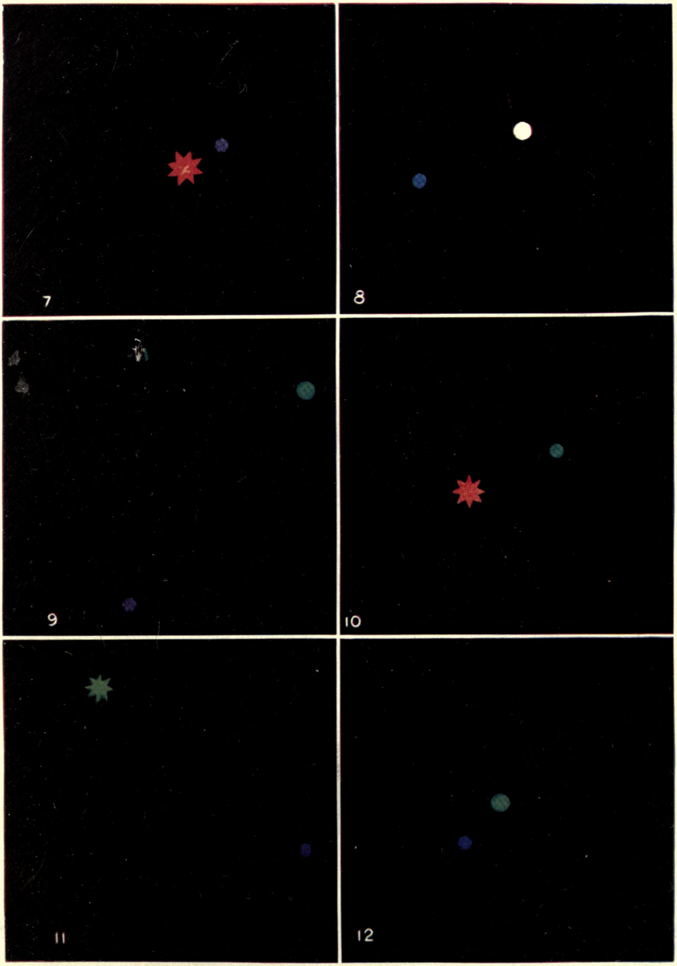
As regards the colours of isolated stars not treated as doubles, an examination of the heavens will lead to its being noticed that single stars of a fiery red or deep orange hue are quite common, but isolated blue or green stars are very rare.

In looking into the expressed opinions of observers who, under various circumstances, have made statements as to the colours of stars, it will be found that frequently great diversity exists—a diversity which is often inexplicable, and which it is hardly permissible to put down to actual changes of colour. Subject to this caution, the following stars may be named as coloured according to the colours prefixed :—

White Stars.—α Canis Majoris, α Leonis, β Leonis, α Lyræ, α Piscis Australis, α Ursæ Minoris.
Red Stars.—α Tauri, α Scorpii, α Orionis.
Blue Stars.—α Aurigæ, β Orionis, γ Orionis, α Canis Minoris, α Virginis.
Green Stars.—α Aquilæ, α Cygni.
Yellow Stars.—α Boötis.

The amateur observer will find it interesting to compare the statement of colours just given with his own ideas on the subject as obtained by naked-eye observations; and I am far from saying that he will be able satisfactorily to confirm the accuracy of the statements made in the foregoing table. There is really only one thing which stands out conspicuously certain in regard to the colours of stars, and that is, the enormous number which are dotted all over the heavens which exhibit various shades of colour intermediate between crimson at one end of the scale and yellowish at the other. An observer who sets himself the task of examining this matter for himself will probably be surprised at the immense number of stars to which he will be able to apply the word "orange" (in various gradations).

Thus far we have been considering single stars and pairs of stars, but the study of sidereal astronomy does not by any means end here, because, when examining the heavens, we come across, as already indeed mentioned, triple, quadruple, and multiple stars; that is to say, stars which to the naked eye appear to be single, but which, with adequate optical assistance, are found to be compound, as these various designations imply. It is not, however, necessary to dwell on these stars, except for the one purpose of stating that, besides there being pairs of stars which we call "binary," because they revolve round one another, and therefore are distinguishable from simple optical



COLOURED STARS.

7. ξ Bootis, orange, purple; 8. ζ Coronæ, white, blue; 9. ϵ Normæ, bright green, bright purple; 10. α Herculis, orange, emerald green; 11. β Cygni. yellow, sapphire blue: 12. σ Cassiopeiæ, pale green, bright blue.

double stars, which are only double in appearance, there are certain triple stars which are subject to the complication that there are three stars in orbital motion. These are known as "ternary" systems. Here we have either 2 stars revolving round one primary, or the 2 smaller stars of the trio revolving round one another, and this subordinate pair jointly revolving round the 3rd, which is really the first, and needs to be called the primary star of the triple system. The possible complications to which such a condition of things brings us face to face are very obvious, and I will content myself by inviting the reader to inspect the diagrams here given without pursuing the matter into further detail.

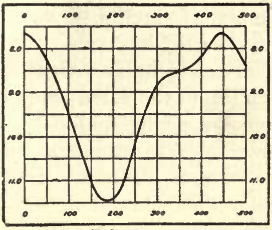
VARIABLE STARS.

Having discussed changes of colour in the stars, the question of changes of brightness naturally comes next, and opens up the subject which bears the recognised title of "variable stars." Suspicions as to changes in the brilliancy of particular stars were long current, but, save in one or two exceptional instances, this branch of sidereal astronomy is of modern origin. Seemingly, the first star to be recognised as systematically subject to marked changes of brilliancy is the star which more than 2 centuries ago received the name of Mira Ceti—a phrase which becomes, when duly spread out, "Mira Stella, the wonderful star in the constellation Cetus," and which supporters of new-fangled pronunciation try to indicate by calling it "Meeray Saytee"! Bayer recorded the star in his Atlas of 1603, and gave it the designation Omicron (*o*), and this is still its accepted scientific title.

This star is one of the most interesting of all the known variables, alike from the regularity with which it accomplishes its changes and the ease with which those changes can be observed by anybody. Its period is 331 days 8 h.; in other words, it reaches its greatest brightness about 12 times in

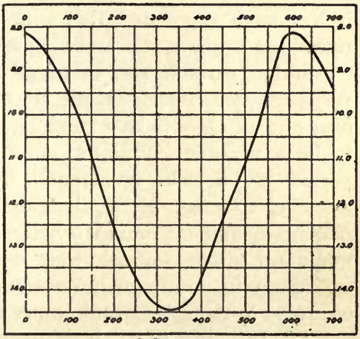
11 years, when it sometimes attains the brilliancy of a star of the 2nd magnitude, at which brilliancy it remains stationary for about a fortnight. It then diminishes during about 3 months, until it sinks down to a star of magnitude $9\frac{1}{2}$, or even becomes totally invisible. It remains in this condition for about 5 months, and then gradually recovers, during the next following 3 months, its maximum brilliancy. The foregoing periods and figures are only to be regarded as average ones, because there is strong evidence that the changes of this star are themselves subject to secondary periods of change; that is to say, that its maximum brilliancy is itself periodical, and that every eleventh maximum is marked by a special display of brilliancy above the average. Hence it follows that, whilst the average duration of the naked-eye visibility is about 18 weeks, in 1859-60 it was observed with the naked eye during 21 weeks, whilst in 1868 it was so seen only during 12 weeks. The variability of Mira was first noticed in 1596 by D. Fabricius.

Another variable star of great interest, perhaps some would think almost more so than Mira Ceti, is Algol (β Persei), the variability of which stands second in point of date, for it seems to have been first recognised by Montanari in 1669, though it was not until observations by Goodricke in 1782 that its period was ascertained with some degree of certainty. This is generally stated in the following form: The normal brightness of the star is that of mag. $2\frac{1}{4}$. From this it descends nearly, but not quite, to mag. 4 during a period of 4 h. 23 m. It remains at its minimum for about 20 m., then in the course of 5 h. 37 m. it regains its normal maximum, and remains there for about 2 d. 10 h. The time occupied in the entire series of changes is 2 d. 20 h. 48 m. The further study which has been given during recent years to the subject of variable stars has resulted in the discovery of a not inconsiderable number which go through their changes in periods measured by a few days, and under physical circumstances akin to those which govern the



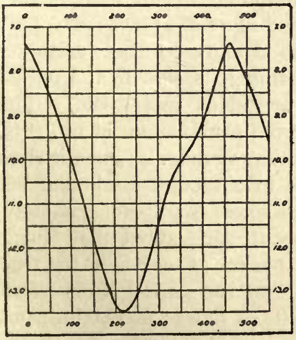
T CASSIOPEIÆ.
0ʰ 6½ – 12

Fig. 264.



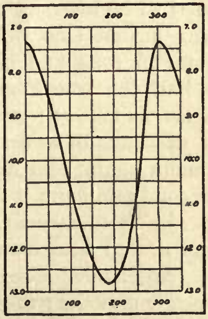
S CASSIOPEIÆ.
1ʰ 6¾ — 13½

Fig. 265.



R AURIGÆ.
5ʰ 6½ — 13

Fig. 266.



R URSÆ MAJORIS.
10ʰ 6 – 13½

Fig. 267.

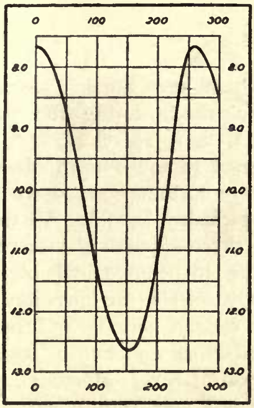
Mean Light-curves of certain Variable Stars.

changes of Algol; and accordingly we now speak of certain stars as "stars of the Algol type"; and by way of explanation it has been suggested that a non-luminous satellite revolves round the primary star and eclipses it at stated intervals.

Another variable star of great interest, which, like Algol, is very handy for observers in the Northern Hemisphere, is δ Cephei, also one of Goodricke's stars, and recognised by him in 1784 to be a variable. Counting from minimum to minimum, its period is 5 d. 8 h. 47 m., and its range of brilliancy from mag. $3\frac{3}{4}$ to mag. $4\frac{3}{4}$, or thereabouts. The interval between maximum and maximum is unequally divided as regards the minimum stage, for the time occupied in descending from maximum to minimum is considerably greater than the time occupied in rising from minimum to maximum. The intervals are 3 d. 19 h. and 1 d. 14 h. respectively.

β Lyræ is a variable which differs very much in the sequence of its changes from those which have just been described, for it has a double maximum and minimum within what is now recognised to be its complete period of 12 d. 21 h. 53 m. This peculiarity misled Goodricke, who discovered the variability of this star in 1784, and induced him to assign to it a period of only half the true complete period as just given. The changes are as follows: starting from a maximum of mag. $3\frac{1}{4}$, the star descends to its first minimum of mag. 4; then it rises to maximum again, and descends to a second minimum, but at this second minimum it descends lower than before, namely, to mag. $4\frac{1}{2}$. It is easy to see how it came about that Goodricke was misled into fixing the period at one-half its true amount. Argelander ascertained that the period itself, taken as a whole, is periodic; that up to 1840 it was increasing, and then began to decrease, which decrease was still in progress when he made that remark in 1866. I do not find any recent observations which throw light upon this point.

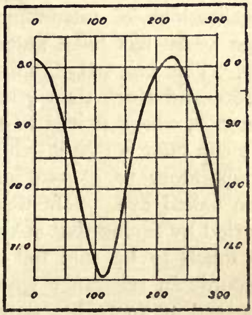
The foregoing stars all belong to the Northern Hemisphere, but the Southern Hemisphere has in η Argûs a once naked-



T Ursæ Majoris.

/12 6½ – 13½

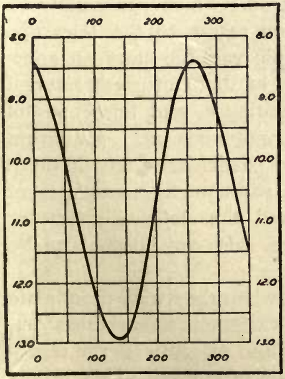
Fig. 268.



S Ursæ Majoris.

/12 7 – 13

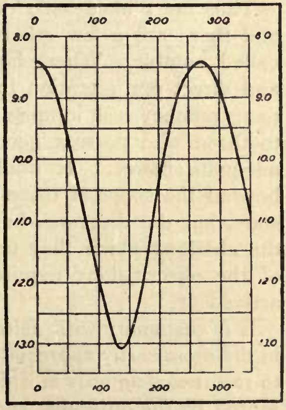
Fig. 269.



S Boötis.

14" 7¾ – 13½

Fig. 270.



R Camelopard

14" 7½ – 13½

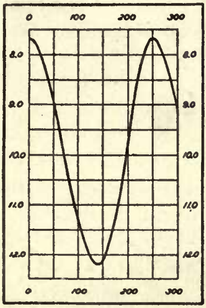
Fig. 271.

Mean Light-curves of certain Variable Stars.

eye variable, the uncertainties of which have puzzled several generations of astronomers. Its magnitude during the past 150 years has been noted as 4, 2, 1, 2, 1, $2\frac{1}{2}$, 3, $4\frac{1}{2}$, 5, 6, 7, $7\frac{1}{2}$. This last magnitude was assigned to the star in March 1886, and since then η seems to have further gone down to mag. 8, where it was in 1907, and probably is still. All that we can infer is that it exhibits two or three maxima at intervals preparatory to a great descent so as to become invisible to the naked eye. Schönfeld summarily settled the question of period by saying that η Argûs has no regular period; and there is much to be said for this unsatisfactory conclusion, which accords in substance with the opinion of Sir J. Herschel, expressed at an earlier date, that this is a star "fitfully variable to an astonishing extent, and whose fluctuations are spread over centuries, apparently in no settled period, and with no regularity of progression."

Thus far I have been dealing with notable naked-eye stars, and there are a few others of that sort which can hardly be called notable. When, however, we resort to the telescope and direct our attention to telescopic variable stars an enormous number rush in upon us, many of them of great interest to those who possess good eyes, patience, and telescopes of adequate power. It would be monotonous and somewhat beyond the scope of these pages to particularise any of these stars, but the diagrams here given will convey some idea of the changes which they undergo and the delicate character of the observations required before safe conclusions can be arrived at.

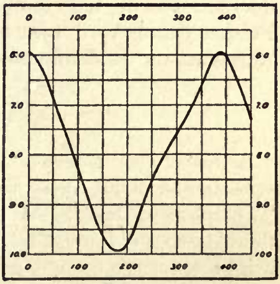
It is customary with astronomers, when they wish to indicate in the most easily appreciated form variations in variable stars, to resort to diagrams in which dates and magnitudes are represented by the ordinates and abscissæ of curves. This brings the changes much more readily home to a reader than mere tables of figures. Figs. 264 to 275, record the changes which were noted to have taken place in certain well-known



R Draconis.

16ʰ 7 — 13<

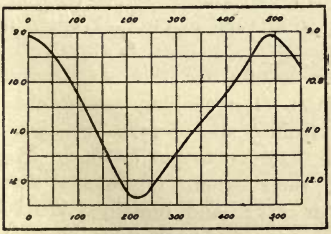
Fig. 272.



T Cephei.

21ʰ 3½ — 10

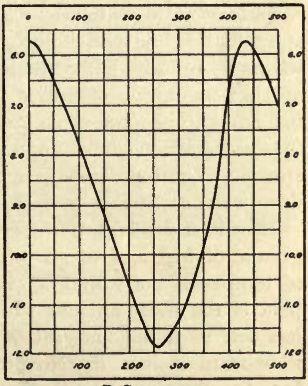
Fig. 273.



S Cephei.

21ʰ 7½ — 11½

Fig. 274.



R Cassiopeiæ.

23ʰ 4¾ — 13<

Fig. 275.

Mean Light-curves of certain Variable Stars.

variable stars at the dates stated, whilst Fig. 276 records the fluctuations in the temporary star *Nova* Persei between February and April 1901 as recorded at Oxford by Mr. A. A. Rambaut, the Radcliffe observer.

TEMPORARY STARS.

A branch of sidereal astronomy which has much of the sensational about it is that which is covered by the title "Temporary Stars." At many epochs in the world's history there have suddenly burst forth in the heavens, and shone as bright stars for limited periods of time, stars which probably ought not to be called stars at all. Some of the objects thus recorded by old monastic and other writers undoubtedly were only mere luminous meteors, or fireballs, and a few of them comets; but, apart from these objects we have trustworthy records of stars suddenly becoming visible in places where no stars had been seen before, and which remained visible for weeks or months before their final disappearance. The cases are not numerous of a star suddenly appearing and rising in brilliancy to become conspicuous, for it has been more common for a conspicuous star to appear suddenly in a place where no star had been previously seen, and then at once to begin a downward career.

It will be prudent, if we desire to take our stand on the firm ground of fact, not to go too far back in seeking for instances of temporary stars, and Tycho Brahe's star of 1572 in Cassiopeia is the most ancient which I desire to put forward. He has left us a full account of it, the substance of which is that it became visible in November 1572, and remained visible for 17 months, or till March 1574. At its best it was brighter than Sirius, and rivalled Venus. Tycho Brahe, having no telescope, of course lost the star as soon as it descended below the 6th magnitude, and nobody seems to have seriously attempted to look into the matter until D'Arrest, in 1864, published a map of an area in Cassiopeia which was supposed to include the place of Tycho's star. Argelander, having assigned a position to the star, pointed out that there was a little star almost exactly in the right place, and Hind and Plummer followed this up in 1873 by stating that this little star was variable. There the matter remains, no one apparently having attempted to follow it up since. The exact position of Tycho's

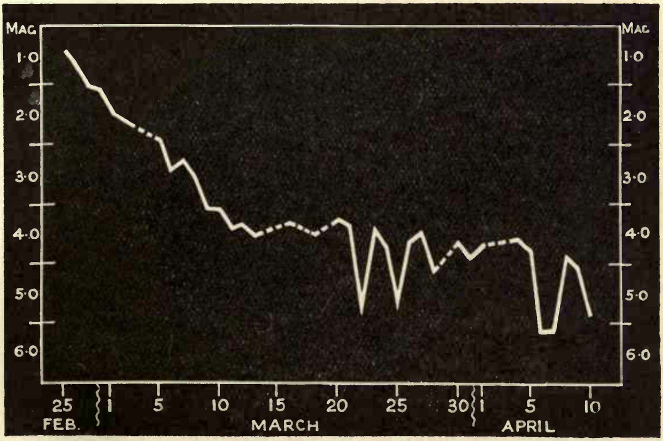


Fig. 276.—Light Changes in Nova Persei, 1901.

star, as given by Argelander, brought up for precession to January 1, 1913, is as follows:—

	h. m. s.		
R.A. .	0 19 56	Declination .	63° 40·0′ N.

The reason that some attention was given to the subject in 1873 was that the theory was current that Tycho's star was a reappearance of objects alleged to have been temporary stars, and visible in 945 and 1264; so that, if those objects had been temporary stars, there was the slight possibility (very slight) that Tycho's star was the reappearance of a variable star whose period was 300 years, more or less. But all this would seem to be an argument devoid of foundation, and there is no solid reason whatever for suspecting that Tycho's star was to reappear after the lapse of three centuries.

The year 1604 was marked by the appearance of a temporary star in the constellation Ophiuchus, which became nearly as bright as Venus, and lasted a year or more. Kepler wrote a book about it which has come down to us.

In 1670 a new star appeared in Cygnus, which rose to the brightness of a star of the 3rd magnitude, and lasted two years from first to last, during which period it more than once increased in brightness, and then diminished, before it finally disappeared.

A long interval elapsed before we had another new star. On April 28, 1848, a 5th-magnitude star was seen by Hind in Ophiuchus, which a few weeks later rose to the 4th magnitude, and then descended to the 11th or 12th magnitude, at which it may or may not still be.

May 1866 gave us a new star, which created a considerable sensation because of the sudden outburst which characterised it. As a star of mag. 9½ it was recorded by Argelander in 1855, but Birmingham, at Tuam, in Ireland, saw it on May 12, 1866, as a star of mag. 2. Combining the negative testimony of Schmidt, of Athens, with the positive testimony of Birmingham, it would seem that this star suddenly rose from the 4th to the 2nd magnitude in about three hours on the evening on which Birmingham saw it. It soon began to fade away, and by the end of the month had fallen to mag. 8. It continued below magnitude 9 all through the following summer, but rose to 7½ in September, and was nearly stationary in brightness for the remainder of the year.

QVADRANS MVRALIS SIVE TICHONICUS.

Fig. 277.—Tycho Brahe's Mural Quadrant for measuring Vertical Angles.

This star is now permanently put upon the list of variable stars under the designation of T Coronæ; but it seems to have been ignored by variable-star observers during recent years.

On November 24, 1876, Schmidt, at Athens, observed a new star of the 3rd magnitude in Cygnus, yellowish in colour. By the end of December it had descended to the 7th magnitude, and afterwards became still smaller. The last recorded observation of it which I have been able to find is dated September 2, 1877, when the spectrum was reduced to a single line, the continuous spectrum and all the other lines having disappeared.

August 1885 saw the outburst in the constellation Andromeda of a new star, which created at the time a great deal of excitement. This excitement was largely due to the position of the star, which, seemingly in the great nebula, was not of it, having the appearance of standing out sensibly in front of the nebula. When first seen, which appears to have been on August 22, or a few days previously, the star was of about the 6th magnitude. It never got beyond that, and rapidly began to decline until it reached about the 11th magnitude, and then it became visually lost in the nebula, though from first to last the impression conveyed on those who viewed it, including myself, was that it had nothing to do with the nebula itself.

Later in the same year, on December 17, J. E. Gore found a new star in Orion which, during its visibility, passed from mag. 6 to mag. 9, or less, and then disappeared, and afterwards again came into view, and is now permanently enrolled as a variable star, though no explanation can be offered of its sudden increase of light in the month in which it was first found. It is now known as U Orionis.

Early in 1892 a new star appeared in the constellation Auriga, the circumstances connected with which are highly interesting. The fact of the star's existence was communicated to Dr. Copeland, Director of the Observatory of Edinburgh, by means of an anonymous postcard, which led him at once to search for and find the star, which he was told was of the 5th magnitude. The authorship of the postcard was afterwards avowed by a certain Dr. Anderson, who found the star by means of McClure's edition of Klein's *Star Atlas*, used in conjunction with a small pocket-telescope.

When news of the discovery was conveyed to the other side of the Atlantic, Professor Pickering, of Harvard College Observatory, found that Anderson's star had been photographed by him 13 times between December 10, 1891, and January 20, 1892. He considered that his plates took all stars down to the 9th magnitude, and that, as the new star did not appear on the plate of December 8, it must have brightened up between December 8 and December 10. The new star, henceforth known as *Nova* Aurigæ, remained of the 4th or 5th magnitude till the end of February, when it rapidly diminished, and on April 26 was no more than of the 16th magnitude. Later on in the summer it brightened up to about the 10th magnitude, and then fell again to the 12th magnitude.

In 1901 a new star appeared in Perseus, which lasted a long time, and underwent various and noteworthy changes. There is some little uncertainty as to who first discovered it. It seems to have had several independent discoverers on February 22, but the first public announcement was made by Dr. Anderson of Edinburgh, the discoverer of *Nova* Aurigæ nine years previously. It is interesting to add that it was also discovered on the same night, February 21, at Kieff, in Russia, by a boy 16 years of age named Borisiak. When Dr. Anderson first saw the star he put its magnitude at $2\frac{3}{4}$, whilst Borisiak, perhaps erroneously, called it $1\frac{1}{2}$. The evidence as to its history seems to show that on February 20 the star had not become visible. After February 22 it became a very bright 1st-magnitude star, though it only remained such for a day or two, and by March 18 had descended to the 4th magnitude, which in June had become the 6th magnitude, and at the end of the year the 7th. These changes were not regular, because its brilliancy oscillated several times. The final history of this Nova was very remarkable, because it seems to have either turned into a nebula, or, in some mysterious way, to have given birth to one ; but the details as to this would occupy too much space for these pages.

Other new stars of recent date are the following: *Nova* Lacertæ, discovered on December 30, 1910, by the Rev. T. E. Espin ; *Nova* Sagittarii, discovered photographically in September 1899 at Arequipa, in Peru, but the fact not known till an examination of the plates in 1911 ; *Nova* Geminorum, discovered in March, 1912, by Enebo at Dombaas, in Norway. It showed spectroscopically the characteristic hydrogen bands, accompanied by dark bands on the side towards the violet.

Professor E. C. Pickering, in 1881, proposed the following classification to link together all the stars which come under the designation of " temporary " or " variable " stars :

1. Temporary stars. Examples: Tycho Brahe's star of 1572, new star in Corona 1866.

2. Stars undergoing great variations in light in periods of several months or years. Examples: o Ceti, and χ Cygni.

3. Stars undergoing slight changes according to laws as yet unknown. Examples : α Orionis and α Cassiopeiæ.

4. Stars whose light is continually varying, but the changes repeated with great regularity in a period not exceeding a few days. Examples: β Lyræ and δ Cephei.

5. Stars which every few days undergo for a few hours a remarkable diminution in light, this phenomenon recurring with great regularity. Examples: β Persei and S Caneri.

In the case of stars belonging to class 5, the observed variations could be very satisfactorily explained by the theory that the reduction in light is caused by a dark eclipsing satellite.

The foregoing accounts of recent new stars will suffice to give the reader a general idea of what these objects are, and I hope to bring it home to amateur astronomers that, if they choose to avail themselves of opportunities which from time to time occur, they may often be able to render useful service to science, and, at the same time, to earn some credit and distinction for themselves.

CHAPTER XII.

GROUPS OF STARS AND NEBULÆ.

Stars in groups classified.—Irregular groups.—Clusters of stars more or less compressed.—Nebulæ.—Classification of nebulæ.—Annular nebulæ.—Elliptic nebulæ.—Spiral nebulæ.—Planetary nebulæ.—Nebulous stars.—Large nebulæ of irregular form.—Exemplification of these classes named.—Distribution of nebulæ and clusters over the heavens.—The Milky Way.—Brief description of its position.—Its historic names.

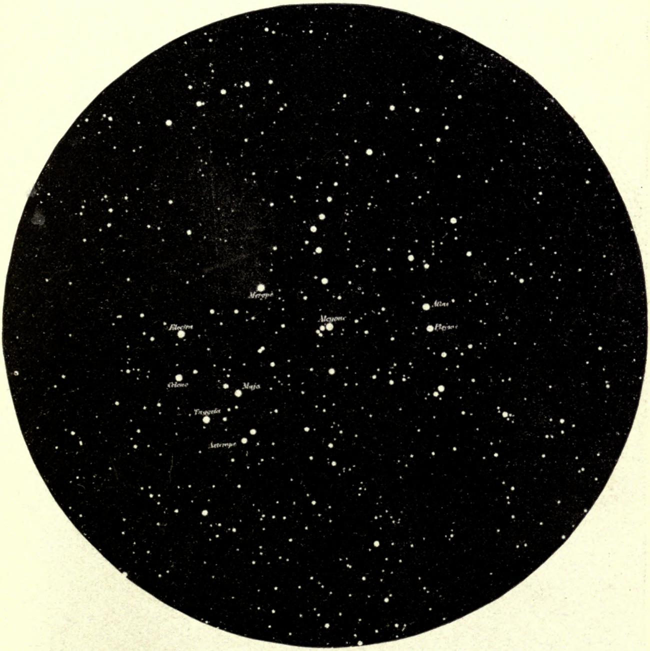
HAVING started in the previous chapter with single stars and gradually got up to multiple stars—which phrase may be said to mean, say, half a dozen stars under one roof, as it were—we must now pass on to groups of stars which are to be met with in the heavens in great numbers and embracing all gradations of quantity from a few dozen up to literally myriads, according to the Greek use of that word.[1]

The variety of these groups to be found in the heavens is very great, both as regards the number of the stars composing the groups, and also as to their general shape. We may conveniently consider the objects now to be described under three general heads, the third of which will need special subdivision by itself. The three main divisions may be as follows :—

(1) Irregular groups, many of them visible to the naked eye.

(2) Clusters of stars more or less compressed and sym-

[1] μύριοι = ten thousand, also "countless."



The Pleiades (*Tempel*).

With the Nebula near Merope.

Nebulæ in the Pleiades, Dec. 8, 1888 (*Isaac Roberts*).

metrical, and resolvable into separate stars with adequate optical assistance.

(3) Nebulæ for the most part irresolvable, however powerful may be the telescopes which are brought to bear on them.

The third class may be subdivided as follows, the subdivisions having regard chiefly to differences of shape.

(i) Annular nebulæ.
(ii) Elliptic nebulæ.
(iii) Spiral nebulæ.
(iv) Planetary nebulæ.
(v) Nebulous stars.
(vi) Large nebulæ of irregular form.

The foregoing classification may be considered as comprehending all the known clusters and nebulæ; but the reader must be warned beforehand that only a few objects in some of the classes, and none in the other classes are at all within the reach of the comparatively small telescopes which the readers of this work are supposed to possess.

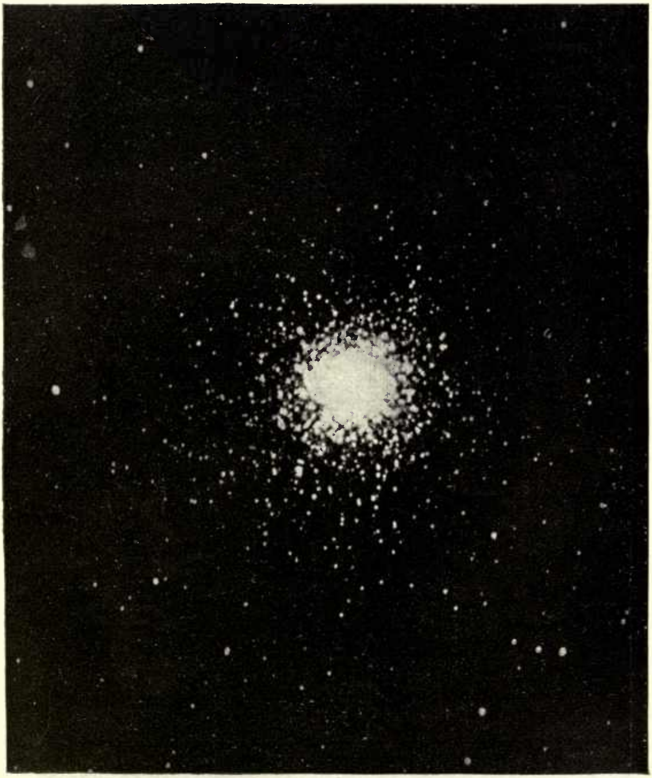
Many of the objects in class (1) are more or less non-telescopic, so to speak; that is to say, are too large and scattered to be advantageously viewed in any telescope other than a low-power opera-glass with a very large field.

The Pleiades and Hyades, both in Taurus, are undoubtedly the best known of these groups. Indeed, so old are they historically that the first mention of them begins with Homer. The tradition is well known, and as old as Ovid, that there were originally 7, but that one of them has been lost. The origin of this idea is unknown, and it would seem that one ought to say that the tradition is scientifically untrue, because, not only can 7 still be counted, but a good many more. This group is really a very good test of eye-sight, because, whilst ordinary eyes often do not get beyond six in the counting, good eyes and extra good eyes can get up to 8, 10, or even 12. A proof that there is nothing magical in the number 7 is found in the fact that 9 of the stars have for unnumbered centuries borne specific names, which, with their magnitudes, are as follows: The brightest is known as Alcyone (*alias* η Tauri) of the 3rd magnitude; next come Electra and Atlas, both $3\frac{3}{4}$; then Maia 4, Merope $4\frac{1}{4}$, Taygeta $4\frac{1}{2}$, whilst Celeno, Asterope, and Pleione are all much about the same size, say mag. 6. But besides these more or less conspicuous members of the group, several dozen stars of smaller size are revealed in the telescope. There is a matter connected with the Pleiades which is somewhat mysterious. In 1859 a well-known observer, Tempel, noticed amongst the group an object which he took to be a telescopic comet; but, as it was afterwards found to be a fixture, and not to be moving, it was clear that it was not a comet, but a nebula which had suddenly manifested itself. As time went on and attention was given to the subject it became certain, not only that Tempel had observed a genuine nebula, but that nebulous matter was to be seen in various parts of the cluster, no less than five of the chief stars (Alcyone, Electra, Maia, Merope, and Celeno) being involved in nebulosity. It seems certain that this nebulous matter has only come into view during the past half-century, but it is impossible to offer any explanation of the fact.

The Hindoos call the Pleiades "The Hen and Chickens." The Australian black-fellows call them "Meamei" = "The Seven Sisters." In *Don Quixote* Sancho Panza describes his fancied ride through space, saying: "We happened to travel that road where the seven she-goat stars were"; and the Don adds: "It was impossible for us to reach that part where are the Pleiades, or the seven goats, as Sancho calls them."

The Hyades constitute a group of stars altogether inferior to the Pleiades in interest, not only because the stars are smaller, but because they are much scattered. Still, they must be treated as being a group, and they have been recognised as such for many centuries.

In the constellation Cancer we have another historic group



The Cluster 13 M. Herculis (*W. E. Wilson*).

ω Centauri.

known as Præsepe, which makes a very effective show in a telescope of large field and low power. This object is sometimes met with in old scientific books under the name of the "Bee-hive," but that name, as well as its Latin name, is lost in antiquity. Fully 2000 years ago it was recorded by two Greek authors as available to indicate the approach of rain, the idea being that, under such prospect, the group lost its sharp stellar appearance and became misty.

The constellation known as Coma Berenices is made up of a number of stars which, though it may be named in connection with the three preceding groups, has its constituent stars too scattered to be quite fairly comparable with them.

We must now proceed to consider the objects which are included under the second of the main heads already specified, namely, Clusters of Stars. These are of various sizes and shapes. Many of them appear in small telescopes as nebulæ and nothing else, but in some cases even a small amount of additional optical power renders it easy to see that the seemingly nebulous mass really consists of a number of separate stars. A certain number of the objects belonging to the class which we are now considering are specially labelled "Globular Clusters." They have received this name because they present the appearance of stars massed together as globes, though the causes which gave them this form and keep them retaining it are unknown. The most striking object of this character in the Northern Hemisphere is the cluster known as 13 M. Herculis for which the Southern Hemisphere provides a magnificent counterpart in the clusters surrounding the Stars ω Centauri and 47 Toucani.

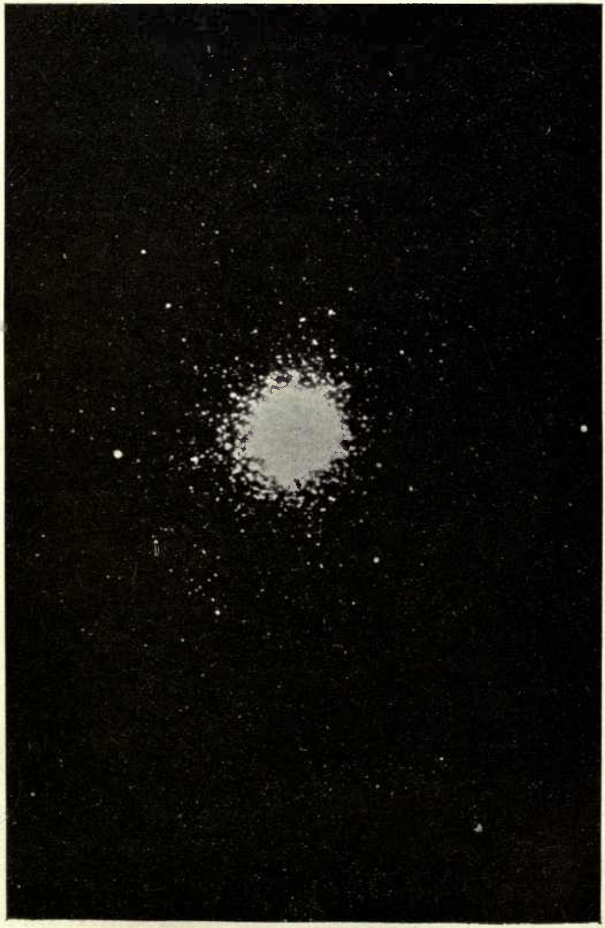
The letter M. attached to the cluster in Hercules, just named, deserves explanation. It stands for the initial of the surname of a famous French astronomer, Messier, who earned the thanks of posterity by cataloguing, nearly a century and a half ago, all the objects in the heavens which he was able to observe in a telescope with an aperture of only 2 inches.

With such a telescope he was naturally unable to realise very distinctly the difference between the objects which we now call clusters and those which we call nebulæ; and he lumped all together under the comprehensive title "Nebulosities and Masses of Stars." His labours, notwithstanding that his opportunities were limited, are still of use to us in so far that, whenever we come across a cluster or nebula with Messier's number and letter prefixed to it, we know at once that it can be seen with a small telescope, however imperfectly.

Smyth described 13 M. Herculis as "an extensive and magnificent mass." Sir J. Herschel saw signs of its stars forming curved lines, which feature Lord Rosse interpreted as indicating a spiral formation. I have not myself seen ω Centauri or 47 Toucani, and therefore cannot speak of them from personal knowledge; but, judging by the language used by those who have seen them, they must be magnificent objects, surpassing the cluster in Hercules. Indeed, Pickering expressly describes ω Centauri as "undoubtedly the finest in the sky," and 47 Toucani as "second only" to ω Centauri.

Next to this as regards the clusters visible in England seems to come 5 M. Libræ, very accurately described by Webb as a "beautiful assemblage of minute stars greatly compressed in the centre." Sir W. Herschel counted not less than 200 stars in it, whilst Smyth's description is very accurate in saying that it has "out-liers in all directions and a bright central blaze." Messier committed himself to an opinion respecting this cluster which illustrates a remark which I have already made, that these objects vary much in appearance, according to the size of the telescope employed in viewing them. We shall see presently many proofs of this. Meanwhile, Messier's remark respecting 5 M. Libræ should be posted up as a caution to men of science. "He assured himself that it did not contain a single star."

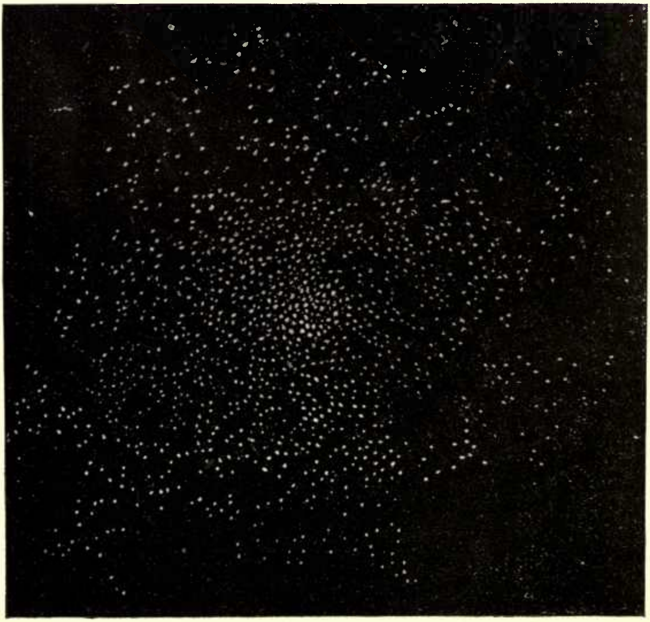
Other clusters of the type of those which have gone before will be found amongst the list in the Appendix.



47 Toucani.

2 M. Aquarii. **5 M. Libræ.**

(*Sir J. Herschel.*)



2 M. Aquarii (*Earl of Rosse*).

This picture shows how a large telescope opens out the stars which appear squeezed together in a small telescope.

Respecting one of these globular clusters, 80 M. Scorpii, a singular circumstance is on record. In 1860 a well-known observer Pogson, directing his telescope to a part of the heavens which should have included the cluster, found that it had disappeared, and that a 7th-magnitude star was occupying its place. A fortnight later the star had disappeared and the cluster was again visible, presenting its normal appearance. These changes were also noticed by two German observers, and therefore there can be no doubt about their reality. It seems impossible to suppose that any physical change had taken place in the cluster, and the conclusion is therefore inevitable that the star was a temporary one, quite independent of the cluster, which had burst out in front of it and lasted a very few days, and had then disappeared, owing to the operation of some unknown cause or causes.

Of clusters, not globular, but large and attractive, 67 M. Cancri may be named as noteworthy. But by far the most striking and beautiful of the loose and irregular clusters in the heavens, probably that which surrounds the star κ Crucis is the finest. Sir J. Herschel, when at the Cape in 1833 and following years, observed this cluster and described it as one of the most beautiful of its class. Some 40 years later, Russell, at the Sydney Observatory, carefully charted its stars, with the result that he found that many of them in the 40 years' interval had moved from Herschel's position, and in consequence (it was to be assumed) of their being endued with proper motion. Russell's description of the cluster is as follows: "The colours of this cluster are very beautiful, and fully justify Herschel's remark that it looks like a 'superb piece of fancy jewellery.'"

We will now pass on to the nebulæ, properly so-called, the number of which has been greatly augmented of recent years. Sir W. Herschel developed Messier's catalogue of 103 objects into hundreds, which Sir John Herschel's labours at the Cape and elsewhere brought up to thousands. In 1864 he published a complete general catalogue of all those then known, which numbered 5079 objects. This catalogue seems to have stimulated the developement of this branch of sidereal astronomy, because when Dreyer republished Sir John Herschel's catalogue revised, corrected and enlarged, the new edition comprised 7840 objects; and this number has since been largely added to, especially by work in America, and as the incidental result of searches for new comets and double stars.[1]

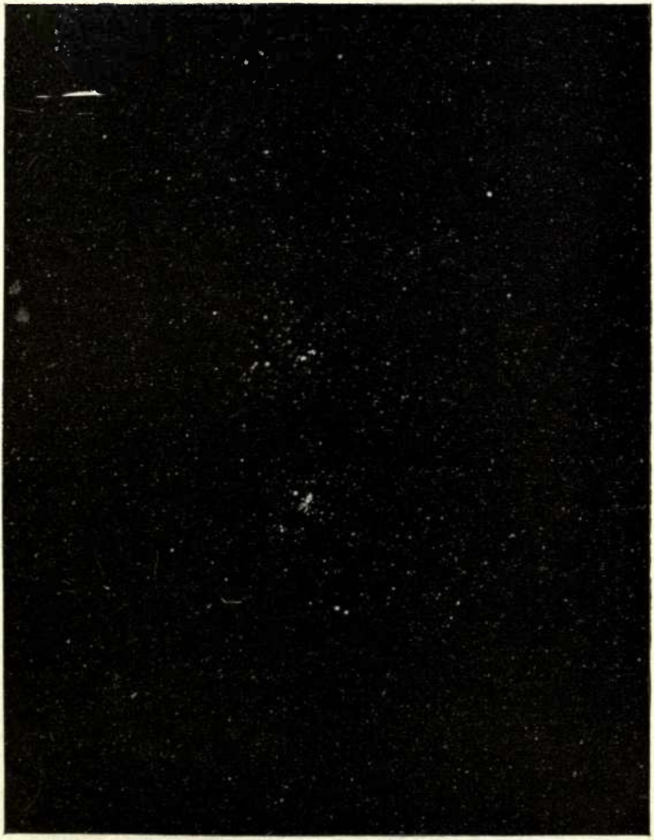
It should be clearly stated that, for the profitable examination of nebulæ of all kinds, large telescopes are indispensable, and that the number which can be viewed even with moderate satisfaction in small ones is very limited; but, in order to present a complete survey of these objects, according to the classification laid down on a previous page, I shall be obliged to name a certain number which are hopelessly beyond the reach of small telescopes.

Of "Annular Nebulæ" the heavens afford only a few examples —scarcely a dozen in all. The most remarkable is 57 M. Lyræ, situated about midway between β and γ Lyræ, and the only annular nebula within reach of a telescope of moderate power. Sir J. Herschel described this as having the appearance of a flat, oval, solid ring with the central vacuity not quite dark, out "filled in with faint nebula like a gauze stretched over a hoop." Lord Rosse, Chacornac, and Secchi, all claimed to have resolved this object into stars, whilst Huggins asserted that it was wholly gaseous.

This question of gaseous nebulæ seems to me one of great difficulty in several respects, and I must confess myself not to be satisfied with many of the claims put forward based on spectroscopic observations.

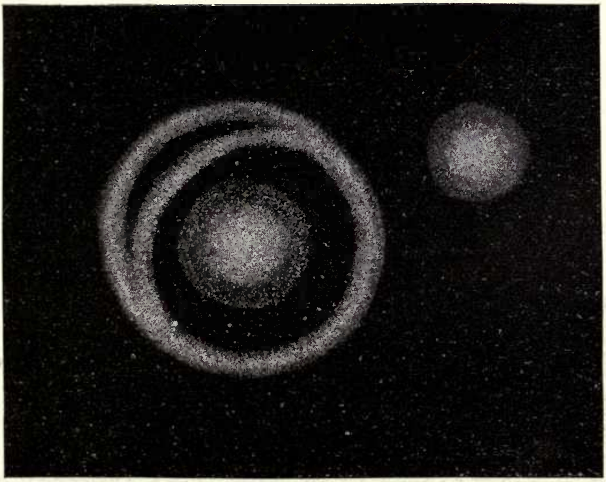
"Elliptic Nebulæ" of various degrees of eccentricity are not uncommon, but there is only one conspicuous large one, namely,

[1] If I do not make use anywhere of the phrase "white nebulæ," which some writers have recently tried to acclimatise, it is because I think it an unnecessary and illogical phrase. Practically all nebulæ are "white."

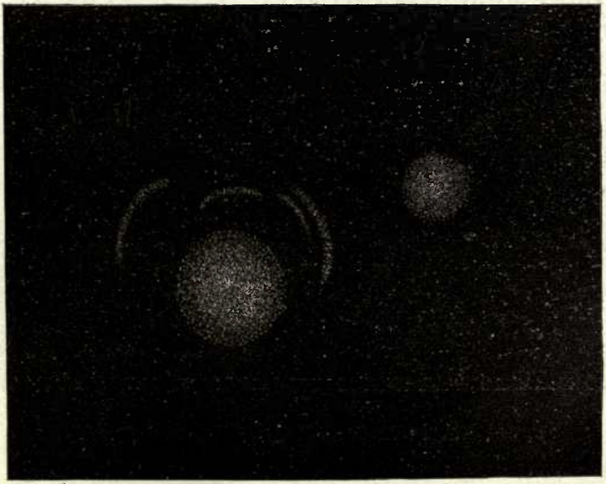


The Clusters 33 and 34 ℍ VI. Persei (*A. A. Rambaut, Radcliffe Observatory, Oxford*).

The Great Nebula in Andromeda (*H. J. Shepstowe*).



(Sir J. Herschel.)



(Smyth.)

The Spiral Nebula 51 M. Canum Venaticorum.

Spiral Nebula in Ursa Major (*H. J. Shepstowe*).

the "Great Nebula in Andromeda" (31 M.). Its elliptic outline is shown in a small telescope, and the nebula is sufficiently large and bright to be seen in any small telescope; but instruments of great size are required to show the curious details of rifts or black streaks which run nearly parallel to the major axis of the oval on the S. side. Taken as a whole, the nebula must be pronounced as irresolvable, and certainly non-gaseous, and a considerable number of isolated stars are to be found within its limits. There is no other elliptic nebula within the reach of small telescopes, and therefore it is not much use my pointing out that there are several which have double stars at or near each end of the ellipse, which in these cases is very elongated compared with its breadth.

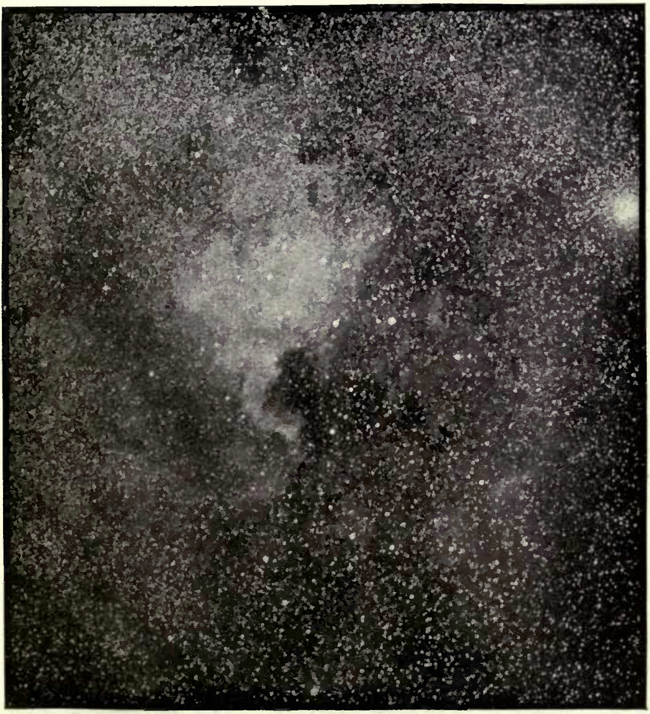
The existence of the class of nebulæ known as "Spiral" or "Whirlpool" nebulæ was first made known by the 3rd Earl of Rosse when he brought his great reflectors at Parsonstown to bear on these objects. Two or three in particular of those whose structure was discovered by him are well known because they have been engraved in a great number of books; but the observations and researches of recent years, especially those of Huggins and Roberts, have rendered it probable that masses of nebulous matter, and indeed aggregations of stars generally assuming a spiral form, are much more common than was supposed when Lord Rosse brought to an end his own discoveries in this field.

The two most important spiral nebulæ, determined to be such by Lord Rosse, are those known as 51 M. Canum Venaticorum, and 99 M. Virginis. The former exemplifies in a very remarkable degree, not only the changes which take place in the appearance of clusters and nebulæ according as they are viewed through small or large telescopes, but also the danger of jumping at conclusions and using dogmatic language in dealing with these matters. Figs. 288 and 289 represent this nebula as drawn by Admiral Smyth, Sir J. Herschel and Lord Rosse respectively, whilst Fig. 290 supplies a photographic view.

Except for the direct evidence of the fact which is available, it would be difficult for any chance spectator to suppose that all these pictures represented the same object. In the case of 99 M. Virginis, the spiral form may be said to be so obtrusively obvious in Lord Rosse's sketch, as not to need even a moment's argument. An inquiring mind will naturally ask the question, What meaning is to be attached to the spiral formations in the heavens which are here brought under notice? I must frankly admit that I am not prepared with an answer to this question; which becomes still more difficult when we call to mind the fact that an American observer, Holden, speaking of a planetary nebula (presently to be described), says that it "is apparently composed of rings overlying each other, and it is difficult to resist the conviction that these are arranged in space in the form of a true helix"—another way of expressing the idea of a spiral being concerned.

The term "planetary" was applied by Sir W. Herschel to certain nebulæ, small in number and, with one special exception, small in size, which exhibit the appearance of discs having well-defined edges, either circular or slightly oval and of uniform luminosity, which features caused them to offer considerable resemblance to certain of the planets. 97 M. Ursæ Majoris is the most striking of these, as it is also the largest, for it has a diameter of 2′ 40″. Lord Rosse's picture of it evidently justifies the name of "Owl Nebula" which he gave to it, albeit his picture negatives the general description of these planetary nebulæ with which I started at the commencement of this paragraph. The planetary nebula which I mentioned just now as presenting the features of a helix is 37 ♅ IV. Draconis, as viewed in the Lick telescope; but of course no ordinary telescope will bring out the details which Holden has described.

Planetary nebulæ seem to possess some peculiarities which differentiate them from nebulæ generally. The great majority of them are situated in, or close to, the Milky Way; they are much more numerous in the Southern Hemisphere than in the



The Nebula 4620 h = 58 ♅ VIII. Cygni (*E. E. Barnard*).

The Nebulæ 81 and 82 M. and a nebulous Star in Ursa Major (*Isaac Roberts*).

Northern ; they are most of them gaseous, according to spectroscopic observations ; and many of them seem to exhibit a bluish tinge of colour.

"Nebulous stars" can only be described as stars which are surrounded by—or, perhaps it will be better to say which seem to be surrounded by—nebulous matter symmetrical or circular in outline. Hind remarked that the stars thus enveloped "have nothing in their appearance to distinguish them from others entirely destitute of such appendages." The brightest nebulous star, recognised as such, is ι Orionis, of mag. 3½ ; though the star which is generally named as the most representative of its class is 45 H IV. Geminorum, which Sir John Herschel described as an 8th-magnitude star "exactly in the centre of an exactly round bright atmosphere 25″ in diameter." There are not many of these stars known, and the few there are cannot be usefully observed except with large telescopes.

(*Sir J. Herschel.*) (*Earl of Rosse.*)

Figs. 293 and 294.—Planetary Nebula 97 M. Ursæ Majoris.

Generally known as "The Owl Nebula."

The 6th and last class of nebulæ which require notice are altogether of irregular form and large size. Though most of them which will now be mentioned are discernible in small telescopes, yet here, again, instruments of great light-gathering power are indispensable for their satisfactory examination.

Mention has already been made of the "Great Nebula in Andromeda," which, for some reasons, might with propriety be enrolled in the class which we are now considering, especially on account of its size and brilliancy, and because its elliptic form, which was the reason for including it under the head of elliptic Nebulæ, disappears almost entirely with optical assistance on a large scale.

Subject to this remark, the "Great Nebula in the Sword-handle of Orion" must be put first in importance in any list of irregular nebulæ. Its size and brightness led to its discovery very soon after the invention of the telescope, and it has received more attention from the pens and pencils of astronomers than any other object in the sidereal heavens. The first feature which immediately forces itself on our attention when it is looked at is the singular vacuity which is called "The Fish's Mouth," from its supposed likeness to the mouth of various sorts of fish. This is no sooner seen than the second object to attract attention immediately does so, namely, "The Trapezium" of stars, the most important of which is θ Orionis, which, on account of its near neighbours, is generally spoken of as a "multiple star." The largest member of the family being θ, the use of the word "Trapezium" naturally implies that there are three other stars close at hand to make up the figure which geometricians call a trapezium: but this is not the end of the matter.

Whilst any small telescope will reveal without much difficulty the 4 special stars, a 5th and 6th come into view when more telescopic power is available; indeed, these 5th and 6th stars constitute a very good test of telescopes of 5 or 6 or more inches of aperture. But it is claimed that three more stars exist in or closely adjacent to the Trapezium, bringing up the total number to 9. The existence of these 3 supplementary stars rests especially on the authority of Huggins, and has been vehemently disputed. A fair summary of the situation appears to be this: that there are other stars in or close to the Trapezium; that they are variable; and that the 6th star itself is variable. This last statement seems undoubtedly true, and, if the 3 smaller stars are also variable, we have a com-

The Great Nebula in Orion (Harvard College Observatory).

The Great Nebula in Orion (*W. E. Wilson*).

plete explanation of the contradictions which have been indulged in on the subject. This nebula, as a whole, illustrates in a striking degree the discordances which constantly present themselves between hand-drawings of sidereal objects and photographs. The hand-drawings of this nebula all fail to do more than convey the idea of its being a flat patch of nebulous matter. Or, if this statement is too definite, it must certainly be said that they fail to convey any sufficient indications of the flocculent texture which is such a special feature of all the photographs which I have ever seen. It is the existence of masses of seemingly flocculent material which makes it so difficult to accept the theory that nebulæ, such as this one, are masses of incandescent gas.

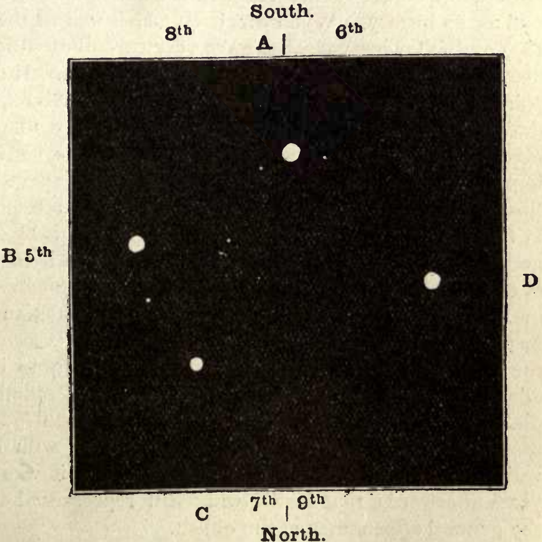
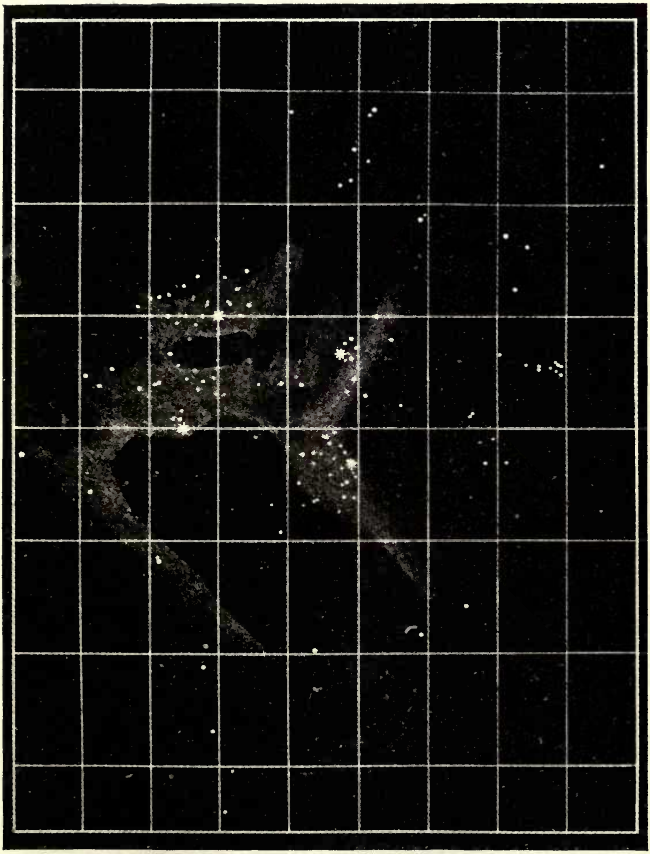


Fig. 297.—" The Trapezium of Orion," Jan. 1866. (*Huggins.*)

The nebula known as 30 Doradûs is a very singular one, owing to the strange convolutions of the nebulous matter, which almost defy description. It is faintly visible to the naked eye, of course as a mere patch, within the limits of the Nubecula Major, to be presently described.

The nebula surrounding the star η Argûs is another very remarkable object—remarkable alike from its special features as well as its history. When Sir J. Herschel was at the Cape in 1833 and following years, he gave very careful attention to this nebula and to the position of the chief star in it. He specially pointed out a void space in the middle of the nebula, and that the star was wholly surrounded by nebulous matter. He remarked that "It is not easy for language to convey a full impression of the beauty and sublimity of the spectacle which this nebula offers as it enters the field of the telescope (fixed in R.A.) by the diurnal motion, ushered in as it is by so glorious and innumerable a procession of stars, to which it forms a sort of climax." Some sensation was caused in astronomical circles in 1863 by a statement, put forth by a Tasmanian observer named Abbott, that the void space had altered in form, and that the star η no longer had nebulous matter close up to it. These allegations were proved to have been quite unfounded, and it is difficult to realise how Abbott could have been led to make them. Herschel had published, in connection with his observations, a careful drawing of the nebula, and it was found, 50 years afterwards, that his drawing still represented accurately the general appearance of the object.

The nebula 20 M. Sagittarii is the chief member of an important group which, perhaps, would be better described as a single mass of nebulous matter pieced together and exhibiting a strange shape. Its special feature is a "three-forked rift or vacant area, abruptly and uncouthly crooked, and quite void of nebulous light." This is Sir J. Herschel's description of it, and he goes on to say that a beautiful triple star "is situated precisely on the edge of one of these nebulous masses, just where the interior vacancy forks out into two



The Nebula surrounding η Argûs (*C. E. Peek*, 1882).

The Nebula surrounding η Argûs.

channels." This nebula is sometimes called the "Trifid Nebula in Sagittarius."

It is unfortunate that Sagittarius should be a constellation not very favourably situated for observation in England, for in the nebula 8 M. Sagittarii we have another striking object of a very diversified shape, and which is a mixture of nebula and stars in the same field. It is an interesting question in regard to cases such as this whether any relations subsist between the nebulous matter and the stars; that is to say, whether the stars are actually connected with the nebula, or are merely optically superposed in front of it. The question is one which, in general, can only be dealt with as a matter of individual opinion. I have already stated on a previous page the strong conviction that, in the case of the temporary star which burst forth some years ago in the great nebula in Andromeda, in viewing the star, we were looking at an object which happened to be in front of the nebula, and had no connection with the nebulous mass which we saw in the background. The nebula 8 M. Sagittarii may be detected by the naked eye; but, of course, a telescope, and one of some power, is needed to bring out its features.

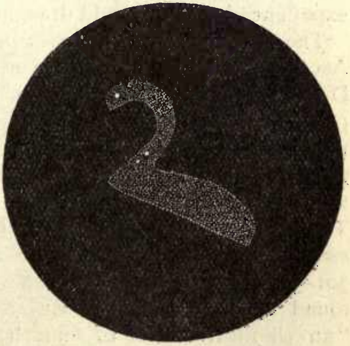


Fig. 300.—The Nebula 17 M. Clypei Sobieskii (*Chambers*).

In the constellation known indifferently as Scutum Sobieskii, or Clypeus Sobieskii, we have a nebula (17 M.) which is often called, but not very judiciously, "The Horse-shoe Nebula," though now the name of "The Omega Nebula" is more generally and properly attached to it. In real truth, when seen at its best, it takes the form of 2 Greek omegas coupled together at their bases by a bar of nebulous matter; but the amateur with a small telescope must be satisfied if he makes out the shape of this object to be that of a swan without legs. One needs, in these days, to be very wary of accepting suggestions of changes in nebulæ, but there does appear to be some evidence that, within 50 years of Sir John Herschel's careful record of the appearance of this nebula, it did undergo some real change of form, according to the testimony of several experienced observers and draughtsmen.

The next object which comes before us in the order of Right Ascension is a very well-known nebula commonly called "The Dumb-bell Nebula in Vulpecula." The name is very appropriate in speaking of it after viewing it with a telescope of moderate size—say, up to 6 or 8 inches of aperture; but greater optical power so completely transforms its appearance that the idea of a dumb-bell quite passes out of one's thoughts. The truth of this statement will be readily realised by an examination in succession of the illustrations given (see Figs. 301–304). In a small telescope it appears like 2 somewhat round nebulosities in contact. Sir J. Herschel saw it with "an elliptical outline of faint light enclosing the two chief masses"; but Lord Rosse's 2 reflectors made material changes in its appearance. His 3-ft. reflector destroyed the regular elliptic outline noted by Sir J. Herschel, whilst the 6-ft. reflector brought about a still more striking transformation, and introduced a considerable number of stars individually recognisable as such.

The constellation Cygnus furnishes a striking nebulous aggregation (No. 4618 of Herschel's "General Catalogue"). This has been described as a very large space 20′ or 30′ long in Declination, and 1 hr. or more wide in R.A., full of stars and nebula mixed.

The Southern Hemisphere contains 2 objects, known re-

Low-power view.

Enlarged from a negative.

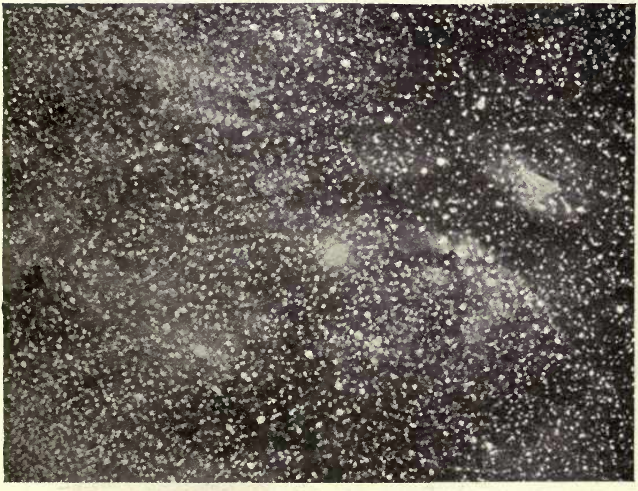
The Dumb-bell Nebula in Vulpecula (*W. S. Wilson*).

(*Smyth.*)

The Dumb-bell Nebula in Vulpecula.

(*Earl of Rosse*, 3-ft. Reflector.)

Nebulous Region of ρ Ophiuchi.



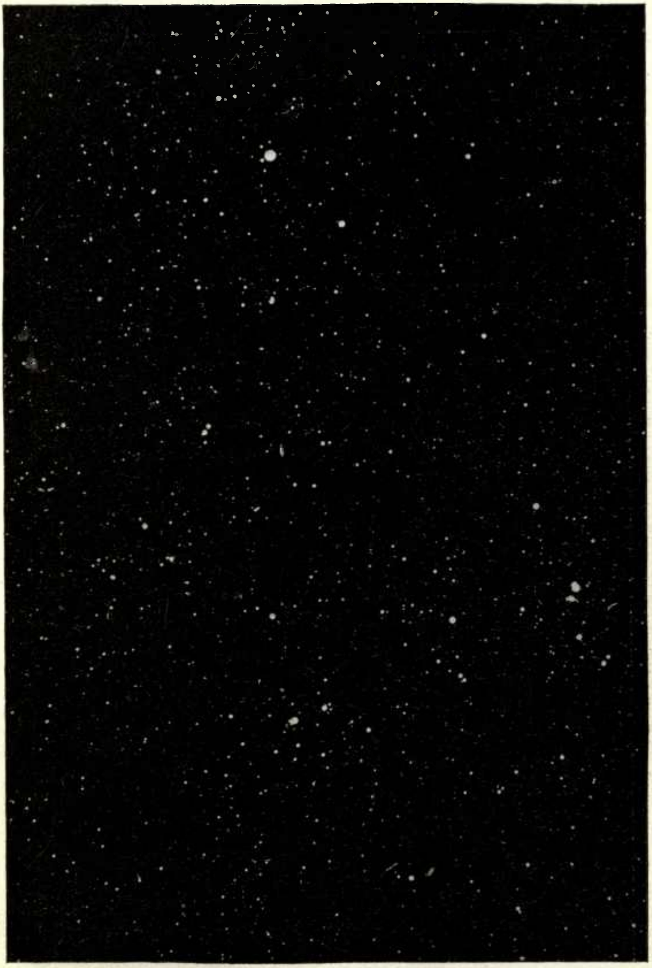
Nebulous Region of γ Cygni (*E. E. Barnard*).

240*b*] Nebulosity not visible in telescope, but disclosed by photography.

The Nebula 14 ♅ V. Cygni (*Lick Observatory*).

The "Trifid Nebula" in Sagittarius.

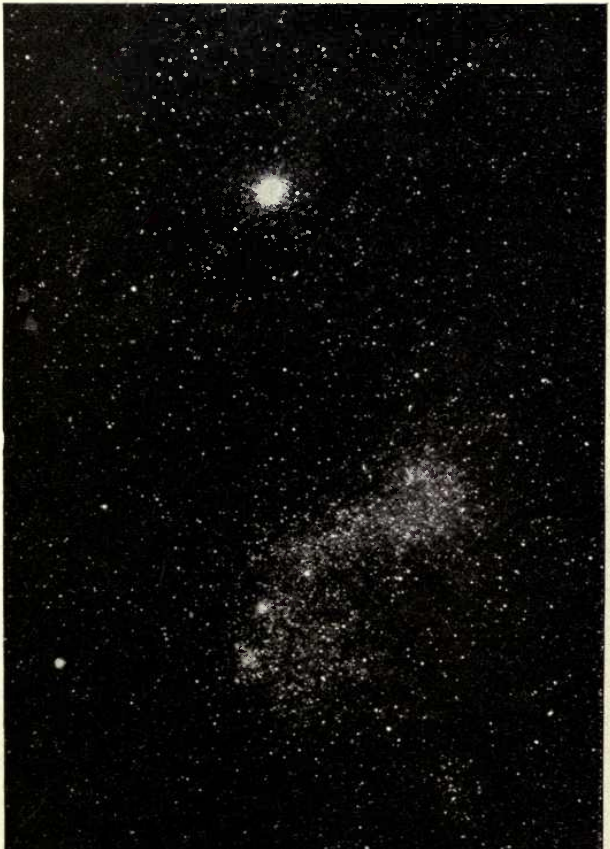
The "Trifid Nebula" in Sagittarius.



Stars in Cygnus (*Henry, at the Paris Observatory*).

The Nubecula Major, or Large Magellanic Cloud.

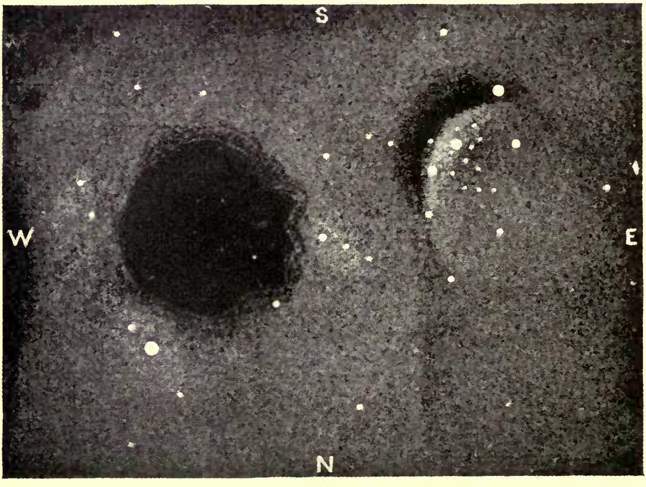
FIG. 312 PLATE CX.



The Nubecula Minor, or Small Magellanic Cloud.

240h

Double Cluster in Perseus.



Black space void of stars with Constellation Sagittarius.

spectively as the Nubecula Major and the Nubecula Minor, which are large patches of nebulous matter which received their names from their cloud-like appearance and relative size. The former is in the constellation Dorado, and the latter in Toucan. Both are visible to the naked eye on a dark night, but the smaller one is overpowered by moonlight. Sir J. Herschel described them as "consisting of swarms of stars, clusters, and nebulæ of every description." The larger one is about four times the size of the smaller. I am not acquainted with any more complete or modern description of either. Unfortunately, the Southern Hemisphere seems altogether lacking in astronomical authors who might write books describing what they had seen in the same way as the multitude of European and American authors have described, and continue to describe, the celestial sights visible in the Northern Hemisphere. This absence of literary enterprise on the other side of the world is much to be regretted, and we still have to draw largely on the great work published in 1847 by Sir J. Herschel, in which he recorded the results of his observations at the Cape in 1834 and subsequent years.[1]

A chapter on clusters and nebulæ would not be complet without some allusion to their distribution in the sky, which is exceedingly irregular. Subject to certain special exceptions, it may be said that the fixed stars, commonly so-called, are distributed fairly evenly over the whole sky; but this is a long way from being the case with the nebulæ, as will be readily understood by a simple inspection of Sir J. Herschel's "Catalogue" of 5079 of these objects, which was published in 1864. An examination of this volume discloses the following striking results. Whilst Hour XII. of Right Ascension includes 686 nebulæ, including clusters, and Hour XI. 421, Hour XIX. has only 79, and Hour XX. only 90. In other words, the constellation Virgo and its neighbours

[1] *Results of Observations made during the years* 1834–8 *at the Cape of Good Hope.*

include $\frac{1}{5}$th of the total number of nebulæ recorded up to the middle of the 19th century; and I do not suppose the relative proportions have been seriously destroyed by the later discoveries. The regions nearest to the Milky Way are least abundant in nebulæ, whilst the two richest regions are those which lie at the 2 poles of that great belt. Another circumstance, doubtless of significance though we cannot tell its meaning, is that the great majority of the nebulæ indicated by the spectroscope to be gaseous are situated either within or on the borders of the Milky Way, whilst in the regions near the poles of the Milky Way such nebulæ are scarce, though there are plenty of non-gaseous nebulæ situated in those localities.

This chapter must not be closed without a few words respecting the Milky Way itself, because it is one vast nebula running right round the heavens in the form of a belt, or ring; at the same time a description of its course, if put into words, would occupy more space than is here available. Any one wishing to follow it right round the heavens through the various constellations can do so in no better way than by patiently going over the ground with Sir J. Herschel's well-known *Outlines of Astronomy* in his hands.[1] It is long and elaborate, but very carefully framed. Suffice it, then, to say that the course of the Milky Way conforms nearly to that of a great circle inclined at an angle of about 63° to the Equinoctial, and cutting that circle in R.A. 6 h. 47 m. and 8 h. 47 m. From this it follows that its northern pole is situated in about R.A. 12 h. 47 m., and Declination 27° N., whilst its southern pole may be considered to be at 0 h. 47 m., and Declination 27° S.

Passing over the numerous and varied attractive features of the Milky Way, which are too numerous and too varied to be detailed here, mention must be made of a singular void space in the constellation Sagittarius, the precise position of which

[1] Herschel's description has been reprinted in my *Handbook of Astronomy*, 4th edition, vol. iii., and some other modern works.

is R.A. 17 h. 56 m., and Declination 27° 51′ S. This black hole is almost circular, and on the N.W. of it there are 4 stars, the brightest of which is orange in colour. To the E. of this hole there is another void space in the shape of a narrow crescent; but this space appears less black and less sharply defined than the main vacuity previously described.

My last words here will be to recall the fact that, strange as it may appear, the idea of spilt milk is associated in several languages with what we still persist in calling "The Milky Way," and that for centuries upon centuries past it has been the subject of grotesque nomenclature and fantastic speculations. Whilst the grotesque nomenclature may be said to have ceased, I fear it cannot be said that, though we have reached the 20th century, fantastic speculations have come to an end.

CHAPTER XIII.

THE CONSTELLATIONS.

The subject one of great interest.—The best way of learning their positions.—The effects of the diurnal movement.—Star-atlases and planispheres.—The constellations best learnt in the open air.—List of stars of the 1st magnitude.—Standard stars of the first 4 magnitudes.—Alignment of Stars.—Origin of the constellations.—Modern additions.—A hasty survey of the Northern Hemisphere.

A VERY attractive chapter might be written on the constellations in history and poetry with respect to their origin, names, and gradual developement in numbers during a period, to put it moderately, of not less than 3000 years; but it would be foreign to the design of this work to deal with the subject from these standpoints, which would be more within the province of the antiquarian than of the astronomer. The scope of this work is so essentially to present the useful and practical side of things that I must be wary of the temptation to stray away from the limits thus imposed on me.

An account of the constellations in detail has been formed into an independent chapter (*post*) to facilitate their study in the open air with as little as possible to embarrass the student beyond the unavoidable distractions of having to handle a star-atlas and a lamp. I thus limit the suggested *impedimenta* because many years' experience has taught me the mischief of trying to do too many things at the same time; and therefore I urge very strongly the importance of earnest efforts to become familiar with the constellations in respect to their positions and the names and situation of the principal stars in each.

It is not an uncommon thing for a writer sitting down to describe the constellations with an educational idea in view to treat each constellation as if it were a parish in a county—a geographical unit standing quite by itself. This, in my opinion, is a way of looking at the constellations which must be carried out with great discretion and considerable reserve, because it is often apt to lead to stars and other objects being lost for the particular night by reason of the diurnal movement taking them out of sight whilst the student is looking another way.

What I mean will be better understood if I put it in this way. When, on a given night, an observer wishes to lay himself out for a night's work, let him begin by ascertaining what constellations are on the meridian when his work begins, and, having just grasped them generally, let him begin by examining the stars which are on the meridian in the extreme South (this for England), and then work backwards northwards on the same R.A. towards the North Pole behind him. He need not trouble about constellations and stars, say, within 30° of the Pole, because these are visible all the year round, and therefore are always within his reach; but I do urge very strongly the advantage of working in accordance with the hour of R.A., which is on or near the meridian, and taking up his objects selected for study as they severally come to meridian, and guarding his eyes and thoughts from wandering promiscuously, not only over the heavens, but even up and down the same constellation. One thing is quite certain: the constellations, as regards their relative positions, can only be effectively learnt by open-air comparisons of the face of the heavens with a star-map.

Whilst there are many star-atlases and planispheres in circulation nowadays, there are undoubted advantages attending the use of a map in which stars are portrayed in white on a dark blue or black background. I have therefore used during many years, with very satisfactory results, the star-maps in Keith Johnston's *Atlas of Astronomy* edited by Hind. Next after this I would name McClure's *Atlas* published by the Society for Promoting Christian Knowledge, which is an English edition of a well-known German atlas, originally compiled by Heis of Münster; but McClure has greatly improved it and added to it. The stars are, however, given as black points on white paper. There is also given a deal of information descriptive of the most striking stars and clusters of stars and nebulæ which deserve examination.

A clever American, Dr. C. J. Kullmer, of Syracuse, N.Y., has invented a "Star-finder" somewhat in the form of an ordinary Equatorial, so far as its fundamental principle is concerned, but with various accessory features, and it has met with a large amount of acceptance in America, though I do not think that the instrument has yet become known in England. The engraving will indicate its general form better than an elaborate description. Regarded as an Equatorial in principle, the arrow takes the place of the telescope tube. The instrument must first be placed facing N. and the dials set for the day and hour; then the constellations can be sighted along the arrow without further change. Star-maps on the dial show the grouping of the stars in their actual position as seen in the sky, and the arrow-points at the constellations, whether they are above the horizon or not, and if the desired constellation is not visible at the time, then, by revolving arrow and dial, the time of rising can be found. The instrument stands about 10 inches high, and the dial is 6 inches in diameter. It is adjustable to any latitude in the Northern Hemisphere. Conversely to finding a constellation or bright star which it is desired to find, it may be used to identify the name of any constellation or bright star towards which the arrow is directed. It also shows sidereal time, which is read off opposite the graduation for March 21. An incidental, but often very useful, item of information, which can be arrived at with the assistance of the printed instructions supplied with the instrument, is this: where a given constellation or position in the heavens will be (so far as the observer's chance of seeing it is concerned) in the sky on a given day. Such information would often be useful to an observer who, knowing the expected position, say, of a new comet on a given day, wants to know whether, and at what hour, such comet will be above his horizon so that he may have a chance of seeing it. Were Dr. Kullmer's invention to become generally known in England it would, I think, be in much request, for we have nothing of the kind in use in this country.

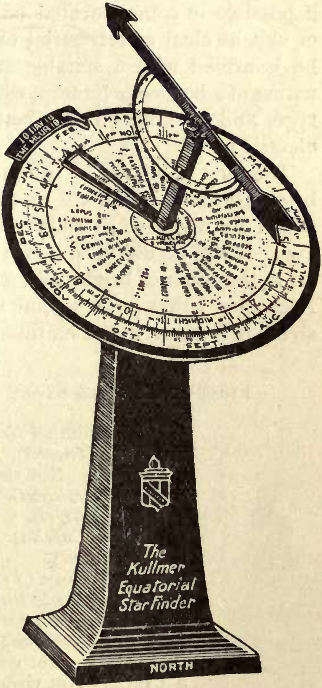


Fig. 315.—Kullmer's "Star-finder."

I will suppose the reader to have made himself acquainted with the apparent sizes and positions of some of the stars, and that he intends to get up the whole subject of the constellations in a systematic manner. The means for doing this will be found in a chapter specially devoted to the constellations in detail,[1] and I will now proceed with a variety of general considerations relating to the stars.

It is assumed that the reader is standing out in the open air,

[1] See Chapter XIII (*post*).

if possible in some elevated position, with as large an expanse of sky, as clear of terrestrial obstructions, as possible, and that he is armed with a suitable star-map, and something in the nature of a bull's-eye lantern, which may be either of the common type, and burning oil; or, better still, that he has a portable electric lamp.

The first thing to be attempted is to try and identify the brightest stars, which are those of the 1st of the 6 magnitudes which are regarded as embracing the stars visible to the naked eye. It will be useful to give a list of these stars in two forms: (1) in the order of brightness, and (2) in the order of their Right Ascension; that is to say, in the order in which they successively rise, come to the meridian, and set.

First-magnitude Stars in Order of Brightness.

α Canis Majoris (*Sirius*).
α Argûs (*Canopus*). Not visible in England.
α Centauri. Not visible in England.
α Boötis (*Arcturus*).
β Orionis (*Rigel*).
α Aurigæ (*Capella*).
α Lyræ (*Vega*).
α Canis Minoris (*Procyon*).
α Orionis (*Betelgeuse*).
α Eridani (*Achernar*). Not visible in England.
α Tauri (*Aldebaran*).
β Centauri. Not visible in England.
α Crucis. Not visible in England.
α Scorpii (*Antares*).
α Aquilæ (*Altair*).
α Virginis (*Spica*).
α Piscis Australis (*Fomalhaut*).
β Crucis. Not visible in England.
β Geminorum (*Pollux*).
α Leonis (*Regulus*).
α Cygni (*Deneb.*).

FIRST-MAGNITUDE STARS IN ORDER OF RIGHT ASCENSION.

	h. m.	° ′	
α Eridani (*Achernar*) . .	1 34	− 57 41	October 17
α Tauri (*Aldebaran*) . .	4 30	+ 16 20	November 28
α Aurigæ (*Capella*) . .	5 10	+ 45 54	December 8
β Orionis (*Rigel*) . . .	5 10	− 8 18	December 8
α Orionis (*Betelgeuse*) . .	5 50	+ 7 23	December 28
α Argus (*Canopus*) . .	6 22	− 52 38	December 27
α Canis Majoris (*Sirius*) .	6 41	− 16 35	December 31
α Canis Minoris (*Procyon*) .	7 34	+ 5 27	January 14
β Geminorum (*Pollux*) . .	7 39	+ 28 14	January 15
α Leonis (*Regulus*) . .	10 3	+ 12 23	February 21
α^2 Crucis	12 21	− 62 36	March 28
β Crucis	12 42	− 59 12	April 2
α Virginis (*Spica*) . . .	13 20	− 10 42	April 11
β Centauri	13 57	− 59 56	April 21
α Boötis (*Arcturus*) . .	14 11	+ 19 38	April 24
α^2 Centauri	14 33	− 60 28	April 30
α Scorpii (*Antares*) . .	16 24	− 26 14	May 27
α Lyræ (*Vega*)	18 33	+ 38 42	June 29
α Aquilæ (*Altair*) . . .	19 46	+ 8 38	July 18
α Cygni (*Deneb.*) . . .	20 38	+ 44 57	July 31
α Piscis Australis (*Fomalhaut*)	22 52	− 30 5	September 3

The dates appended are those on which the stars in question will be found on or near the meridian at midnight.

It will be noticed that these stars are nearly equally divided between the Northern and Southern Hemispheres; that 10 are Northern and 11 are Southern stars.

Seidel has suggested the following as standard stars for their respective magnitudes:

Mag.
1. α Aquilæ, α Virginis, α Orionis.
2. α Ursæ Majoris, γ Cassiopeiæ, Algol (at max.).
3. γ Lyræ, δ Herculis, θ Aquilæ.
4. { ρ Herculis, λ Draconis (too bright).
   { μ Boötis, θ Herculis (not bright enough).

The reader is recommended to make himself familiar with all the stars in the foregoing lists, because those in the first list will serve to give him an idea of where the respective constellations and indirectly where the other constellations are to be found, whilst the second list will help him to recognise a star of a named magnitude because he will know what a star of such a magnitude should look like.

One of the most worrying difficulties which has to be faced in studying the constellations, is the varying positions which they occupy between their rising and setting. This really amounts, more or less, to their being upside down at setting, compared with what they look like when rising. This inevitable transformation is another reason for students confining their attention as much as possible to constellations which are on the meridian at the time that study is going on; or, at any rate, to constellations within a couple of hours or so on either side of the meridian. The fact that such upside-down changes do indeed apparently take place will be better realised by an examination of the annexed diagram than by any attempt to explain the matter verbally.

Having identified a few conspicuous stars, the student must habituate himself, first of all, to drawing imaginary lines from one star to another, either literally on his map or mentally in his head; and then to seeing whether he can pick up in the heavens a particular object he wants by running his eye across the sky in accordance with the line or lines on his map, which he must mentally reproduce by recalling his map. This process of star-hunting is technically called "allineation" or "alignment." It is obviously difficult to put in writing how to do it, and the student must learn to do it for himself by the exercise of thought and ingenuity. For instance, if he sees on his map that the distance from star α to star β in a certain constellation is so much, and that the small star μ which he wants to look at is in the same straight line with α and β and $\frac{2}{5}$ths of the distance beyond β that β is from α, he must estimate, by more than one attempt perhaps to see, when looking up at the stars, whither $\frac{2}{5}$ths forwards from β

will take him: then, if his estimate on the map is fairly correct, and if he is able to estimate where $\frac{2}{5}$ths will take him on the sky, he will find that the star μ for which he is looking is in the place where he ought to find it.

This method of finding unknown stars by means of imaginary lines drawn to and from known ones is the only means available to those unprovided with an equatorial telescope with its customary Right Ascension and Declination circles. There are various popular star-charts and books with diagrams in circulation with suggested lines drawn on them hither and thither between different stars. Some of these books will be useful to the tyro, but it not unfrequently happens that the connecting lines are engraved too heavily, and not only disfigure the plates, but embarrass the eye in consulting the plates.

Though I do not intend to give a detailed statement of the constellations on their historical side, it may be well just to summarise what their history is. It begins, for my present purpose, as far back as Ptolemy, who flourished A.D. 100–170 at Alexandria. He enumerated 48 Constellations, 21 of which were Northern, 12 Zodiacal, and 15 Southern. Tycho Brahe, who died in 1601, added 2. Bayer (he of the *Atlas*) added, or rather perhaps accepted as additions, 12 constellations, all of them Southern. Royer, in 1679, added 5. Halley, about the same period, added 1, Robur Caroli, to commemorate the oak of King Charles II. Flamsteed's maps contain 2 constellations, presumably invented by himself; and Hevelius in 1690, added 11. During the 18th century no fewer than 27 constellations, nearly all of them Southern, were set up by Lacaille and others. Many of these 18th-century additions have been either formally or informally repudiated—a fact which will explain names appearing in books and maps published a century or so ago which are not now to be found in modern maps or in modern lists.

The total embraced in the statement just made mounts up to 109. Even that number does not exhaust the names which have been proposed but promptly ignored. The situation was well summed up once by Sir J. Herschel, who caustically wrote as follows :—" The constellations seem to have been purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens, where no memory can follow them ; bears, lions, and fishes, small and large, Northern and Southern, confuse all nomenclature."

Constellation reformers have, as was to be expected, sprung up at various times, but, as often happens with reformers, they did not obtain much thanks. Two, however, stand out especially unworthy of thanks, owing to their reckless and ill-advised schemes of reform, namely, Dr. B. A. Gould and R. A. Proctor.

Subject to reservations which have already been laid down, the following may be offered as a brief general summary of the positions of certain of the constellations relatively to one another.[1]

We will start with Ursa Major, the Great Bear, the most conspicuous of the constellations which never set in Great Britain, Canada, and the Northern States of North America. The tail and hind quarters consist of 7 brilliant stars, 4 of which (α, β, γ, δ), have long been compared to a waggon, the other 3 (ϵ, ζ, η) being the horses ; or the 7 taken together make "The Plough," a very old English name. The hind wheels, or the two farthest (β, α) from the horses, are known as "The Pointers," because they point to the Pole-star (α Ursæ Minoris) at the tip of the Little Bear's tail ; and farther on straight ahead to the constellations Cepheus and Cassiopeia, situated in the Milky Way where it is nearest the Pole. Cassiopeia includes several bright stars so grouped that they form the letter M or W, according to the aspect in which they are viewed. The two most northerly wheels of the waggon (δ α, Ursæ Majoris) point to the bright star Capella (α Aurigæ), which is also circumpolar in our latitudes.

[1] Condensed from my *Handbook of Astronomy*, vol. iii.

The stars in Ursa Major may be usefully employed as scales of distances for degrees of arc. The nearest "pointer" (α) is $28\frac{3}{4}^\circ$ from the Pole; from α to β is 5°; from β to γ is 8°; from γ to δ is $4\frac{1}{2}^\circ$; from δ to ϵ is $5\frac{1}{2}^\circ$; from ϵ to ζ is $4\frac{1}{2}^\circ$; from ζ to η is 7°.[1]

Descending diagonally across the heavens along the Milky Way from Cassiopeia towards Capella we come to α Persei, and a little farther on we find the variable Algol (β Persei); if we pass across the Milky Way in the opposite direction we shall arrive at α Cygni, whilst beyond this and a little out of the Milky Way is Vega (α Lyræ). Draco includes a long chain of stars sweeping partly round the Little Bear; and in the space bounded by Cassiopeia, Cygnus, and Draco, is Cepheus.

Another very conspicuous group in the Northern Hemisphere is that known as "The Square of Pegasus." Near γ Pegasi, and pointing directly towards it, are two conspicuous stars in Andromeda (α β), and a third (γ) is a little beyond them. Andromeda, as a constellation, will be readily known by the connection of its α with the 3 stars of Pegasus (α, β, γ) which make up the Pegasus "square."

An imaginary line through the Great Bear and Capella will reach in a forward direction the Pleiades; and then, turning a right angle towards the Milky Way, will reach Aldebaran (α Tauri) and the shoulders, α, γ, of Orion. Orion is the most striking constellation in the whole heavens, comprising as it does so

[1] The lack of astronomical knowledge in high places is amusingly and strikingly brought out in a recently published book by Professor James Stuart. Alluding to conversations he had had with Mr. Gladstone, he says:—"It was on one of these occasions, on a bright starlight night, that Mr. Gladstone said, when he had been looking at the stars, 'Why is it that the Great Bear seems so much more frequently in the sky than other constellations?' I said, 'Because it never sets.' He said, 'Do you mean to say that it never sets? I thought all the stars rose and set.' When I explained the matter to him it seemed somewhat of a new idea, and he said, 'Well, I think that explains Homer's phrase, ὀψὲ δύων, if applied to the Great Bear—that is to say, "late in going down."' Mr. Gladstone was never anything of a physical scientist."—J. Stuart, *Reminiscences*, London, 1912, p. 240.

many conspicuous stars, namely, α, γ, in the shoulders, δ, ϵ, ζ in the belt, and κ and β in the legs. Aldebaran is a star of reddish tint, and the most prominent in the V-shaped cluster of the Hyades, which is not far from the Pleiades. Aldebaran, the Pleiades, and Algol make the upper, while α Ceti with Aries form the lower points of a W. The head of Aries is denoted by two principal stars (α, β).

A line from the Pole-star taken midway between the Great Bear and Capella passes to α and β Geminorum, the two well-known stars Castor and Pollux; continued southwards it will meet Procyon (α Canis Minoris). From thence, by bending the line across the Milky Way and carrying it as far again, it will reach Sirius (α Canis Majoris) and so southwards to α Columbæ Noachi.

Algol and α and β Geminorum point at Regulus (α Leonis) the Lion's heart, at one end of an arc with β Leonis, the tuft of the Lion's tail at the other end. S. of and preceding Regulus is Cor Hydræ (α), the space between them being occupied by Sextans.

The Pole-star and the middle horse of the Great Bear (ζ) direct us to Spica (α Virginis) at a considerable distance, whilst beyond and in the horizon will be Centaurus.

The Pole-star and the first horse of the Great Bear (η) point nearly to Arcturus (α Boötes), which forms with Spica and Regulus a splendid triangle. In a southerly direction another triangle is formed by Arcturus, Spica, and Antares (α Scorpii).

Corona Borealis is nearly in a line between Vega (α Lyræ) and Arcturus (α Boötis), whilst the head of Hercules and the head of Ophiuchus lie between Lyra and Scorpio. In the Milky Way, below the part nearest to Lyra, and on a line drawn from Arcturus through the head of Hercules, is Altair (α Aquilæ), which makes, with Vega and α Cygni, a conspicuous triangle. Closely following Aquila is Delphinus, a small constellation with 9 rather conspicuous stars.

Two of the stars in "The Square of the Pegasus," already mentioned (β, α), point, at double their distance, southwards to Fomalhaut (α Piscis Australis).

The line of the Ecliptic may without difficulty be traced by the eye by means of the stars now to be enumerated. Not far from the Pleiades are the Hyades and Aldebaran (α Tauri), a little S. of the Ecliptic. To the N.W. of Aldebaran, at some distance, is the chief star of Aries (α), whilst to the N.E. of that star are α and β Geminorum. Regulus (α Leonis) is on the line of the Ecliptic, and Spica (α Virginis) is only a little S. of it. The Ecliptic thus known, the zodiacal constellations may be easily distinguished in their successive order from W. to E. Thus Aries lies immediately between Andromeda on the N. and Cetus on the S., the 3 constellations reaching nearly from the horizon to the zenith; Taurus will be recognised by the Pleiades, Aldebaran (α) and the Hyades; Gemini by Castor and Pollux, (α, β); Cancer, the highest, or most northerly of the signs, by the cluster Præsepe, but as a constellation, having no stars larger than β, and that only of mag. $3\frac{3}{4}$; Leo from the stars Regulus (α) and Denebola (β); Virgo by Spica (α); Libra by β (which, however, is only of mag. $2\frac{3}{4}$); Scorpio by its brilliantly red star Antares, and 9 other stars of the 3rd magnitude, or brighter; Sagittarius, the lowest or most southerly of the signs, with its ϵ of mag. 2; Capricornus, with its δ of mag. 3; Aquarius, under the neck of Pegasus, with no stars as bright as mag. 3; and Pisces, between Pegasus, Andromeda, and Cetus, also with no bright stars.

It must be understood that the foregoing paragraphs are very rough as regards the information they give, and do not embrace the constellations of the Southern hemisphere, which are invisible in England.

CHAPTER XIV.

TELESCOPES.

Telescopes are of two kinds.—Reflectors, Refractors.—Various kinds of reflectors.—Brief description of each.—Principle of a refractor.—Spherical aberration.—Chromatic aberration.—The opera-glass.—Stands for telescopes.—Importance of a good stand.—Equatorial stands.—Advantages of an equatorial mounting.—Accessories to a telescope.—Driving-clock.—Sidereal clock.—The housing of a telescope.—Advantages of an observatory.—Detailed description of how to build one.

THIS chapter is not intended to be either a treatise on optics, or even a full statement of the different classes of instruments used in astronomy.

I only purpose to offer some information likely to be useful to amateurs able and willing to give a certain amount of time and lay out a moderate amount of money in the purchase of instruments suitable for observing some of the more easy celestial objects which have been described in the preceding pages.

TWO KINDS OF TELESCOPES.

Telescopes are of two kinds; and there is a radical difference between them. In a "Reflector" the rays of light coming from a distant object are received on a curved surface of metal, or silvered glass, and reflected back to a "focus," where they are viewed by a subsidiary piece of optical apparatus in the nature of a microscope, and which is called an "eye-piece."

In a "Refractor" the rays of light are received by a glass lens, through which they pass, and, after passing, are brought to a point called a "focus," where they are viewed by what I have called a sort of microscope, though its proper name is "eye-piece," as already given.

To compare reflectors and refractors as regards their relative merits is not altogether easy, because measurements in feet and inches of each are not comparable. A reflector 6 inches in diameter is an instrument altogether different from a refractor of the same dimensions. Such a reflector is less efficient, and less handy, but, it must be admitted, is also less costly than its refractor brother; but, notwithstanding these facts, I do not recommend reflectors, for several reasons, and one in particular. The mirror, which constitutes the essential feature of the reflector, is difficult to keep in condition; that is to say, however good its condition at the start, it sooner or later gets out of condition. If it is of polished metal it soon tarnishes, if of silvered glass it gets dull, and in either case it is troublesome to get at either for moving or cleaning.

As between one reflector and another, it must be explained that there are some differences which make reflectors of one type not quite so unhandy as those of another type. There are 4 principal types of reflector in use, namely, the "Gregorian," the "Cassigranian," the "Newtonian," and the "Herschelian." The 2 former of these are the least inconvenient to use because the mirrors, which are at the eye-end of the tube, being pierced in the centre, the observer looks straight at his object, whereas in the Newtonian and Herschelian forms the eye-piece and the observer are at the side of the tube, and therefore there has to be a diagonal reflector inside; and the observer, every time he wishes to look with the naked eye at the object he is observing, has to twist his body round. A Herschelian reflector, especially if it is a large one, is still more troublesome to work, because the eye-piece is up in the air, and therefore the observer must be there also. However, Herschelian reflectors are quite obsolete, and this, to some extent, is true of the Gregorian and

Cassigranian forms. The real competition nowadays is between Newtonians and refractors, and a purchaser will have to exercise his own discretion in making a choice, and in many cases will be swayed by the apparently cheaper price of the Newtonian, whilst ignorant of its drawbacks, some of which have been stated. It must, however, be confessed that the substitution in recent times of comparatively light silvered-glass mirrors for the old-fashioned heavy metal mirrors has done something to popularise the Newtonian reflectors of moderately large size.

A refractor takes its name from the fact that it receives light from an object on the outer side, and brings it nearly to a point called the "focus." Such a telescope, in its simplest form, consists merely of a double convex lens at one end of a tube, which forms an image of the object to be viewed, whilst a second and smaller double-convex lens, fixed at the other end of the tube, serves as a simple microscope to magnify the image formed by the first lens. The first is called the "object-glass," whilst the magnifying lens is called the "eye-piece." This is stating the matter in its broadest and most elementary shape, and, though it is quite possible to construct a telescope with only two pieces of glass combined as stated, practically it is desirable to arrange things a little more elaborately. Two simple lenses combined as above reveal certain optical inconveniences called "spherical aberration" and "chromatic aberration." The result of spherical aberration is that the object does not come to as sharp and defined a focus as is desirable, whilst chromatic aberration is indicated by the fact that the image of the distant object on view is inconveniently fringed with colour. These two drawbacks, which, when a large lens is used for an object-glass, are very serious, are "corrected" (as the expression is) by making both object-glass and eye-piece compound instead of simple; that is, by forming both object-glass and eye-piece of two lenses instead of one.

On the right disposition of these lenses, as regards the curvature given to them, depends the success or failure of the optician's efforts to cure the inconveniences referred to. All this, however, is very technical, and does not concern the general reader, who buys his telescope with all these points worked out by the optician, and he has nothing to do with them except to pay his purchase-money on the supposition that they have been properly dealt with. In all cases, however, an intending purchaser will do well to consult an expert friend, if he has one within reach, in order to ascertain that both the optical part of his proposed purchase and also the metal working-parts are all satisfactory.

Up to this point I have been talking of the telescope in its simplest form, but it must be borne in mind that, short of a telescope properly so-called, a not inconsiderable amount of useful and profitable astronomical study can be accomplished by the aid of a common opera-glass, binocular, or field-glass. This especially applies now and again to observations of comets, eclipses, and occultations. An opera-glass, of course, is naught else but 2 small telescopes placed side by side, one for the use of each eye. Such an instrument, in its common form, starts with an assumption which is frequently contrary to the fact, namely, that both eyes of an observer are alike, and that what suits one eye will suit the other eye. This is often not the case, and accordingly in the better-made and higher-priced binoculars provision is made, not only for eyes being different, but for the centres of the eyes of one person being at a different distance apart compared with the eyes of another person.

In making preparations for carrying on astronomical observations the question turns entirely at the outset on the money available for providing the outfit. Of course, this may be anything from £5 up to £5000. But what I have in view in these pages is an effort to assist in a very modest outlay—say, anything between £5 and £100—leaving the question of an apartment in which to house the instrument to stand over to the end of this chapter, and be dealt with separately.

STANDS FOR TELESCOPES.

When asked, as I often am, to give advice as to the purchase of a telescope one point invariably crops up—the difficulty of impressing on an inexperienced purchaser the importance of providing his telescope, whatever its size or price, with a suitable and efficient stand. If the aperture of the telescope is to be no more than 2 inches, and the cost perhaps £10, the only stand which such a telescope would have, or want, will be a tripod of some sort, either entirely of brass to stand on a table (known as a "pillar-and-claw stand"), or of metal and wood combined to stand on the ground. Such an instrument will have 2 motions, up and down and right and left. Now these motions, quite convenient and suitable when the objects to be looked at are terrestrial, are very inconvenient and unsuitable in dealing with celestial objects, and for this reason: the stars moving across the sky by virtue of the diurnal motion (as explained in Chapter XI., *ante*) do so diagonally (or on the skew), and a telescope which normally moves up and down and right and left does not readily lend itself to moving askew.

EQUATORIAL STANDS.

A telescope mounted so as to follow the movements of the stars requires to be tilted so that the main part of the stand shall point exactly to the Pole. This secured, then one pushing motion of the telescope incessantly from left to right will keep any star once brought into the field of view continuously in view, so long as the pushing motion lasts. In other words, the stand which we started with, whose technical name is an "Alt-azimuth," has been converted by being tilted into an "Equatorial." Various expedients for this conversion have often been suggested, but they are rough and troublesome, and the intending purchaser of a telescope had much better begin at the outset by buying a properly devised "Equatorial Stand," as an apparatus for following the star by one movement is technically called.

The various stands which are illustrated in this chapter will show the progressive developement of stands, from the smallest and humblest "pillar-and-claw" up to the largest and most costly equatorials of world-wide celebrity. It is not contemplated to give any detailed account of these large instruments, but only to make the reader acquainted with such developements of improvements and accessories as will keep the expenditure within the limits, more or less, of £100.

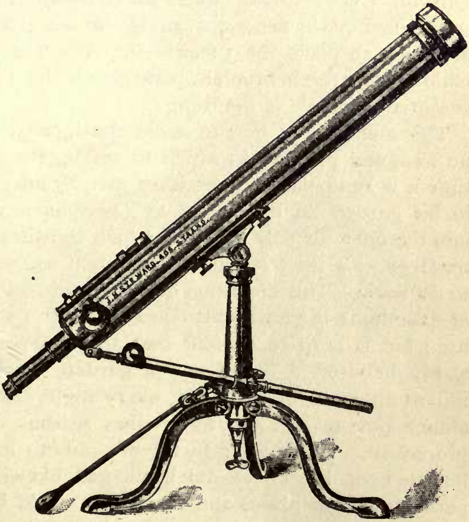


Fig. 316.—Astronomical and Look-out Telescope ("Pillar and Claw").

Two things come up for consideration as soon as we have decided on mounting the telescope as an equatorial. (1) Shall the stand be portable, or be a fixture somewhere? And (2) shall the pushing motion required to keep an object constantly in the field be given by hand or automatically?

As regards the stand to carry an equatorial, such stands, in the form of wooden tripods, are easily portable when they are required to carry telescopes of no more than about 4 in. of aperture. But an equatorial is shorn of its special usefulness if unprovided with setting circles, such as are required to bring it to a point in the heavens whose R.A. and Declination are known. Even without circles an equatorial stand is wasted if some fixed marks are not available on the ground out of doors on which to place the 3 feet of the tripod so as to ensure the main axis of the instrument pointing to the Pole, which is the essential principle of the thing.

This difficulty of how to avoid the inconvenience of having no assigned position in which to set up the tripod, after each time it is removed, is sometimes met by an observer erecting in his garden an iron stand as a permanency, and taking out into the open air only the head which constitutes the equatorial, together with the telescope, every night whenever he proposes to do work. This condition of things secures a certain amount of exactitude in getting his equatorial into its proper place for use ; but it is quite evident that, to carry backwards and forwards between a house and a garden a telescope, and the important parts of its stand, every night that it is wanted is alike a time-taking, and, for various reasons, an unsatisfactory procedure. It is better by far not only to have a fixed stand, but to keep the equatorial head, and likewise the telescope, permanently in place, and cover the whole by a structure of some sort which may be called either a shed with a movable top or an observatory with a revolving dome, which obviously sounds much better.

ACCESSORIES TO A TELESCOPE.

With an instrument properly housed it becomes possible to add, not necessarily at first, if funds do not permit, but later on, a driving-clock. This is simply an arrangement of clockwork which, when coupled on to the telescope by suitable means, drives or pushes the telescope continuously forwards, so as to keep the object which is under observation continuously in view without the necessity of the observer constantly having to push the telescope—a labour which is not only very tedious, but one which hinders him using his hands for making notes or drawings.

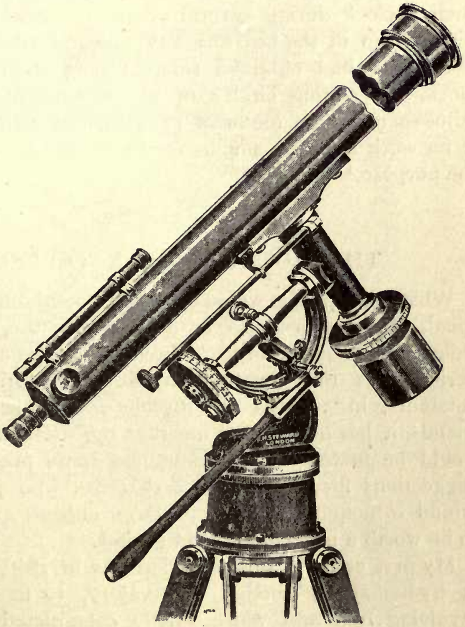


Fig. 317.—3-inch Portable Equatorial Telescope.

With a telescope equatorially mounted, and provided with setting circles and driven by clockwork, a timepiece will be required exhibiting sidereal time; in other words, announcing what is the Hour of R.A. which is on the meridian at any given moment. Of course, a properly constructed sidereal clock, graduated to 24 hours, is desirable, but it is a luxury; and a common French dining-room clock, costing £2 or £3, answers the purpose of a sidereal clock if it keeps fairly good time, and if the owner is able to obtain Greenwich time every day or two from a local post-office or otherwise. In my early days as a young astronomer I did a great deal of work with such a clock during several years, and had no difficulty in picking up in the heavens any object I wanted to find, so soon as I had obtained sidereal time from my make-shift clock, the setting circles of my instrument being in good adjustment. The methods of adjusting an equatorial to fit it for work must be sought for in books specially written for the purpose.[1]

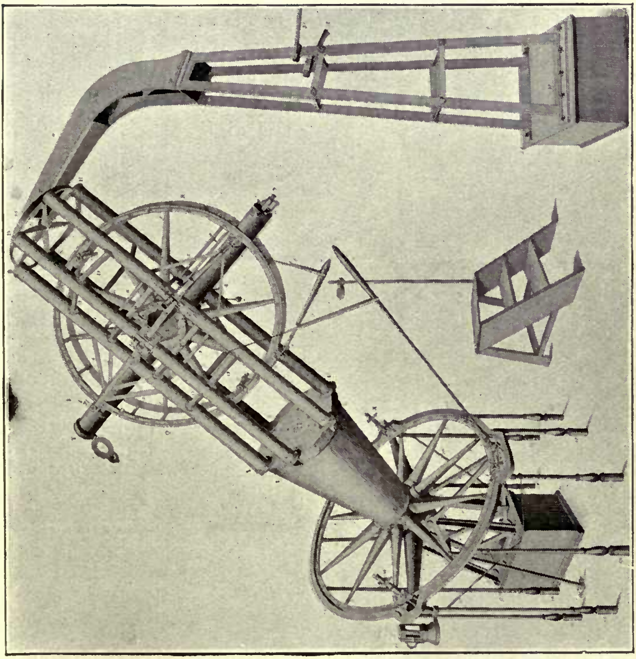
THE HOUSING OF A TELESCOPE.

What some people would call a telescope-house, as they would speak of a motor-house or a chicken-house, is scientifically called an "observatory." Having had some practical experience in the construction of observatories suitable for amateurs, in 3 cases for myself and in several cases for friends, it has occurred to me that the usefulness of this book would be increased if it contained some practical hints and suggestions for the guidance of those who possess, or who intend to acquire, a telescope large enough and good enough to be worth a permanent fixed shelter.

My first essay in this direction was in 1866, when I put up at Sydenham a wooden observatory, 10 ft. square, with a revolving roof and walls, wholly constructed of timber, the roof and walls being covered with weather-boards screwed to the jointed timbers. I will not further describe this structure, the builder's charge for which was £58, because I have much more recently erected at Sydenham what is more or less a facsimile of it, with some alterations and improvements suggested by the

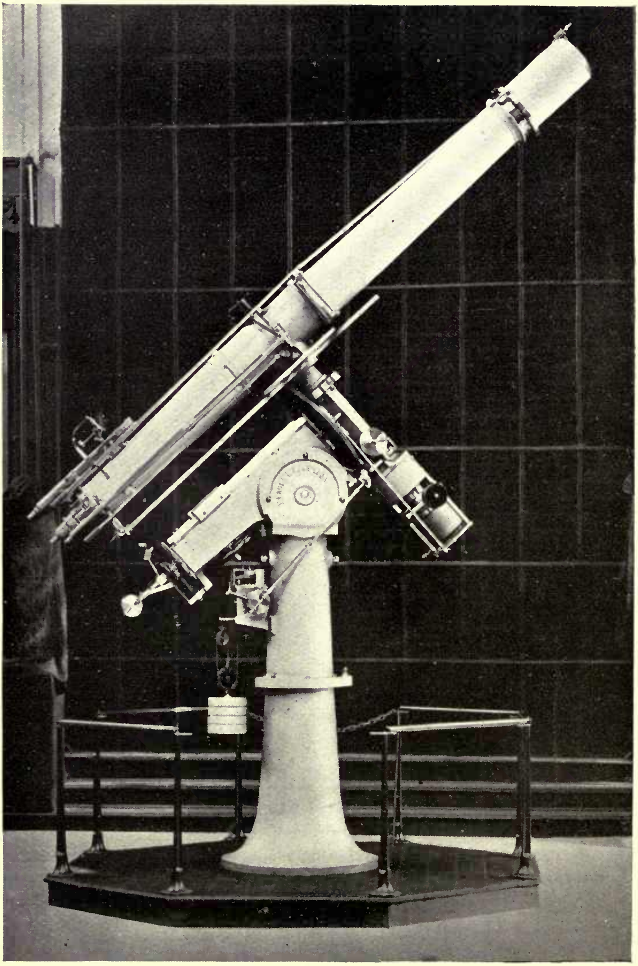
[1] See, for instance, my *Handbook of Astronomy*, vol. iii., "Astronomical Instruments."

FIG. 318 PLATE CXII.



General View of the Old-fashioned Equatorial Instrument.

(From *The Philosophical Transactions*, 1793.)



Equatorial Telescope, with Object-glass of 10 inches aperture (*Cooke*).

experience of years. Suffice it to say, regarding the 1866 observatory, that when circumstances compelled me to go and reside in a different part of the country, I at once found a purchaser for it, who was much struck with the ease and facility with which the whole was taken to pieces and conveyed into Hampshire.

In 1869 I went to live in a house at Bickley which had a tower, and, by arrangement with my landlord, I supplied, as the roof of the tower which he built, a revolving dome to cover a 4-in. Cooke equatorial. This dome was of wood, weather-boarded, and of practically the same design as the roof erected 3 years previously at Sydenham.

Moving to East Bourne, in 1874, to a house of my own, built after my own plans, I provided a tower about 50 ft. high as part of the house, the topmost story of which was built and fitted up as an observatory, surmounted by the wooden dome brought from Bickley. This eventually covered a 6-in. Grubb equatorial, with which instrument I carried on observations during a period of 28 years.

My reason for making the top of the tower appurtenant to the house into an observatory was because my 5 years' experience at Bickley taught me the great advantage of so doing.

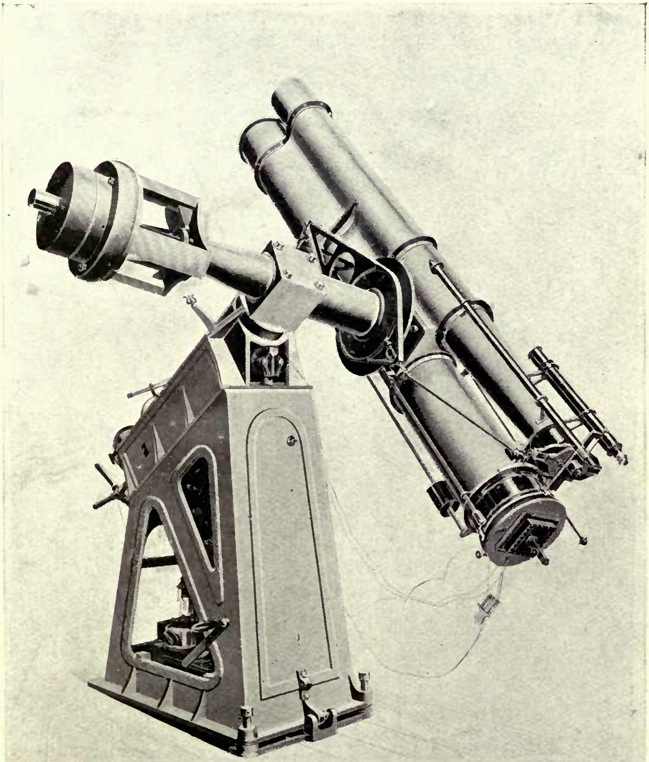
Inducements to observe in cold, wintry weather are very much more effective when the observer is able to walk to and from his observatory under cover; compared with a different state of things which he has to face when it is a question of dressing up in a greatcoat and other things preparatory to walking any number of yards in the open air, possibly over damp grass, or through snow.

Many years ago a writer in *Nature* made a ridiculous attack on my plea for putting a movable dome on the top of a high tower, such as mine at East Bourne, because, sooner or later, the said roof would be found to have descended into the garden. How baseless this writer's foolish opinion was, is sufficiently shown by the fact that my dome passed unscathed through 32 winters and summers at East Bourne in a situation very much exposed to the full force of south-westerly gales, whenever they occurred, no other precautions being taken than two ties of not very thick rope. Only once, during the whole long period named, did I ever see the dome rise off its ball-bearings to an extent suggesting that, if the rope had not been there, it might have gone overboard. As a matter of fact, often for many weeks and months together I neglected to tie the rope, and nothing happened.

I proceed now to describe my fourth observatory, to be seen at Sydenham, which, as I have said above, embodies previous experiences. Its revolving dome (by the way, it is not a dome but a 13-sided polygon) has occupied in more than 40 years three different sites, and its timbers, without even the exception of a square inch of surface, are as sound and as good as on the day on which they left the carpenter's shop at Uckfield, in which they were originally put together. This last-named fact I attribute entirely to the circumstance that, instead of following the usual trade custom of giving outside woodwork 2 or 3 coats of paint all at once at long intervals of time, I made it a rule, as far as possible, to put on a single coat of paint something like every second year.

It will be useful to explain the successive steps involved in the erection of an observatory, taking the reader through the actual *modus operandi* based on the fiction that I am describing an entirely new structure, and not one a portion of which had actually been erected previously somewhere else.

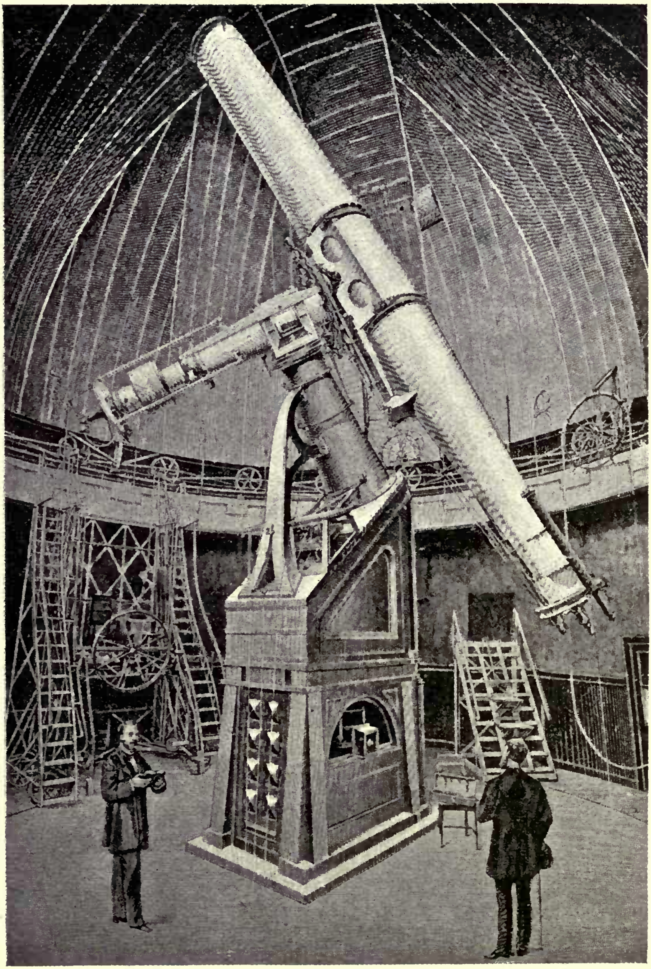
A good solid foundation is a *sine quâ non* to start with, for without it a telescope of any considerable weight will constantly be getting out of adjustment, even though there may be no risk of it and its house toppling over. The extent of the care which it is expedient to spend over foundations is largely a geological question. A rocky, gravel, or chalk soil is usually very stable,



STANDARD PHOTOGRAPHIC EQUATORIAL.

As supplied to the British, Colonial, and Mexican Governments, for the International Photographic Survey of the Heavens.

Standard Photographic Equatorial, for the International Survey of the Heavens (*Sir H. Grubb*).



27-inch Refractor of the Vienna Observatory (*Sir H. Grubb*).

except that rock is often very susceptible to changes of temperature, but this would not, as a rule, involve inconvenient or dangerous settlements. It is far otherwise, however, with a clay soil. This is a very trying soil to deal with where the stability of a structure of great weight has to be secured in a limited area, such as the pier of an equatorial weighing anything from a quarter of a ton to 2 or 3 tons. The soil at Sydenham is a stiff clay, which at different seasons of the year is either very wet and sticky or hard and dry and full of fissures. Accordingly, to prepare for an observatory the plan of which was to be a square 10 ft. on each side, I excavated a space 12 ft. square and 9 in. deep, and filled the same with 77 navvy barrow-loads of cement-concrete composed of broken stone, fragments of brick, old glass, and crockery, and indeed of any hard rubbish for which I had no use, and which I wanted to get rid of.

This concrete foundation was left untouched, as it happened, for about 3 months, an interval amply sufficient, of course, to test its stability. On this concrete bed, a square enclosure of brickwork was built in the form of a dwarf 9-inch wall of 8 courses of bricks, the topmost one being formed of bricks on edge set in cement.

Of course it will be understood that so extensive a concrete foundation as that which I provided is quite unnecessary in a general way, and that the only place where concrete is necessary by way of foundation is under the centre of the observatory, that it may serve as a base for the brickwork pillar which is to carry the iron stand of the equatorial, presuming that the telescope is to be mounted equatorially in the German fashion. Whether or not the walls require to be built on concrete must depend on local circumstances. Ordinarily it will not be necessary for observatories of the type with which this section is intended to deal.

I will now give particulars of my foundations. I may as well remark that the large quantity of rough core which I used was rather because I had it and wanted to get rid of it, than because it was really necessary.

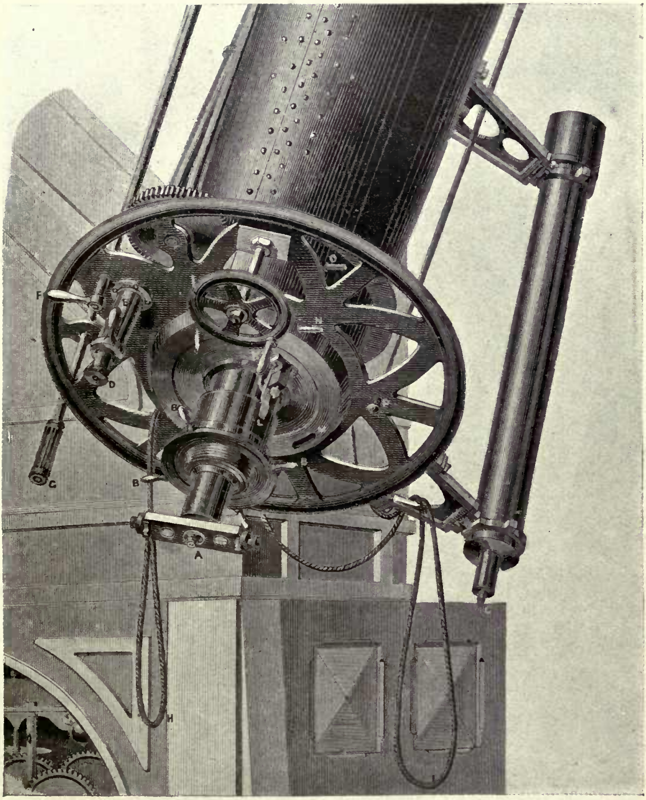
Foundations.

The following are particulars of the foundations, and of the cost of the same :—

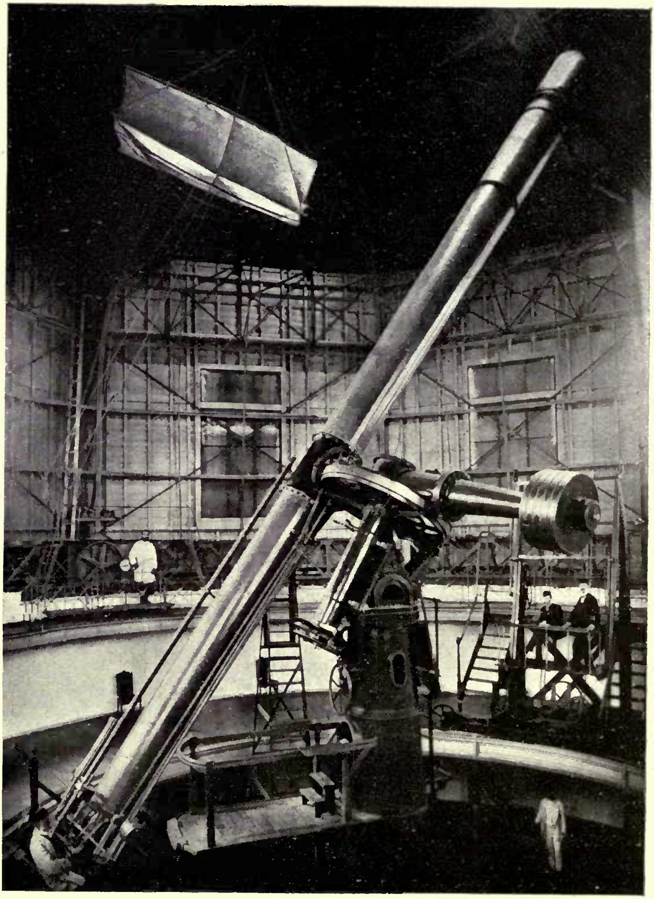
	£	s.	d.
Excavation of 108 cubic feet (labour) . . .	0	12	0
Concrete :			
77 barrow-loads of broken stone, etc. . .	1	10	0
5 bags of cement		16	0
Labour	1	7	0
	4	5	0

Brickwork in Walls and Floor.

The foundations being finished, the next thing to be done was to build a dwarf wall running round four sides of a square 10 ft. across. This wall received, in my case, only the four-sided wooden frame which constituted the walls of the observing-room; but in ordinary cases this wall would be called upon to carry the joists of the floor of the said room. I preferred, however, at Sydenham not to have a wooden floor, but to form a floor by means of an additional layer of concrete, rising about 6 in. inside the quadrangular enclosure formed by the brick wall and brought to a smooth surface by cement. The advantage of such a surface for an observatory floor is the facility with which observing chairs or stools, or indeed seats of any kind, can be pushed hither and thither ; for a boarded floor, especially one formed of imperfectly seasoned boards (as is often unavoidable when economy has to be considered), is very inconvenient and disagreeable. A concrete floor is, moreover, more easily cleaned and kept clean. The one only objection is that it is cold to the feet, but this can be got over by having a mat or



Eye-end of the Vienna Refractor.



30-inch Refractor of the Pulkova Observatory (*Repsold*).

two, capable of being moved from place to place at pleasure. The following was the cost of the—

CONCRETE FLOOR.

	£	s.	d.
34 barrow-loads (say 50 cubic feet) of coarse, broken stone	1	14	0
31 barrow-loads of small broken stone, or gravel .	1	18	9
Mortar, composed of 6 barrow-loads of sand, $1\frac{1}{2}$ bags of lime, and a little cement . . .	0	6	7
5 bags of cement for top dressing	1	0	0
Labour	2	7	10
	7	7	2

The above cost includes a few bricks, and some cement and labour, for fixing the door-frame, building the pillar for the equatorial stand, and two steps outside the observatory.

The lower walls were formed, as has been already stated, of 8 courses of red bricks in 9 in. work, the topmost course being bricks on edge. The two first courses in the ground were of common stock bricks, being cheaper than the Sussex red bricks. The pier to carry the equatorial was circular and raised 21 inches above the surface of the floor, and was surmounted by a circular piece of York stone.

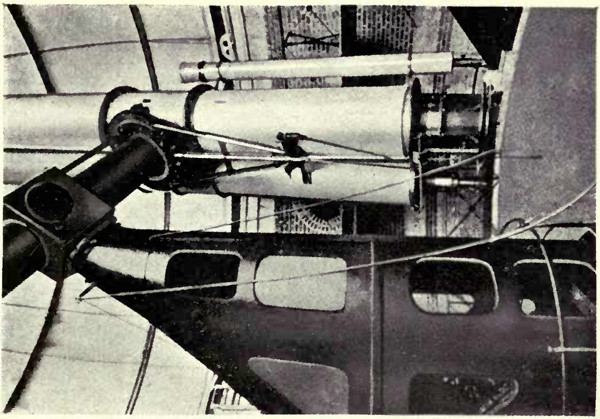
The cost of this brickwork, exclusive of the pillar, may be exhibited as follows :—

BRICKS AND MORTAR FOR THE JOB.

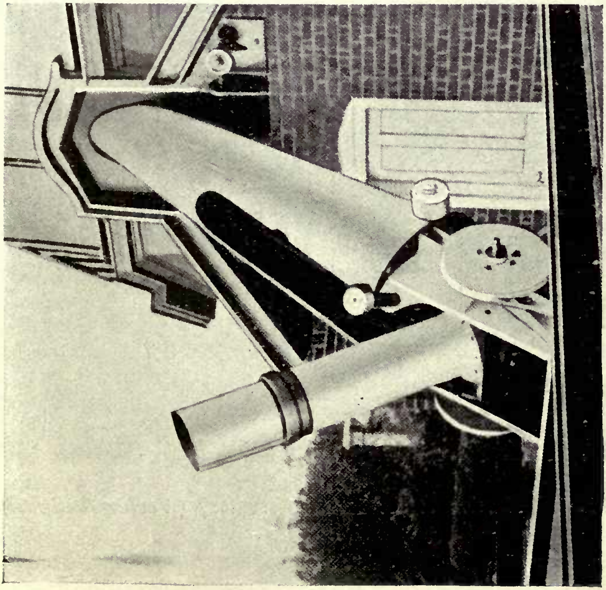
	£	s.	d.
1100 red bricks	3	5	0
200 stock bricks	0	7	0
18 barrow-loads of sand ($1\frac{1}{2}$ cubic yards) . .	0	12	0
$4\frac{1}{2}$ bags of lime ($\frac{1}{2}$ cubic yard)	0	4	10
Labour	3	16	0
	8	4	10

We have now to consider the upper (wooden) walls of the observatory. These are formed of upright and horizontal timbers, 4 inches square in section. The uprights are 12 in number, tied together at the top, in the middle, and at the bottom. The actual construction consists of 4 frames put together in the first instance as independent frames and then joined together by strong bolts with nuts. All the frames are 6 ft. high; 2 of them are 10 ft. 8 ins. long and the other 2 (which fit into these) are 10 ft. long, so that when all 4 are fastened together, and in their places, the external length of each side of the square is 10 ft. 8 ins. Each of the sides is trisected by means of the uprights. In the centre third of one side a door is hung. The upper half of the centre third of 2 of the other sides is appropriated to a window, whilst the fourth side is covered throughout.

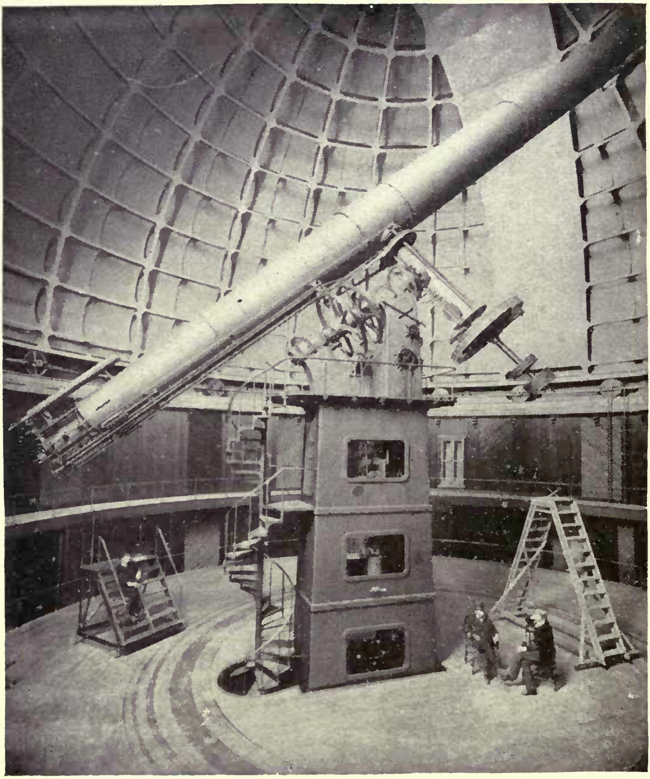
As regards the outer covering of the walls, I had some difficulty in making up my mind. In my first Sydenham observatory the walls were weather-boarded, and painted inside and out. Weather-boarding is a perfectly satisfactory method of covering a frame, but at Sydenham, in 1908, I decided on using galvanised corrugated iron, as much more quickly put up and much cheaper. I considered the possibility of using uralite, but rejected it, as I found that the fixing of it would be troublesome. In an observatory erected in the Isle of Wight by a relative of mine, and on very much the same principles of construction, the outer covering of the frame-work was upright match-boarding, with the usual grooves and tongues. This also is a perfectly satisfactory covering where time and cost have not to be studied, and where material of good quality can be obtained. In my Sydenham observatory the frames are not covered at all inside, and I think they are best left uncovered. Of course, the effect of covering the framework is pleasant to the eye, but on the other hand it renders more difficult the problem of keeping the inside and outside temperature of an observatory equable, which is a matter of much importance, to secure the good definition of objects seen through any telescope.



Photographic Equatorial of the Radcliffe Observatory, Oxford.



Siderostat Equatorial of the Cambridge Observatory.



36-inch Refractor of the Lick Observatory (*Warner & Swasey*).

Upper Walls.

	£	s.	d.
Timber frame-work, door, 2 windows	8	10	0
Lock and sundry fittings	0	9	9
17 pieces of galvanised corrugated iron (6′ × 2′) and screws	1	12	11
Labour for fixing the wall-work	1	1	8
	11	14	4

The entrance-door is on the N. side, and there are windows on the E. and W. sides. These supply adequate light, and may be regarded as away from what is normally the windward or stormy points of the compass, so far at least as the South of England is concerned. The windows, each about 2 ft. square, open as casements, with hinges on the upper side. Hung in this way, not on the right or left sides, as is usual with casements, the windows, even when open, do not generally allow rain to blow in if it should so happen that they have been left open and rain comes on during the observer's absence.

Use is made of the transverse ties of the framework of the walls by treating several of them either as they are, as shelves, or as supports for shelves of greater width than the 4 in. of the ties themselves; but 4 in. is quite sufficient for a shelf to accommodate most of the loose articles which are required inside an observatory, except the larger books and such things as boxes containing eye-pieces, etc.

The clock is placed in the S.W. angle of the observatory. It may be described as a very good ordinary regulator, showing, of course, sidereal time, with a secondary dial graduated to 24 hours. It was made by a very first-rate London clockmaker, now deceased, who, I think, had never heard of a sidereal clock; anyhow, had never made one until he made mine under my supervision. It cost £28, and often goes for many weeks with a rate of about a second a day—not bad, for what I may call a merely civilian clock.

At East Bourne I used to rate it by means of a transit theodolite discarded from the Ordnance Survey, and which I therefore picked up cheap; but now at Sydenham I have no transit instrument, or even a substitute for one, as I find it easy enough to convey the time from the Westminster clock every few days by means of a good watch with a second's hand. This celebrated clock, as is well known, is seldom more than 1 second wrong. The time thus obtained and imparted to my clock after an interval of an hour or two is never sufficiently wide of the exact time to cause any difficulty in finding a celestial object by means of the equatorial, my meridian being, it is to be remembered, only by a very little difference W. of Greenwich.

Proceeding onwards, and, as a literal fact, upwards in the construction of the observatory, the next and, in a certain sense, final matter is the roofing-in, and this is the most difficult and troublesome matter of all. It is so because a revolving top (commonly called a dome, though in small observatories it is seldom such), the plan of which is a circle, or a polyhedron rising from a circle, has to be arranged to work on the top of the square of the walls. It is in effect a circle inscribed in a square, to use the language of geometry, which has to be dealt with, and it is self-evident that the circle must be so contrived that it has a bearing on the middle of the straight sides of the square, which means, of course, that the 4 corners of the square obtain no cover from the domed roof.

In order to obtain as stable a bearing for the dome as possible, the angles of the wall-frames are tied by substantial pieces of timber, which convert what was a quadrangle into a not quite regular octagon. If this conversion is judiciously carried out by the joiner the effect is that the revolving dome is provided with a substantial bearing which is practically circular and continuous.

The corners mentioned above as exposed to the sky have to be filled in with a water-tight roof. This is best done by providing a triangular ceiling at each corner of match-board covered with lead, turned up about 2 inches against the channel-plate (to be described presently), and turned down over the edge of the walls to an extent sufficient to prevent rain being blown up under the lead. An overlap of 2 inches should in general suffice, unless the building is in a very exposed situation. I have used lead, and recommend it, because it is, of course, water-tight if put on by a competent plumber, and can be used again if the observatory has to be removed to another locality. It is true that lead is expensive, and cheaper materials may be employed, such are sheet-zinc, tarred felt, and painted canvas, including Willesden canvas; but these materials can never be removed for use a second time, and the 3 last-named are not only perishable in a general sense, but are difficult to keep in water-tight repair.

Here it may be remarked that an eaves-gutter to carry off the rain which falls on the roof may perhaps be deemed by some persons to be desirable, but this is a refinement which I have not adopted, because the rain-water which falls on the roof runs downwards more or less clear of the walls to the concrete footings of the brick wall outside the building, whence it finds its way, by gravitation, to an ordinary storm-water garden drain some 6 feet below the level on which the observatory is built.

Flat Part of Roof.

The cost of the flat roofing at the corners just described was as follows:

	£	s.	d.
60 ft. run of 6-in. match-boarding	0	7	6
Labour (carpenter)	0	19	11
71 sq. ft. of 3-lb. lead	2	1	9
Labour (plumber)	0	16	6
Nails, screws, and other materials	0	1	6
	4	7	2

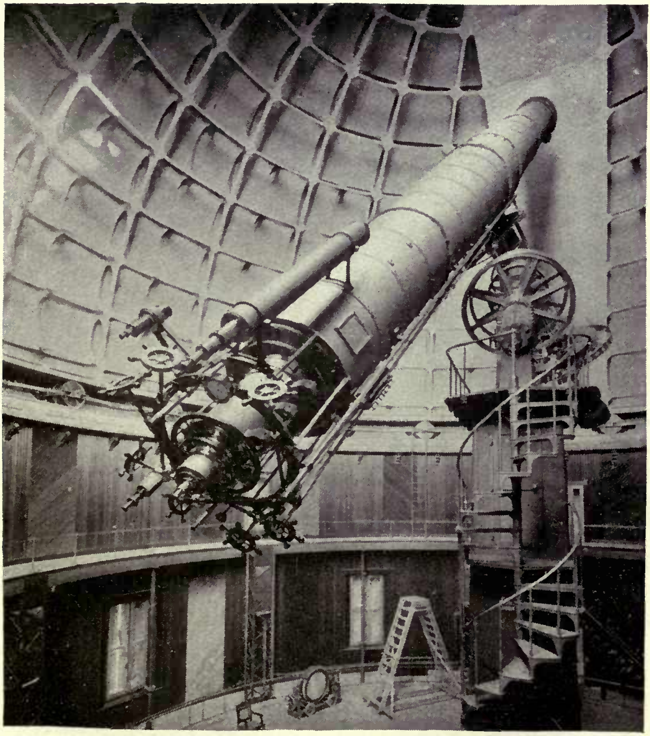
The Dome.

We now come to the most troublesome feature in every observatory—the construction and movement of the dome.

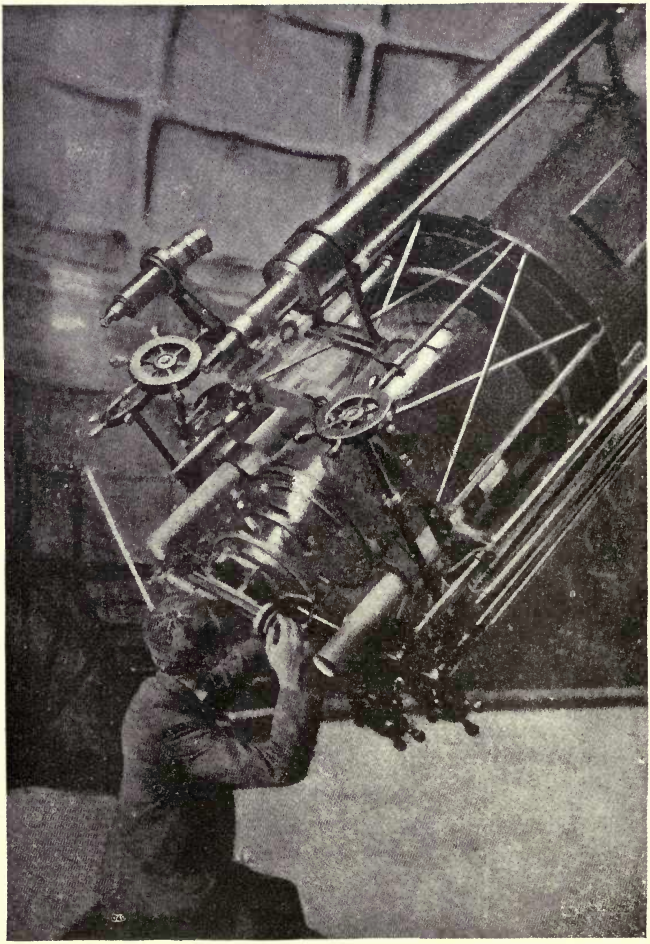
On the top of the 4 walls and on the continuous bearing already mentioned there is fixed a circular wall-plate, as it is called by the builders. This plate is formed of timber put together in pieces about 2 ft. in length, so that when they are all fitted together they shall make a ring 9 ft. 8 in. in its internal diameter, and 10 ft. 4 in. in its external diameter ; in other words, the width of the rim is 4 in. On the top of this are fixed segments of a circle, 9 in number, of cast-iron, slightly hollowed in the middle, with a rim $1\frac{1}{2}$ in. high on the outside, and somewhat less on the inside. Thus is formed a sort of circular tramway, in which 3 or more iron spheres or old-fashioned cannon-balls, about 4 in. in diameter, run. These permit the rolling movement of the dome.

I have only 3 such balls for the 10-ft. dome, but 4, or even 5, might perhaps be better. They would, however, only be better if they were all very truly identical in diameter. It is doubtful whether 5 such balls could be obtained in simple cast-iron ; they would have to be turned to a given diameter in a lathe by a competent workman, which would involve a good deal of extra expense beyond the cost of the simple casting. Yet, unless they were true spheres and of identical diameter to a nicety, they would be useless for distributing the weight of the dome over the additional points of bearing beyond the bearing afforded by the 3 balls with which one started.

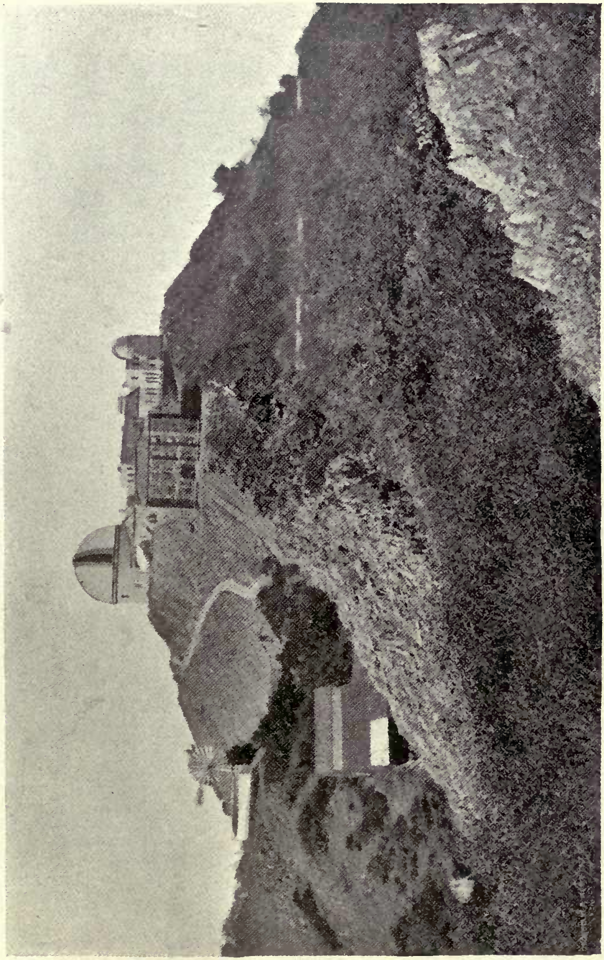
It should be added that even 3 balls have a tendency to get together, however carefully they may have been started with an angular interval between them of 120°. I find it a good plan to mark on the dome itself inside, or on the circular wall-plate, points which are 120° apart, and now and again to bring 1 ball up to one of these marks, and then see how



36-inch Refractor of the Lick Observatory (*Warner & Swasey*).

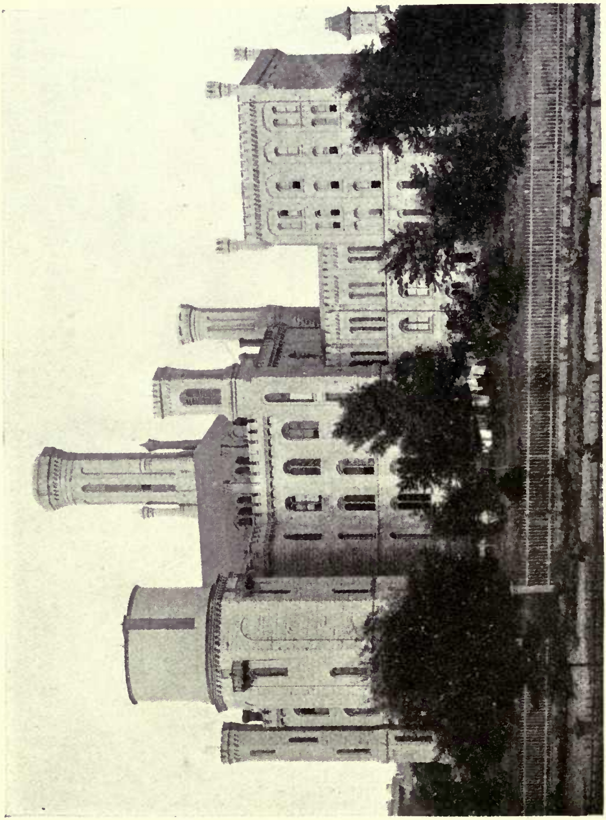


Eye-end of the Lick Refractor.



Distant View of the Lick Observatory from the E. (*H. E. Mathews*).

FIG. 330 PLATE CXXIII.



The Dearborn Observatory, Chicago University.

far the other 2 balls have got away from what should be their marks. When the displacement has become considerable it should be rectified by prising up the dome (with a strong lever, such as a piece of quartering), so as to set free the 2 displaced balls, which can then be moved backwards or forwards to their proper positions. It is obvious that if the balls get very much displaced, so that, say, the interval between 2 of them has become as much as 160° or 180°, a very great strain is put upon the dome, which will tend to overbalance itself, and come down upon the iron channel-plate so as eventually not to be movable at all, even under the most powerful manual pressure.

The construction of the dome is the most difficult, and indeed the only difficult, part of the whole undertaking. We have, first of all, to start with a cill, on which the roof has afterwards to be built up. It is absolutely necessary that this cill should be very strong and rigid, because it has not only to sustain the weight of the rafters and roofing of the dome, but also to stand the strain due to the fact that the whole of the superincumbent weight rests on only 3 points (*i.e.* balls), and, moreover, is subject to the strain which naturally arises each time that the dome is pushed round on its ball-bearings.

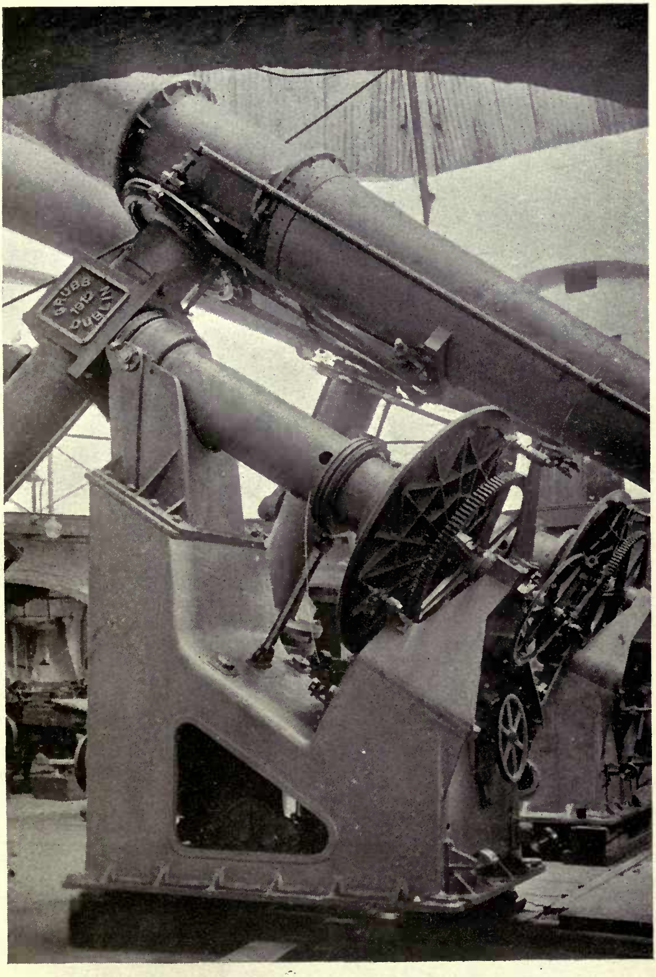
When the diameter of the cill is no more than about 8 ft. the cill may be best made of 5 or 6 layers of 1-in. boarding, cut in segments and glued and screwed together, the joints of each one of the 5 or 6 rings thus superposed breaking joint with the ring on either side of it, until the desired thickness is arrived at by the requisite number of rings. On the inside of the composite ring thus built up a band of sheet-iron may be fastened by way of giving further stiffness.

As the diameter of my dome was more than 8 ft., to wit, 10 ft., I had the foundation cill of the dome constructed somewhat differently. Instead of its consisting of one ring of 5 or 6 layers of wood in contact, it consists of 2 rings, each of one thickness of stout timber, $2\frac{1}{2}$ in. thick, separated from one another by stout upright ties 7 in. long, and secured on the upper side and on the lower side by coach-screws countersunk on the lower side. This gives a very strong and substantial compound ring on which to build up the roof.

To the underside of the foundation cill, however it may be constructed, 2 concentric rings of iron are fixed by screws passing through holes in the iron rings. The holes for the screws must be countersunk. These rings must be carefully forged, or, better still, be made of rolled iron about 1 in. wide and $\frac{1}{2}$ in. thick. The central point between these 2 rings, when fixed to the wooden cill, and the central point of the hollow channel in the fixed plate (already described) of the main building, must coincide exactly—that is to say, must be circumferences of circles of absolutely identical radius. Unless there is this absolute coincidence there will be great and inconvenient friction when the dome comes to be turned round on its ball-bearings. It is this part of the whole observatory which most requires careful setting out and good workmanship.

From the upper side of what I have called the foundation ring rise the rafters, 14 in number. These do not meet in what is called, in an ordinary roof, the ridge-piece, but at various points in a rectangular framework, about 2 ft. by 1 ft. 6 in., the exact size depending in every case upon what is wished to be the pitch of the roof, and the width, when open, of the shutters. The fourth side of the rectangle is, so to speak, non-existent—that is to say, it is formed by a cross-bar of iron, set edgeways, so as to block as little as possible of the sky when the telescope is directed to that part of the sky which lies behind the bar. Two shutters, meeting one another half-way, rise on hinges attached to 2 adjacent rafters, which, of course, for that purpose, are arranged parallel to one another. The rectangular frame, which is supported by the rafters, constitutes a flat roof to the dome.

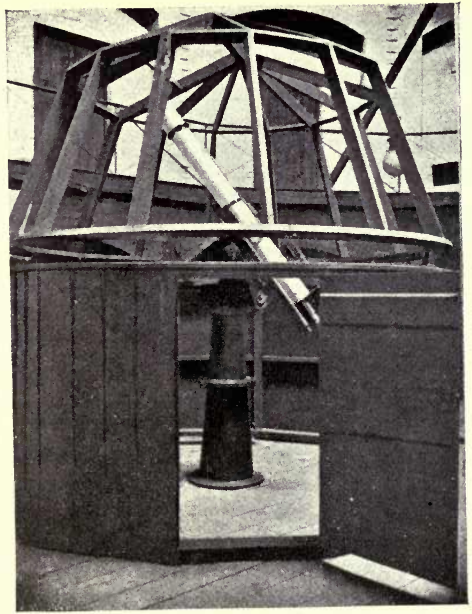
In order that the telescope may be able, on occasions, to be pointed to the zenith, this flat roof is made to open on hinges at the back (*i.e.* away from the shutters), and is guided up and



Equatorials under Construction at the Dublin Works, 1912 (*Grubb*).

No. 1 for the Johannesburg Observatory; Object-glass 26 inches.
No. 2 for the Santiago Observatory, Chili; Object-glass 24 inches.

The Author's Observatory, at Lethen Grange, Sydenham.



Simple Wooden Framework of Revolving Roof, suitable for covering with either papier mâché or canvas.

down by having 2 iron quadrants working through iron catches, motion being imparted by a pair of ropes running through pulleys inside the sloping roof. The flat roof is covered with thin lead, and the hinges are protected by large pieces of leather running all along the back-side, and made, as far as possible, waterproof by means of paint. By the foregoing arrangement the flat roof, or lid, of the dome (as perhaps it had better be called) may be raised from the horizontal, through 90°, to the vertical ; but I rarely raise it so much, not wishing to strain the leather covering of the hinges.

In order to open the 2 main shutters, the lid has to be raised 3 or 4 in. to get it clear of the shutters. Special provision is made by grooves on each side of each shutter to keep out the rain, or, rather, to allow any rain which gets in to run down.

The shutters can be, and often are, arranged on a different plan, whereby they do not lift but slide, one sliding to the right, one to the left ; or the two are replaced by one which may be constructed to slide either to the right or to the left as may be wished. The lid also, in this form of construction, slides on bearings of its own, formed as a framework outside the sloping roof. I have never been called upon to manipulate shutters arranged in this fashion, and therefore cannot speak from personal knowledge of them ; but I should fancy that it was more difficult with such shutters to exclude the rain than with shutters such as I have at Sydenham. At any rate, my lid, which was constructed to slide in this way, I had altered at once to its present form.

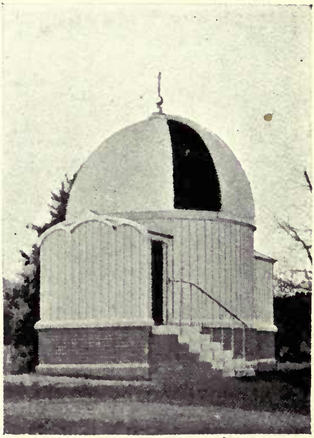
There is yet another form of shutter which has some advantages in windy situations. It really consists of two shutters, but, instead of lifting in two halves, or sliding to the right or left, as just described, it slides up and down ; and when down—that is, open for use, projects downwards, overhanging the eaves of the building. This is very inconvenient. If up-and-down shutters are to be employed at all, they had better be so arranged as never to uncover more than half the opening in a vertical direction. In other words, to open the observatory for use, the upper half of the shutter must slide down over the lower half; or the lower half must slide up behind the upper half.

This method of procedure is open to the objection (which in certain temperatures of the atmosphere is very real) that it limits the ventilation of the observatory, and requires a cumbersome system of weights to counterpoise the shutters when they go up and down; which weights dangle about inside the observatory in a way which is exceedingly inconvenient, though more or less unavoidable. Besides these objections, this system of shutter is much more expensive to construct, and not easy to maintain in smooth and pleasant working order, to say nothing of the difficulty of excluding rain and making the place watertight.

The question of the material for the roof I have always solved by using $\frac{1}{2}$-in. match-board, fastened with screws, and well stopped with white lead and painted. When my observatory was re-erected at Sydenham in 1908, after 37 years' exposure to the weather, not one single board was found to be in the least decayed or damaged so as to need replacement. Two or three boards had been cracked in taking them to pieces at East Bourne, but these cracks were readily made good by white lead-stopping and paint. In the case of a new roof constructed of boards suspected to be insufficiently seasoned, it might be a good precaution to cover them with canvas, well painted on both sides, and fastened down with copper tacks.

Willesden canvas, sheet copper, or zinc (without boards), may also be used for the dome. I have heard Willesden canvas well spoken of, but have not used it in any position exposed to the weather for any length of time. The copper or zinc may be of the ordinary roofing thickness, or even thinner. The pieces must be cut into sectors to fit the bays of the dome. Each piece must be secured at the top and bottom, and on cross-battens, with copper or zinc nails; but the sides must be

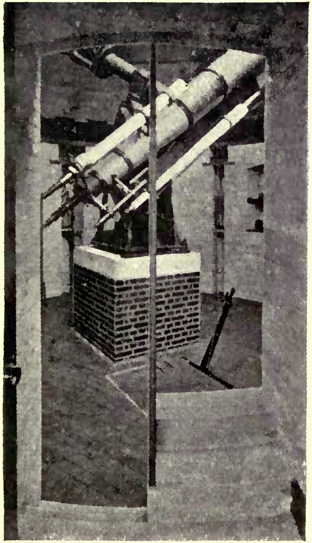
20-ft. Papier-mâché Dome erected at the Royal Observatory, Cape Town, with opening extending beyond the Zenith (*Grubb*).



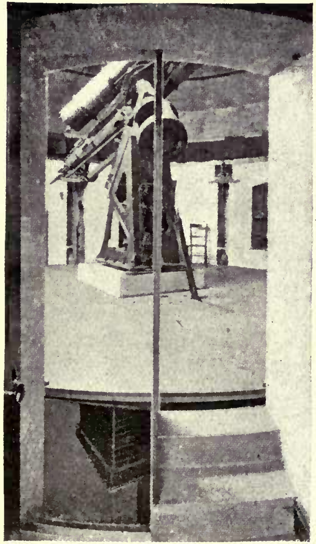
15-ft. Papier-mâché Dome, mounted on iron-framed Observatory covered with wood (*Grubb*).

Barcelona University (*Grubb*).

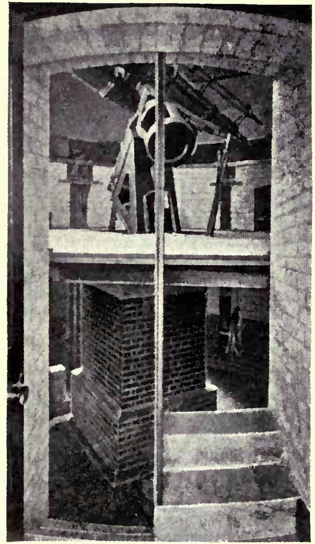
Papier-mâché Dome of 37-ft. diameter, erected at Calton Hill Observatory, Edinburgh (*Grubb*).



Lowest Position.



Mean Position.



Highest Position.

Elevating Floors for Observatories.

Three views of Sir H. Grubb's Lifting Floors as applied to a small observatory of 20 ft. diameter, and worked by a handle without hydraulic power.

counter-lapped (not soldered) in order to allow for expansion by summer heat. Patterns for the sectors must be prepared in brown paper after the frame of the dome has been put together.

Dome :

	£	s.	d.
Contract price of dome, including iron rings and iron channel-plate	30	18	11
Labour: carpenter putting same together at Sydenham	1	19	8
	32	18	7

Adding together all the items given previously under their various heads (about £69), it may be taken that the Sydenham observatory, as it stands, represents a cost of, as nearly as possible, £70, after adding the value of some etceteras which I did not have occasion to buy specially. The cost of reproducing it *de novo* might be more, because of the rise in the price of labour and materials since the dome was constructed in 1869; but, on the other hand, several pounds might be saved in the foundations.

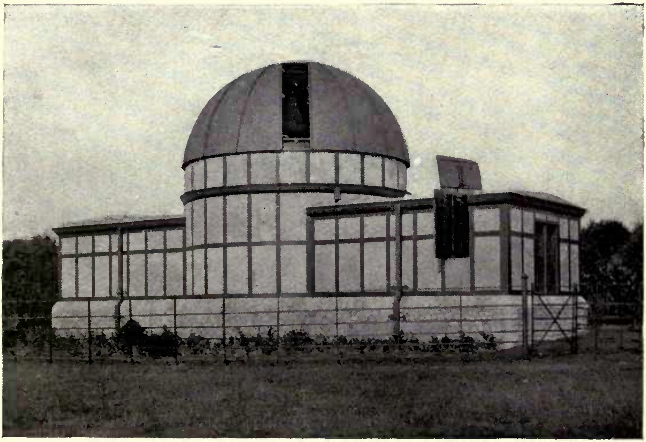
Thus far I have been describing what I have, more or less, done myself, or what has been done under my own direct supervision; but I am prepared to find that many of my present readers will think that my observatory, as it now stands at Sydenham, is too solid; in other words, has been too costly for the purposes of amateurs of moderate means and ambition, though it was far from my intention to spend on it more than I could help.

I fear there might be some foundation for this criticism, and, accordingly, I would recommend, as an alternative to my plans, a proposal which was put forth nearly 40 years ago by the late Rev. E. L. Berthon, Vicar of Romsey, the inventor of the now celebrated "Berthon" boat. A description of Mr. Berthon's form of observatory, from his own pen, appeared in *The*

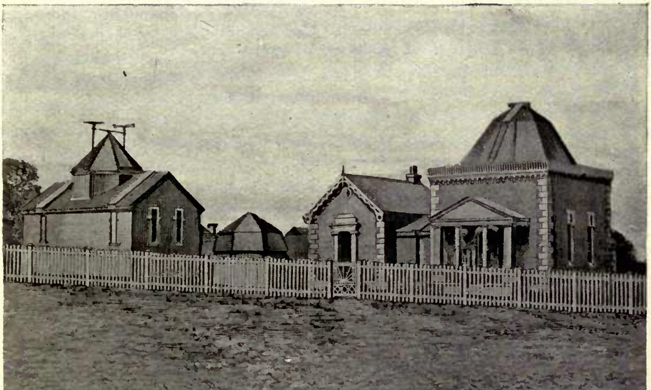
English Mechanic of October 13, 1871; and, as a consequence of the publicity acquired in that way and otherwise, I have reason to believe that a number of structures on the Romsey model have been erected in various parts of the United Kingdom.

One such was put up about 20 years ago by the late Mr. T. R. Clapham, of Austwick Hall, near Lancaster, a description of which, from his own pen, appears in the second volume of my *Handbook of Astronomy.* Mr. Clapham was a clever and ingenious amateur mechanic, and his observatory, which I have visited, represented Mr. Berthon's ideas, with sundry minor improvements and developements of an advantageous character; but I will not go over again the ground which Mr. Clapham kindly occupied for me in the pages of the book which I have just mentioned.

My object in going into the foregoing details has been to encourage my readers who possess telescopes which, though in a certain sense portable, are not readily portable, to make them fixtures, and house them in observatories properly fitted up. There can be no question whatever that a smaller telescope, equatorially mounted on a fixed stand, and protected from the weather, is capable, in careful hands, of yielding more useful and profitable results, and in a more pleasant and convenient manner, than a larger telescope mounted only on an altazimuth stand which has to be carried in and out of a dwelling-house on every occasion that it is used. It is not always easy to instil such ideas as these into the minds of junior astronomers starting on an astronomical career. To all such I would simply say that I am giving expression to the experience of half a century derived from the ownership in succession of telescopes with apertures of 1½ inches (unmounted), 3 inches (mounted on an equatorial block without circles), 4 inches (mounted equatorially in an observatory) and 6 inches (ditto). Perhaps the most common mistake made by juniors of the type which I have now in mind is that of spending all their available money in increas-

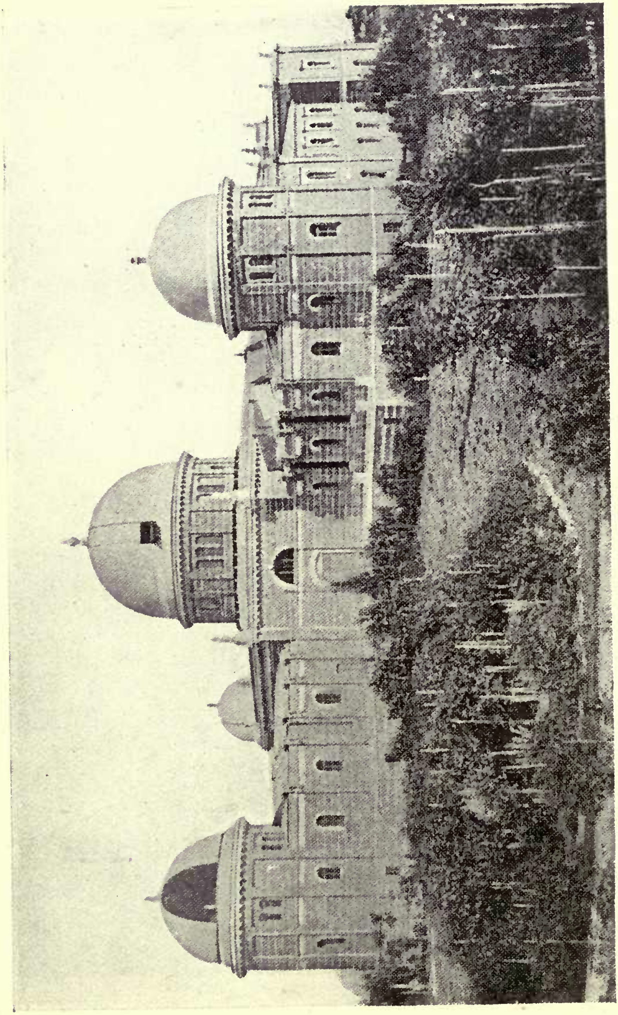


Sir W. Peek's Observatory, Rousden, Devonshire.



Mr. J. Tebbutt's Observatory, Windsor, N.S.W.

FIG. 343 PLATE CXXIX.

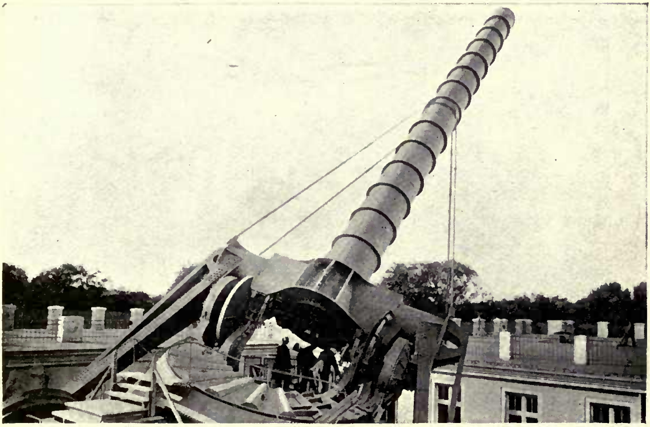


The Imperial Observatory, Vienna.

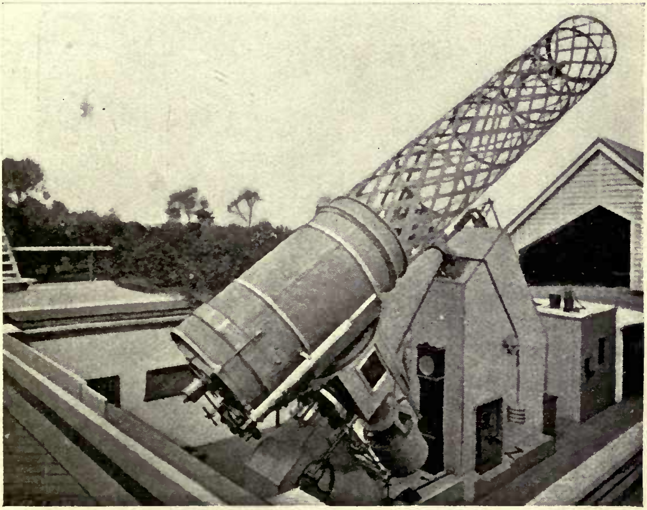
ing the aperture of their instrument, and in regarding its stand and its house as minor matters. This is a very grave mistake, especially in regard to its stand. The use or non-use of an equatorial mounting, however rough, with circles however coarse in their graduations, contrasted with an altazimuth mounting, however smooth and delicately made, is great: it means the difference between an hour's work in studying a dozen objects with ease, or 2 hours' work in hunting for and studying half a dozen objects with trouble and difficulty.

I have met with cases of persons owning equatorials with detachable telescope-tubes whose *modus operandi* is to keep the tubes in boxes in their houses, and have equatorial stands in the open air in their gardens covering up the circles, etc., with boxes or waterproof covers when not in use, carrying the tubes out of the house and back again as was required; but, however unavoidable in view of particular circumstances this procedure may be, it is not one which will be found conducive to good work or much work.

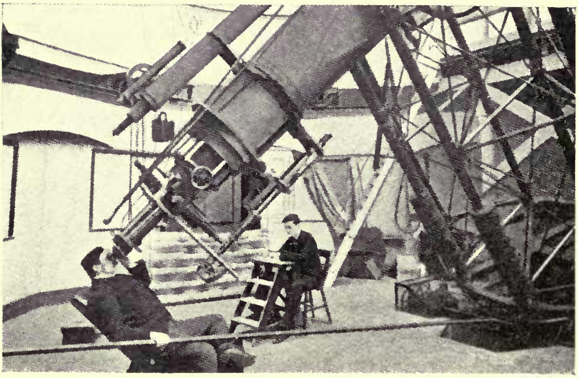
Fig. 344 is a view of a telescope of entirely novel construction so far as its mounting is concerned, which has been erected near Berlin by an enterprising German astronomer, Dr. Archenhold, in spite of much hostile criticism on the part of German men of science. The problem to be solved was how to work a telescope of great size and power without the expense and inconvenience of a very bulky and unhandy stand covered by an enormous dome expensive to construct and laborious to manipulate. The difficulty of working giant telescopes with tubes 50 feet or more long is very great, especially when it is a question of observing at one time objects low down towards the horizon, and at another time objects overhead in the zenith. This difficulty nowadays is met in large observatories, constructed regardless of expense, by surrounding the main pier of an equatorial with a travelling floor, which can be raised or lowered at the pleasure of the observer. Such a system is illustrated elsewhere (see Figs. 338–340, *ante*). By means of such a floor the observer can put his seat in any position which suits him, but the time and labour involved in bringing about the necessary changes are very obvious. Dr. Archenhold has been able to arrange to keep the eye-piece near the centre of motion by swinging the telescope tube in a great fork, which, provided with suitable counterpoises, permits of the tube being run up into the air as may be required, whilst the heavy movable parts are placed on a solid concrete foundation, which secures due stability coupled with great compactness. In this way the working parts of the mounting are housed under a structure not expensive or difficult to build, because of no considerable size, whilst the telescope tube, when not in use, is brought down into a horizontal position and protected from the weather by a cheap portable roof, which is made to run on it or off it as required. The result of fitting up the instrument in this fashion has been to do away with the necessity of having a large and costly dome; and the whole instrument, with its protecting roof, has cost no more than about £13000, of which £2300 went in the object-glass, which is said to be an excellent one, by Steinheil, of Munich, and is 27 inches in diameter. It will be interesting to watch the future history of this novel construction, which was only finished and brought into use in April 1909.



Telescope at the Treptow Observatory, Berlin.

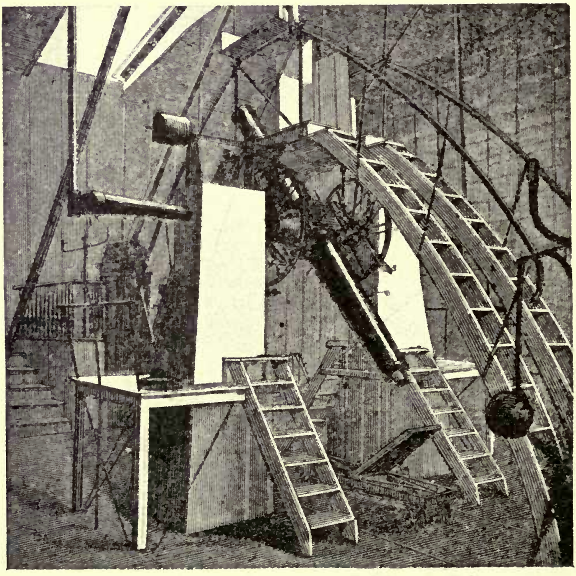


4-ft. Reflector of the Melbourne Observatory.



28-inch. Refractor of the Greenwich Observatory.

In use for visual work.



Meridian Circle, U.S. Naval Observatory, Washington.

CHAPTER XV.

TIME AND ITS MEASUREMENT.

Years.—Months.—Weeks.—Days.—Hours.—The Sidereal year.—The Mean Solar Year.—The Anomalistic Year.—Hipparchus.—The Calendar and the reforms it has undergone.—By Julius Cæsar.—By Pope Gregory XIII.—His Calendar adopted by England.—But not by Russia.—"Old Style."—"New Style."—The Lunar Month.—The Week.—Quotation from Laplace.—Savages count time by "Moons."—Divisions of the Day.—The 24-hour Day.—a.m. and p.m.—Railway time.—The "Prime Meridian."—Greenwich chosen for this.—Standard time.—Usage of different Nations.—Where does the day begin?—The Transit Instrument and how to use it for obtaining the time.

"TEMPUS FUGIT" is a truism which affects us all, from babyhood to dotage; but it is a matter which, on its historical side, has many fascinating features.

A chapter on "Time and its Measurement" might readily reach a great length, but I will put forward now rather the utilitarian side. The subject will be most conveniently approached by posing certain questions to be used as pegs on which to hang such information as it is intended to give. Let us start, then, with the following questions:—

1. What is a year?
2. What is a month?
3. What is a week?
4. What is a day?
5. What is an hour?
6. Where does time begin and end?
7. How is it measured?
8. Who starts and runs the almanac?

All these questions may be said, at the first glance, to have a very commonplace appearance, and the solid science which lies behind them all is far from being obvious ; nor do the questions, when properly handled, admit of such simple and easy answers as might at first sight appear.

What is a year? The answer is the time occupied by the Earth in performing one complete journey round the Sun. This answer seems sufficiently simple, but it is not so in reality, because we have to consider where the Earth starts from, and where it arrives at the end of the interval which we call the "year." This interval, *simpliciter*, is the interval which elapses between two successive passages of the Sun through the same equinox, and *primâ facie* ought to be the time which elapses from the moment when the Sun leaves a fixed star until it returns to it again. This kind of year constitutes the "sidereal year," and in our current notation consists of 365 d. 6 h. 9 m. It unfortunately happens, however, that the equinoxes are not fixed points, but are possessed of a small retrograde motion from E. to W., which is constantly in progress, and the result is that the Sun gets round again to the equinox from which it started before it gets round to the Star from which it is supposed to have started. The difference of time is a little more than 20 minutes, so that the year (which we call the "mean solar year") is 20 minutes shorter than the year measured by the stars, or sidereal year. The length of the mean solar year is therefore 365 d. 5 h. 48 m., neglecting fractions, and is the year which we talk about in common conversation and in almanacs prepared for terrestrial purposes.

Besides this, astronomers take note of the "anomalistic year," which is different again, being 365 d. 6 h. 13 m., and depends upon the rather abstruse fact of the line of apsides of the Earth's orbit being subject to a progressive motion in virtue of which the time between the Earth passing one perihelion and another differs from both the mean solar year and the sidereal year.

The month and the week depend more directly upon the Moon than upon the Sun for their basis, as we do not speak of a solar month or a solar week. Still, we have the calendar month of 30 days, which is of very ancient origin, having been handed down to us from a remote period when the Sun was assumed to pass through the 12 signs of the Zodiac at an even pace, with 30 days allotted to each span ; but, as this supposition is at variance with the fact, it was soon found that, to treat the year as consisting of 12 months of 30 days each, or 360 days in all, led to such an estimate of the year landing people in difficulties. Hence arose the necessity of putting on an odd period of several days to secure some sort of uniformity between the movement of the Sun (or to speak more correctly, the movement of the Earth round the Sun), and the year as adopted for the purposes of civil reckoning. When an adjustment of some kind was first found to be indispensable it began with the addition of 5 days to the year, one of which was allotted to certain of the 12 months. Then it was discovered, and this more than 2000 years ago, that 5 days was not enough, and that it ought to be $5\frac{1}{4}$ days. Next it was found that the period of $5\frac{1}{4}$ days was several minutes too much, and that 5 h. 55 m. was nearer the mark. This discovery was due to the great Greek astronomer, Hipparchus, who flourished in the 2nd century B.C. It is in the highest degree creditable to him that he arrived at a value so very near the truth, for the best modern results show that he was only wrong by about 6 minutes. This statement does not exhaust the details of this very tangled question. Julius Cæsar was the man who may be said to have started our calendar nearly in its modern form. He could not, of course, take count of fractions of a day, and was obliged to assume that the discrepancy already mentioned was an exact quarter of a day, and would be cured by dropping in a whole day every fourth year. [1] The idea was plausible, and it answered its pur-

[1] The bissextile day = the *second sextile day*, or the 6th day before the Kalends of March (the Roman Notation) reckoned *twice*.

pose for a long while, but by the middle of the 16th century things had gone astray again, so that the year began 10 days out of place from the day settled by the Council of Nicæa as the 1st day of the year, namely March 21. This was the origin of what we call the Gregorian reform of the calendar, which took its name from Pope Gregory XIII., who brought it about in 1582. He succeeded in imposing his suggestion on the States of Europe of the Roman Obedience, but the Protestant States and the Greek Church did not follow suit. In England the new style was not adopted till 1752, when by Act of Parliament 11 days were ordered to be dropped out of the English chronology at that epoch. This enactment caused a good deal of annoyance and inconvenience at the time, and explains why in so many places in English history we find double dates, marked O.S. (old style) and N.S. (new style), and why the national financial year, which used to end at Lady-day, now ends on April 5. Even to this day the Greek Church sticks to the old Julian calendar, and the discrepancy between the two styles has grown to 13 days.

Various other expedients have been propounded, some of them of great exactness, for rendering more scientifically exact the Gregorian Calendar, with its arrangement of leap years and so on, as we now use it ; but, as it is a matter of adding or subtracting an extra day in the course of several thousand years, no useful purpose would be served by dwelling on any of these proposals in this place.

The Lunar Month of 28 days, or thereabouts, must be mentioned, not that it has any great bearing upon our daily affairs except as regards a calendar of the high and low tides of the ocean—a matter which comes home to dwellers on the sea-coast.

We must now say something about the "week," which is a unit of time of the widest application. Its origin is lost in antiquity, and, though it is usual to regard it as the one-fourth portion of the lunar month, it is impossible to doubt that, after all said and done, it is a memorial of the creation of the world, and therefore in use for nearly 6000 years. Laplace's observations on this subject deserve to be noted: "The week, from the very highest antiquity, in which its origin is lost, has, without interruption, run on through ages uniting itself with the successive calendars of different nations. . . . It is, perhaps, the most ancient and most incontestable monument of human intelligence, and appears to indicate that all such intelligence came from one common source"—which, Laplace might have added, was divine.[1]

The part played by the Moon in the computation of time must not be too lightly esteemed because, from the earliest ages and down even to the present time amongst savage and semi-civilised nations, the phases of the Moon, beginning with the first appearance of the New Moon, furnish a chronological scale accessible to everybody and easily utilised. Hence we find that savages often indicate considerable periods of time, which we should speak of as so many months or years, by saying that such and such a thing happened so many "Moons" ago. This meaning, in other words, that, since the event in question happened, they have seen the Moon wax and wane so many times. It is easy to see that, if a canoe was upset on the day that the young Moon was first seen, and that a young Moon was seen again last night, the interval is that of one "Moon," an interval which might be indicated in days if, since the accident, every sunrise or sunset had been noted by means of a notch cut in a stick. Even this method of computing intervals of time has been used on occasions; for instance, by shipwrecked crews.

This brings us to the next unit of time—the "day." This, of course, is in universal use all over the world by everybody for every conceivable purpose, but here again the insoluble problem comes before us, Who invented the idea of dividing

[1] Bishop Christopher Wordsworth, in his *Commentary on Genesis*, has some interesting remarks which deserve attention.

the day into 24 hours, or the alternative reckoning of 12 hours of day and 12 hours of night? Here, again, are questions which cannot be answered off-hand, and which in a certain sense are unprofitable questions. Hipparchus seems to have divided the day into two equal portions of 12 hours each, beginning one of his portions at midnight and the other at noon; but it is not clear whether this was his own original idea or whether it was borrowed from somebody else. So many systems were formerly in vogue, alike as to principles and details of counting the hours, that it would be monotonous to attempt to describe them. Suffice it to say, generally, that whilst the total of 24 was in general use, there have been great varieties of practice as to the grouping and as to the starting-points of the hours. While some started from sunrise, others started from sunset. While some started from midday, others started from midnight. Others, again, ignoring a 24-hour division of the day, grouped the hours into triplets or quadruplets, which last-named system still prevails on board ship under the name of "watches."

Even the present generation of inhabitants of the Earth have seen, or are seeing, some momentous changes, two in particular which may be said to be not remotely connected with the introduction of railways. So long as people travelled in horsed vehicles, or on foot, there would never be much confusion between a.m. (*ante-meridian*) and p.m. (*post-meridian*) because, as a rule, in by-gone centuries people did not travel by night, or begin anything extending into the small hours of the morning. When, however, long main lines of railway, covering hundreds or even thousands of miles, became available for travel, the question of time-tables, and of resort to them by passengers, became serious, and the a.m.'s and p.m.'s of our forefathers became very ensnaring. The English railways, in that conservative spirit of the nation which occasionally is not to be admired, have met the difficulty by various shifts, none of which can be pronounced satisfactory. Whilst one line uses light-faced figures for times between 6 a.m. and 6 p.m., and black figures for the hours of night between 6 p.m. and 6 a.m., another line uses the same sort of figures for all hours and contents itself with a.m. and p.m., and leaves it to the passenger to find his way through the time-table as best he can. A third line, keeping to the same sort of figures, indicates times between noon and midnight by a thin line between the hour and the minute figures. These expedients are all very lame and unsatisfactory. Certain foreign nations have done much better by boldly taking the 24 hours of the day as the only proper scale, and timing their trains from 0 o'clock to 24 o'clock. Without doubt this is what, sooner or later, we shall come to in England, following, for instance, the Italians, and more recently the French (to some extent), who have not only adopted the 24-hour day for railway purposes, but for every purpose.

The second modern change in the computation of time alluded to above has had reference to what is called the "prime meridian," or zero for time on the Earth. Formerly every nation computed its time from its own capital, or some such equivalent fixed point of longitude. Thus, time in Great Britain was reckoned from the Greenwich meridian; in Ireland from Dublin; in France from Paris; in Spain from Madrid; in Germany from Berlin, and so on. So that a traveller passing, say, from Spain into Germany, would start with his watch showing Madrid time. When he entered France he would have to alter his watch from Madrid time to Paris time. When he quitted the eastern frontier of France his watch, regulated by Paris time, would be no good for German railway time-tables; and so on. The inconveniences attaching to this state of things have probably been experienced by many readers of these pages, but they are diminishing, and in the near future will practically cease to exist because the whole world is learning the advantage of having only one prime meridian for the whole world. By common consent, the meridian of Greenwich has been selected as the prime meridian of the world, with provision for local adjustments to meet the fact that the Earth turns on its axis once in 24 hours, and that it cannot, therefore, always be noon or midnight at every place on the Earth's surface at the same absolute moment of time.

What those adjustments are we have now to consider in a summary form, but, for details, reference must be made to such publications as *Whitaker's Almanac.*

It has been agreed by various nations that they shall take their time from Greenwich by differences of only whole hours, so that our ideal traveller from Spain to Germany will never have to alter the minutes and seconds of his watch, but only to remember that when he gets into Germany, or Austria, the official hour will be one hour in advance of Greenwich; in Turkey and Egypt 2 hours in advance, and so on. On the other hand, when he goes to America he will find that the official hour at New York is 5 hours behind Greenwich, and that the time is spoken of as "Eastern Time," the word "eastern" having reference to the position of New York with respect to the States of America. Further W., as he crosses the American continent, he will come upon three other "times"—namely, "Central," "Mountain," and "Pacific" times, which are respectively 6, 7, and 8 hours behind Greenwich time, whilst Eastern Canada starts the scale with "Atlantic" time, 4 hours slow of Greenwich. This system of nomenclature, depending on Greenwich, is not limited to the Northern Hemisphere, because our South African and Australasian Colonies have similarly adopted the Greenwich meridian. Some of these have split the hours and taken the intermediate ½-hour as the local standard time. It will show the comprehensiveness of this movement for standardising local times when I state that in Victoria, New South Wales, and Queensland local times are linked to 10 hours fast of Greenwich, whilst South Australia has chosen 9½ hours, and New Zealand 11½ hours fast of Greenwich for their respective bases.

The annexed diagram, which is published here by the kindness of the Society for the Propagation of the Gospel, though it

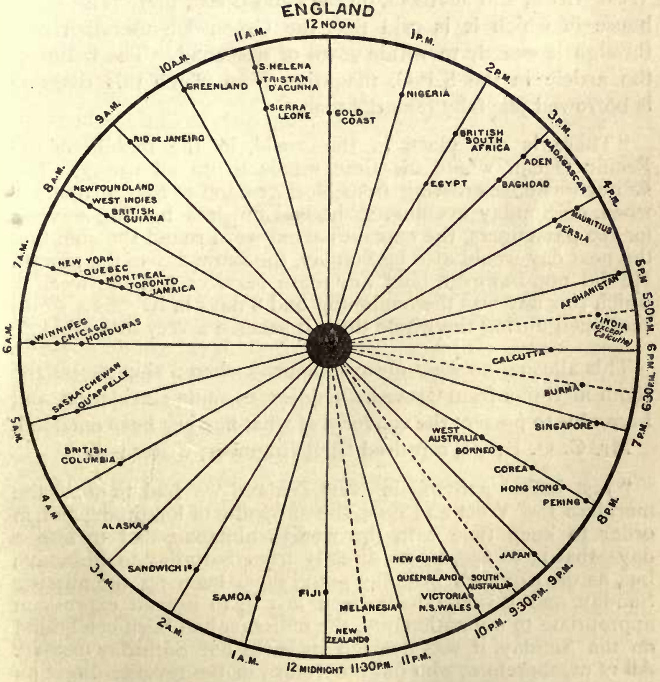


Fig. 348.—Time all over the world (*by permission of the S.P.G.*).

is not actually graduated according to the official nomenclature dependent on hours in advance of or behind the Greenwich meridian, will yet serve the useful purpose of informing readers what are the local times relatively to Greenwich of the countries which are named.

The meridian of Greenwich runs through France and North-West Africa, and at Accra, on the Gold Coast, there is a certain house of which it is said that the Greenwich meridian cuts through it exactly to within $\frac{1}{100}$th of a second. The writer of the article in the S.P.G. magazine from which this diagram is borrowed playfully remarks that :—

"There is one place in the world, in the middle of the Pacific Ocean, where the time seems to go all wrong. The Editor was once crossing from New Zealand to South America, when, on Sunday evening, as he had finished holding services for the passengers, the captain passed word round the ship that the next day would also be Sunday, the same day of the month. He did not, however, hold any more services, but the week of which this day was the beginning had 8 days in it. As a storm continued during the whole time, it seemed a very long week."

This allusion to what always happens when a ship passes the 180th meridian from Greenwich, deserves some elucidation, and I am able to present the converse of what has just been narrated.

Mr. C. O. Burge, a retired Civil Engineer, writes :—

"Just before arriving in New Zealand we had to cross the meridian 180° West and East, the antipodes of longitude, and, in order to keep time with the world's almanac, had to lose a day—that is to say, to go directly from Saturday to Monday ; but, as the captain's birthday would have been on the missing Sunday, and it would have been lost if, to use an expression appropriate to my nationality, the omission had been celebrated on the Sunday, it was decided to leave out Saturday instead. All of us, therefore, who did not return in the reverse direction lost a day never to be recovered, unless in the little pieces of the extended days of our return to the old country, possibly years later, while those who remained in the Antipodes never got it back at all. For us, there were only 364 days in that year, a sort of true Leap Year, for we jumped over a day—a missing

"'Syllable of recorded time.'

"In the case of voyages in the opposite direction—that is to say, eastwards across this meridian—an extra day must be interpolated to keep time with the world. It is said that an Irishman, which he wasn't at all, as he would say, being born on the ocean, was launched into this sea of troubles on the day following the 29th February of a Leap Year when the ship in which his mother was a passenger was crossing the 180° meridian eastwards. His natal day was therefore the interpolated 30th of February, which for him never occurred again. So, though he lived to a great age, he never had a subsequent birthday." [1]

This chapter may include the asking of, and the trying to answer, a very tricky question, "Where does any given day, say, New Year's Day, begin?" The most definite answer which can be given seems to be this—that, in the case of all nations which use maps which have the longitude of Greenwich as their zero longitude, their day must be regarded as commencing at the longitude of 180° E., and that accordingly as one starts from that longitude and works westwards, so the day begins, place by place, on the surface of the Earth as the E. longitude diminishes from 180° down to no longitude at all, which is therefore Greenwich itself.

As the 180th degree of E. longitude passes through a point in the Northern Hemisphere in Eastern Siberia, and in the Southern Hemisphere slightly to the E. of New Zealand, therefore in a certain paradoxical, or imaginary, sense the day for people in the Northern Hemisphere, whose longitude standard is Greenwich, may be said to depend on Eastern Siberia [2] as the place where their day begins, whilst people in the Southern Hemisphere under corresponding circumstances may be said to have their day start from near the eastern coast of New Zealand.

[1] C. O. Burge, *Adventures of a Civil Engineer*, p. 244. London, 1909.

[2] This is only true in theory, because practically the line of demarcation is treated as passing through Behring's Straits, and all Siberia as having *East* longitude for *time purposes*.

The foregoing pages may suffice for furnishing some elementary ideas on the general principles which underlie the measurement of time from the standpoint of one who regards the matter in its immediate bearings on the daily affairs of life; but a good deal more would have to be said before the subject of "Time" could be deemed at all exhausted. It would be necessary to tell the reader how the astronomical facts which control our measurement of time are brought down from the heavens on to the surface of the Earth, and how everything is tabulated to form the basis, first of our calendar, and then of our almanacs—but all these things would take us too far afield from the main purpose of the present volume.

In the chapter on the telescope[1] I have named all the equipment necessary for the ordinary purposes of an amateur observer; but if he wishes to go beyond the mere telescope and the clock, and the building to house both, there is one accessory instrument which he will find very useful, namely, the transit instrument for keeping his clock correct without the necessity of bringing the time home by his watch every few days, and then having in each case to convert the civil mean time into sidereal time.

The principle of the transit instrument is very simple, and the practical use of it is not at all difficult or troublesome; so much so that in remote country districts, away from towns and railway-stations, one occasionally comes upon a non-scientific country gentleman who, making no professions of astronomy, has and uses a transit instrument of some sort for mere time-keeping purposes.

The principle of the instrument is this: that every star crosses the meridian of a given place at a definite time, as laid down in the *Nautical Almanac*; and, if instrumental means are at command for determining the exact moment when a star crosses the meridian, and a *Nautical Almanac* (or some sufficient substitute) is also at command, the time is imme-

[1] Chapter XIV., *ante*.

diately obtainable. The accuracy of the result will depend upon the precision of the instrument used and the care which is exercised. Accordingly a large and carefully adjusted transit instrument will give a more accurate result than one which is small and only roughly adjusted. And such an instrument will give a better result than no instrument at all, for the time of the meridian passage of a star can be ascertained by such a thing as a wall running truly N. and S., the arrival of the star coming up from the E. in the line of the wall

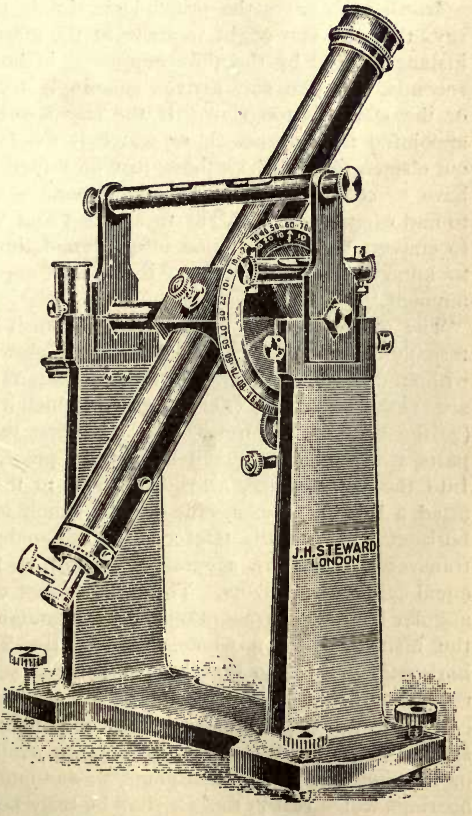


Fig. 349.—The Transit Instrument for obtaining the time.

being noted by a clock, or even a watch with a seconds hand.

In all such cases the principle is simply this: the almanac says that the star ought to arrive at the meridian at a certain instant marked by the time expressed in hours, minutes, and seconds. If the star arrives seemingly too soon the clock or the watch is too slow. If the star should arrive after its appointed time the clock or watch is too fast. In carrying out observations such as those just described the observer will have to convert sidereal time into mean solar time in order to find when the star ought to appear; and he will also have to convert mean solar time into sidereal time when he wants to know what hour of R.A. is on the meridian at a given moment.

The ordinary small or "Portable Transit Instrument" externally consists of 3 principal parts, which will be understood without difficulty by looking at the illustration (Fig. 349). There are (1) the telescope; (2) the stand on which it is mounted; and (3) the declination circle. The telescope tube is made in 2 parts, which are connected by a centre-piece, a cube in shape. Into the centre-piece, at right angles to the main tube, are fitted 2 branch tubes usually conical, which together form the horizontal axis of the telescope. The smaller ends of these transverse tubes are accurately ground to form 2 perfectly equal cylinders or pivots. These pivots rest on Y's, which are angular bearings surmounting the side-standards which support the instrument as a whole. One of the Y's is fixed in a horizontal groove, so that by means of a screw a small azimuthal motion may be imparted to the tubes as a whole which constitute the upper portion of the instrument. The vertical screws which go through the base are available for raising or lowering the entire instrument so as to make sure that the bearings which rest in the Y's shall be truly horizontal.

At one end of the horizontal axis a graduated circle is fixed, which is to be so adjusted that the telescope can be set to stars of any given declination. This circle is divided into degrees and subdivisions of a degree to be read, when great exactness is required, by means of a Verneer. At the opposite end of the horizontal axis provision is made to receive light coming from a lamp, and designed to illuminate the wires which are fixed in the eye-piece of the telescope. This light from the lamp, when it reaches the centre-piece, is reflected up the telescope to the eye-piece by means of a diagonal reflector fixed in the tube. A movable striding level runs across from standard to standard to be used to ensure the horizontality of the horizontal axis. The lamp may or may not be furnished with a sliding diaphragm to admit much or little light according as the star to be observed is a bright one, or a small one likely to be overcome if too much light is admitted.

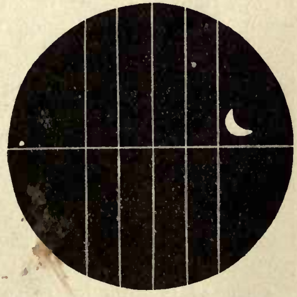


Fig. 350.—The Planet Venus and a Star as seen in a Transit Instrument.

Assuming that the transit instrument, so far as its special features have already been described, is in good working order, the climax of its success depends upon the wires which appear in the field of view when the instrument is open for use (Fig. 350). Literally only one vertical wire is required, because, supposing the instrument is in proper adjustment when the telescope is moved up and down, that one vertical wire travels in the meridian of the place of observation. It is, however, found in practice that an observer watching a star crossing one wire is more likely to make a trifling mistake in estimating the right moment by the clock than if he notes clock-time at 5 wires and strikes an average. It is usual, therefore, to provide 5 vertical wires, the calculation of an average from which is easy. While it must be stated that 3 wires are better than 1, but not so good as 5, yet 7 are better than either 3 or 5, and are provided in the large Transit Circles used in the great public observatories.

There is in every transit instrument one horizontal wire which serves to subdivide the field of view horizontally, and to indicate the place where the star may be expected to cross the field if the declination circle has been properly adjusted to the tabular declination of the star; but the horizontal wire has no direct connection with the results yielded as regards the time. It need hardly be stated that the accuracy of the ultimate result depends upon the instrument as a whole being accurately adjusted to its work, and this means that when moved up and down it should always be in the meridian; that the horizontal axis should be truly level; that the wires and the object should both be in focus at the same time; that the centre wire should be exactly in the optical axis of the telescope; and that the main tube should be truly at right angles to the horizontal axis. All these requirements are obtained by means of suitable adjustment screws, which need not be more particularly described here.[1]

Fig. 351 is intended to represent graphically a thing which is not very generally understood—the "Equation of Time": what it is, and why it should exist, or be required to be acted upon. The explanation is really very simple. We talk roughly of the day as an interval of time depending on the Sun crossing the meridian every day, or really on the rotation of the Earth on its axis—and such is the case, broadly stated; but the day which depends on the Sun differs from and is longer than the sidereal day by an amount (3 m. 56 s.) which, though trifling, will disturb the even course of events unless adjusted somehow, and the equation of time, as it is called, supplies the means of adjustment. The *fons et origo* of the whole inconvenience is

[1] See for such details my *Handbook of Astronomy*, vol. ii., "Astronomical Instruments," and other books of the like nature.

the fact that the Earth's orbit not being a circle, but an ellipse, the Earth's pace in moving round the Sun (or the apparent daily motion of the Sun through the zodiac) is not uniform, but is faster with the Sun in perigee in January than it is with the Sun in apogee in July. Hence it follows that, to keep an even day of 24 hours throughout the year (the "mean solar day"), we must equalise in some way the irregular length of the

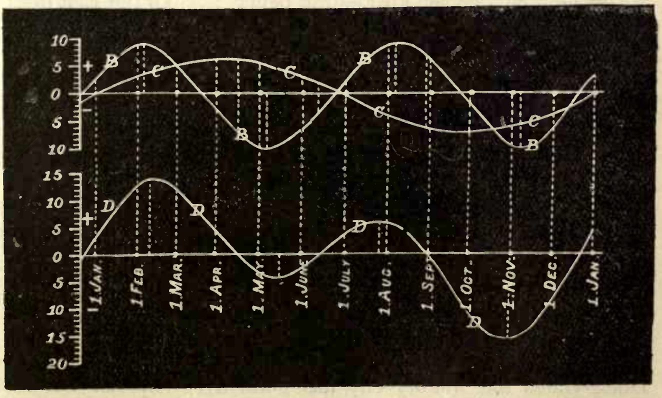


Fig. 351.—Diagram to represent graphically the Equation of Time.

apparent solar day, and the Equation of Time is the expedient adopted.

I have never seen the actual circumstances involved in the measurement of time and the differences of time resulting from the Earth's rotation on its axis so graphically expressed as they have been by Mr. E. W. Maunder in an obscure but very excellent monthly penny magazine called *The Cottager*, published by the Religious Tract Society. The whole article is worth reading, but the particular passage which I wish to assimilate will make the idea sufficiently clear. The ideal observer is supposed to have gone up in a balloon from a place in East London, near the East India Dock Gates, and to have risen say 500 ft.—somewhat higher than the cross of St. Paul's. The writer then proceeds as follows :—

"Taking a watch in our hand, we will note what happens. As we look out, we see all London below us. To the E. it does not stretch very far, but we can trace it on both sides of the winding Thames out to Barking and Woolwich. N. and S. it stretches farther ; W. we cannot see distinctly where it ends.

"It is not the great city itself, however, to which I wish to draw your attention, but to the fact that it is all on the move. It is slipping away from under us, ten times faster than any express train in which we ever rode. We started from the Dock Gates—our watch has only beat 6 seconds—and the great tower of Limehouse Church has rushed by. We see St. Paul's hurrying to us ; in 12 seconds more the Tower passes us on the left, and 6 seconds later the great Cathedral has reached us.

"Four seconds more bring the Law Courts beneath our feet ; another 12 seconds and it is the Marble Arch. It takes only 7 seconds for Hyde Park and Kensington Gardens to glide by ; and Shepherd's Bush, Acton, and Ealing are sweeping forward towards us. In 1 minute from the time that we rose up at the Dock Gates the mighty city has gone by. Another minute takes us out of Middlesex, and in 10 minutes from our start we pass Bristol. If we had tried to reach it by the Great Western Railway we should have required 2¼ hours for the journey."

CHAPTER XVI.

THE SPECTROSCOPE ASTRONOMICALLY.

What is a spectrum?—The decomposition of sunlight.—Brief history of the application of prisms to sunlight.—Labours of Grimaldi.—Of Sir I. Newton.—Of Wollaston.—Of Fraünhofer.—The lines in the spectrum named by him.—And after him.—Some details as to these.—Their interpretation.—The labours of Huggins and others.—Application of the spectroscope to celestial objects.—Secchi's star types.—Motions of the stars as ascertained by the spectroscope.

A SPECTROSCOPE is, of course, from its very name,[1] an instrument for examining a spectrum, and therefore we must begin at the beginning, and learn what a spectrum is, and how an instrument for examining it is constructed. But before getting as far as this it will be desirable to give a little historical retrospect.

The celebrated Italian astronomer and ecclesiastic, Antonio Secchi, S.J., once remarked that it might almost be said that, in offering to us the brilliant colours of the rainbow, the Creator has in effect invited us to examine the composition of light and to study its nature. This mystery, however, was not revealed to us until a comparatively recent period. The "triangular glass" (as the prism was once called) has long been known: its power to colour the rudest objects, and to transform them into a cluster of precious stones, was a source of amusement for the world in general, though a matter deemed little worthy of the notice of the philosopher.

[1] Spectrum, and σκοπέω, I view.

A certain Grimaldi was one of the first to study the prism scientifically, and he did so with much care and success. He made a hole in the shutter of a darkened room, through which he let in a ray of sunlight, which he submitted to the action of his prism. He was thus enabled to break up his ray of light, which came from the Sun, and so obtain the solar spectrum, which in due course he carefully described. After this experiment, he proceeded to transmit rays of sunlight through glass spheres filled with water. This enabled him to propound an explanation of the rainbow, which was subsequently worked out by Newton. Grimaldi's *modus operandi*, reproduced pictorially, was the basis of all those engravings, showing how a ray of simple white light is split up into colours, which are found in every book ever written on the subject.

It seems hardly necessary to dwell on the details of this, though perhaps I had better do so. The ray of light entering a room through the hole in the shutter meets the prism, and, passing through it, comes out on the opposite side, not as a single ray, as it entered, but split or decomposed (to use the technical term). When it reaches the screen it has become a wide strip of coloured light, red at one end and violet at the other, with many intermediate shades of colour in between. Newton repeated the experiment in consequence of information derived from Grimaldi, and so far improved upon it as to point out that passing the spectrum through a second prism did not cause any further change. He communicated his supplementary discovery to his friend Arland, of Geneva, in a rough pen-and-ink sketch, to which he prefixed the important legend, "Nec variat lux fracta colorem" (The decomposed light undergoes no change).

This impossibility of decomposing any further a ray which has already traversed one prism constitutes in reality the discovery made by Newton ; but he got a step beyond this, for he recomposed white light out of colours by determining the proportions in which it was necessary to do this in order to reproduce a light analogous to that of the Sun. He also assigned names to the different colours.

A long interval of time elapsed after Newton before any substantial progress was made in this department of Optics. Wollaston was the next man. In looking at a narrow slit of sunlight through a prism, he saw that the spectrum, instead of being continuous, showed gaps in the form of black streaks, which divided the spectrum into many compartments. This discovery attracted no attention, and remained without fruit until Fraünhofer, wishing to determine more exactly the index of refraction of certain sorts of glass which he was using, perceived, and, so to speak, rediscovered what Wollaston had previously discovered. He contrived methods of studying these streaks, sketched them, and eventually defined their positions relatively to one another by direct measurement. In consequence of his industrious labours, the black streaks or lines just alluded to are universally known nowadays as "Fraünhofer's Lines," though priority for their discovery rests distinctly with Wollaston.

There is no great difficulty in seeing these lines. It is necessary to look directly at the slit, and to focus the eye-piece of a telescope of sorts on to the slit, so as to see the slit very clearly defined. Then, after having placed the prism in the path of the luminous rays, and in the position which answers to that of minimum deviation, the telescope must be brought to bear on the prism, and when the eye-piece is again duly adjusted, by being brought to a focus, the lines will be visible. If the prism is a good one, and the telescope is achromatic, a great number of very fine lines will be seen.

Fraünhofer applied to the principal lines observed by himself certain letters of the alphabet; capitals for some, and small letters for others. These leading lines must be looked for as follows: A in the extreme red; B in the moderate red; C in the reddish-orange; D in the yellow-orange; E and *b* in the green; F at the commencement of the blue; G in the indigo; H in the violet. These standard letters, as they may be called, are in universal use, but subsidiary letters have been introduced since Fraünhofer's time, and also certain figures for facilitating the comparison of the different parts of the solar spectrum with the recognised table of wave-lengths. The caution may, perhaps, well be given here that the lines do not correspond with what might be regarded as the boundaries of the colours of the spectrum, but are wholly independent of them.

These letters being understood generally, some details may well now be given which will make their use as an index to the solar spectrum better appreciated. A is a strong line close to the red end of the spectrum. B is a strong and rather broad line in the red near its middle. Between A and B is a group of several lines collectively called *a*. C is a dark and well-marked line where the red is passing into orange. Between B and C Fraünhofer counted 9 fine lines; between C and D he counted about 30. D, in the orange, where it is passing into yellow, consists of 2 strong lines close together. Between D and E Fraünhofer counted 84 lines. E, in the yellowish-green, is a compound band of several lines, the middle one of which is stronger than the rest. At *b* there are 3 strong lines, the 2 farthest from E being close together. Between E and *b* Fraünhofer counted 24 lines, and between *b* and F more than 50. The lines F, G, and H, which are at the commencement of the blue, in the indigo, and in the violet respectively, are well defined. Between F and G Fraünhofer counted 185 lines, between G and H 190 lines, and many lines beyond Hand between H and I at the extreme violet end of the spectrum.

It will readily be realised that these dark lines are gaps or breaks in the spectrum, but it will not be so easily realised why there should be these gaps, indicative, as they are, primarily, of the absence of rays of certain refrangibilities from the beam of sunlight which we are supposed to be describing. It is obvious that something lies behind the absence of so many intermediate rays of light, narrow though they be, and slight as may be the joint effect they may have on the spectrum of the Sun on a cursory inspection of it.

The story of the history of the successive stages in which knowledge gradually accumulated in the interpretation of these mysteries is far too long to be told here, but the substance of it is this: that various metals and earths in a state of incandescence or combustion, when examined through the prisms of a spectroscope, yield certain bright lines, and that in many cases the distribution of these bright lines is coincident with the presence of dark lines in the spectrum of sunlight.

When some of these spectra are carefully compared with the lines in the spectrum of the Sun, and the coincidence of bright lines of known origin with dark lines of unknown origin is established, the inference is drawn (through stages of proof which I do not detail) that the absence of light where the dark lines appear is due to the presence in the Sun of a substance identical in nature with a substance which is on the Earth, and is, when examined, found to yield the particular bright lines just spoken of, and no other bright lines.

The example usually cited to illustrate this is that of sodium. Formerly no interpretation could be given of the D lines in the solar spectrum. At a later stage in the progress of experiments it was found that, when sodium (or its equivalent, common salt) was burnt in the flame of a spirit-lamp, there was presented in the spectroscope no other prominent lines, bright or dark, than the double D line. Hence physicists came to the conclusion that sodium in the form of vapour was one of the substances which is burning perpetually in the Sun. I must cut a long story short by saying that many researches and experiments by various eminent men at various dates and at various places have led to the inference that a large number of metals and mineral substances known on the Earth exist on the Sun, and, by suitable treatment by means of spectroscopes, can be individualised. On the other hand, there are lines in the solar spectrum which cannot be interpreted except on the assumption that there are the Sun substances absent from the Earth, and physicists have felt themselves justified in individualising some of these, and giving them newly invented names, such as helium and coronium.

In the first instance, and during all the early years of the use of the spectroscope astronomically, its application was chiefly to the Sun, and, though Fraünhofer carried out some experiments on certain conspicuous stars, it cannot be said that the method of spectrum analysis was applied on any considerable scale in other astronomical fields than the Sun until Huggins, in 1864, began his famous researches into the constitution of planets, comets, clusters, and nebulæ.

Thus far general principles. The next matter which should receive attention is the construction in practice of spectroscopes for actual use in the study of, not simply the Sun, but any and all celestial objects. This, however, is a large subject, altogether beyond the scope of this elementary volume.

And, indeed, the subject of astronomical spectroscopy itself is far too vast to be brought in at the tail-end of a popular book on general astronomy, and is, moreover, a study not likely to be taken up by the readers for whom this volume is more especially designed. I shall therefore conclude by alluding to two topics which may perhaps induce a few of my readers to wish to go a step further by the aid of books specially dedicated to spectroscopic astronomy.

The first matter to be mentioned is Secchi's classification of stars. Whilst Huggins, working in conjunction with his friend, Dr. W. A. Miller, of King's College, examined something like 100 stars spectroscopically, Secchi investigated the spectra of about 500 stars, and was led to distribute them into 4 classes or types, an account of which he published

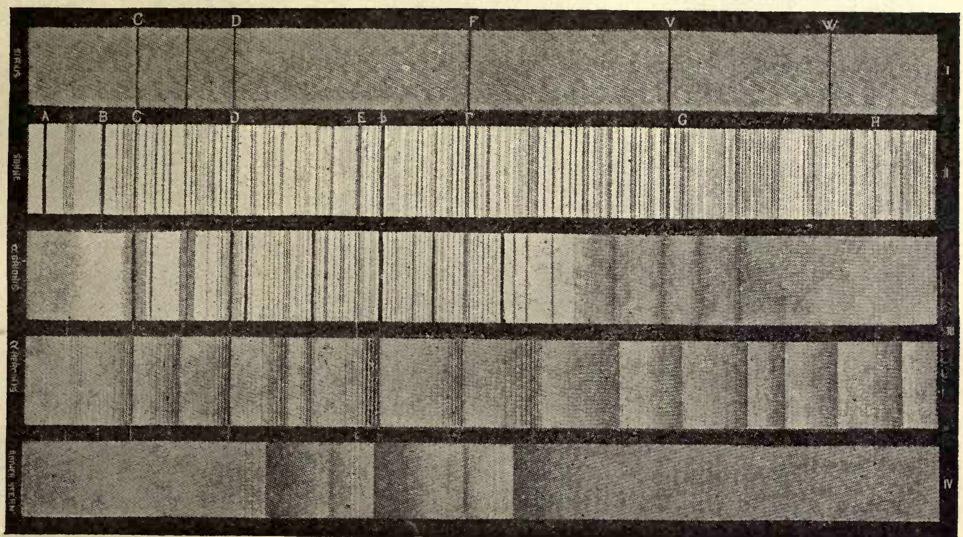


Fig. 352.—Secchi's Types of Stellar Spectra.

in 1868. Secchi's types may be briefly summarised as follows :—

1. White stars, of which Sirius and Vega are types, yielding spectra crossed by 4 broad dark lines, due to hydrogen, much broader than those in the solar spectrum. Sodium and magnesium may be easily identified in such stars.

2. Yellow stars, such as Aldebaran, Capella, Pollux, Arcturus, and *a* Cygni, wherein the hydrogen lines are much less conspicuous than in Type I., but metallic lines, magnesium especially, are numerous.

3. Stars with exceedingly beautiful spectra, crossed by 10 or more dark bands, each band very dark and sharp on the violet side, and gradually growing fainter towards the red end. Betelgeuse (*a* Orionis), *a* Herculis, and Antares (*a* Scorpii), are the principal stars of this type.

4. Red stars, which show 3 broad dark bands, shaded in the reverse direction to those of the 3rd type.

These 4 types of stellar spectra are generally recognised by astronomers, though, after Secchi, far more numerous observations, carried out by Vogel, Dunér, Lockyer, and others, led to other classifications. However, Secchi's 4 types have not been generally superseded, though it ought to be added that he himself was inclined to constitute a 5th class of stars showing bright lines in their spectra.

The following points may be stated summarily.

The following stars have banded spectra :—*a* Orionis ; *o* Ceti ; *a* Herculis ; μ Ursa majoris ; β Andromeda ; *a* Tauri ; β Pegasi ; *a* Scorpii ; γ Crucis. Stars of the helium type are mainly distributed in the galactic zones ; Orion stars are mainly of the helium type ; Sirian stars of the hydrogen type ; Procyon stars of the calcium type.

The last matter in connection with stellar spectroscopy, which must just be named, is Huggins's interesting and ingenious application of the spectroscope to isolated stars, with the view of determining their velocities of approach and recession in the line of sight to and from the Sun. Though the whole idea of such an attempt to prove stellar movement by means of the spectroscope seems a high flight of imagination, yet it does not appear that there are sufficient grounds for distrusting the results arrived at in the case of several dozen stars, though these results require us to talk about miles per second as the pace at which the stars in question are travelling to and from somewhere.

CHAPTER XVII.

TABLE OF THE CONSTELLATIONS, WITH A BRIEF DESCRIPTIVE ACCOUNT OF EACH.

By the entries in the column headed "Centre" it is meant to be inferred that a line of Right Ascension and a line of Declination taken off the map will intercept at a point which may be regarded as about the centre of the constellation. This, however, is only true of the more compact constellations, for there are some, like Draco, Cetus, and Argo, which are so long and straggling that they extend over several hours of R.A. When, therefore, I state that the constellations are here arranged in the order of R.A., the statement must be regarded as needing some qualification in many cases. In the column of "Declination" + means North, and — South.

Name of Constellation.	Centre.	
	R.A.	Decl.
	h. m.	°
Pisces	0 20	+ 10
Sculptor (*Apparatus sculptoris*)	0 30	— 35
Andromeda	0 40	+ 38
Phœnix	1 0	— 48
Cassiopeia	1 0	+ 60
Cetus	1 45	— 12
Triangulum	2 0	+ 32
Fornax (*Chemica*)	2 25	— 33
Aries	2 30	+ 20
Hydrus	2 40	— 72
Perseus	3 20	+ 42

Name of Constellation.	Centre.	
	R.A.	Decl.
	h. m.	°
Horologium	3 20	− 52
Reticulum (*Rhomboidalis*)	3 50	− 63
Eridanus	3 50	− 30
Taurus	4 30	+ 18
Cælum (*Cæla sculptoris*)	4 40	− 42
Dorado	5 0	− 60
Orion	5 20	+ 3
Lepus	5 25	− 20
Pictor (*Equleus pictoris*)	5 30	− 52
Mensa (*Mons mensa*)	5 40	− 77
Columba (*Noachi*)	5 40	− 34
Camelopardus	5 40	+ 70
Auriga	6 0	+ 42
Canis Major	6 40	− 24
Gemini	7 0	+ 24
Monoceros	7 0	− 3
Canis Minor	7 30	+ 6
Argo (*Puppis*)	7 40	− 32
Lynx	7 50	+ 45
Argo	8 0	− 40
Cancer	8 30	+ 20
Argo (*Carina*)	8 40	− 62
Volans (*Piscis Volans*)	8 40	− 69
Argo (*Malus*)	9 0	− 30
Argo (*Vela*)	9 30	− 45
Antlia Pneumatica	10 0	− 35
Sextans	10 10	− 1
Leo Minor	10 20	+ 33
Leo	10 30	+ 15
Chamæleon	10 40	− 78
Hydra	11 0	− 12
Ursa Major	11 0	+ 58
Crater	11 20	− 15
Crux	12 20	− 60
Corvux	12 30	− 18
Musca Australis	12 30	− 68
Coma Berenices	12 40	+ 27
Canes Venatici	13 0	+ 40
Centaurus	13 20	− 47

Name of Constellation.	Centre.	
	R.A.	Decl.
	h. m.	°
Virgo	13 20	− 2
Boötes	14 35	+ 30
Circinus	14 50	− 63
Lupus	15 0	− 40
Libra	15 10	− 14
Apus	15 30	− 76
Serpens	15 35	+ 8
Corona Borealis	15 40	+ 30
Triangulum Australe	15 40	− 65
Ursa Minor	15 40	+ 78
Norma	16 0	− 49
Draco	16 0	+ 60
Scorpio	16 20	− 26
Ara	16 50	− 55
Ophiuchus	17 10	− 4
Hercules	17 10	+ 27
Corona Australis	18 30	− 41
Scutum Sobieskii	18 30	− 10
Telescopium	18 40	− 52
Lyra	18 45	+ 36
Sagittarius	19 0	− 25
Pavo	19 10	− 25
Aquila (with Antinoüs)	19 30	+ 2
Sagitta	19 50	+ 18
Vulpecula et Anser	20 10	+ 25
Cygnus	20 30	+ 40
Delphinus	20 35	+ 12
Capricornus	20 50	− 20
Microscopium	21 0	− 37
Equuleus	21 10	+ 6
Indus	21 20	− 58
Piscis Australis	21 40	− 32
Cepheus	22 0	+ 70
Grus	22 20	− 47
Aquarius	22 20	− 13
Lacerta	22 25	+ 43
Pegasus	22 30	+ 17
Toucan	23 45	− 68
Octans	Polar	(South)

A few lines will now be given to each of these constellations by way of assisting an observer in finding them and in recognising their constituent stars.[1]

Pisces (The Fishes) is a dull and uninteresting constellation, the precise whereabouts of which can only be discovered by glancing upon it from neighbouring constellations. It immediately adjoins, to the S., the "Square of Pegasus," by means of which, therefore, it can be readily found. The 2 brightest stars are η and γ, each about mag. $3\frac{3}{4}$.

Sculptor is a southern constellation, barely visible in England. Its brightest star, α, is only of mag. 4.

Andromeda ("The Chained Lady") is one of the largest and most important constellations in the northern heavens, containing as it does 3 stars of the 2nd mag. (α, β, γ), whilst δ is $3\frac{1}{2}$, and υ and o are both $3\frac{3}{4}$.

Phœnix, a southern constellation, has the following bright stars: α $2\frac{1}{2}$, β and γ both $3\frac{1}{2}$, and ϵ $3\frac{3}{4}$.

Cassiopeia ("The Lady in her Chair") is a constellation of great extent and of much interest to the telescopist, owing to the fact that a part of the Milky Way, very rich in stars, runs through it. Its naked-eye stars include the well-known W. group. The chief stars are: α 2, γ and β $2\frac{1}{4}$, δ $2\frac{3}{4}$, and η, ϵ, ζ, all about $3\frac{1}{2}$.

Cetus (The Whale) is a very large constellation as regards its area, but of no great interest from a naked-eye or telescopic point of view. Its most interesting object is the celebrated variable star *Mira*. The chief stars are: β 2, α $2\frac{3}{4}$, ι, η, τ, and γ, all $3\frac{1}{2}$, and θ, ζ, υ, all $3\frac{3}{4}$.

Triangulum (The Triangle). This is one of the ancient constellations, notwithstanding its small size. Its principal stars are β 3, and α $3\frac{1}{2}$.

Fornax Chemica (The Chemical Furnace). In speaking of

[1] The more exact valuations now in use take account of differences of magnitude amongst the larger stars to tenths. These refinements are, however, ignored in the paragraphs which follow, and the magnitudes are given only to quarters of a magnitude.

this constellation it is usual to drop the word "Chemica." It has no brighter star than one of mag. $4\frac{1}{2}$.

Aries (The Ram). In the Ram's head there are 3 moderately conspicuous stars which serve to indicate the position of the constellation. These are: α 2, β $2\frac{3}{4}$, and γ 4.

Hydrus (The Small Snake). This is a southern constellation not far from the S. Pole. Principal stars: β $2\frac{3}{4}$, and α and γ, both about 3.

Perseus. This is a very brilliant constellation, because it embraces a very rich portion of the Milky Way. Its chief stars are: α 2, β $2\frac{1}{4}$, ϵ, γ, ζ, δ, all about 3, and ρ, $3\frac{3}{4}$. β Persei, better known by its Arabic name of "Algol," is a very remarkable variable star of short period.

Horologium (The Clock), a southern constellation, has one fairly conspicuous star, α $3\frac{3}{4}$.

Reticulum (The Net) is also a southern constellation. Chief stars: α $3\frac{1}{4}$, and β 4.

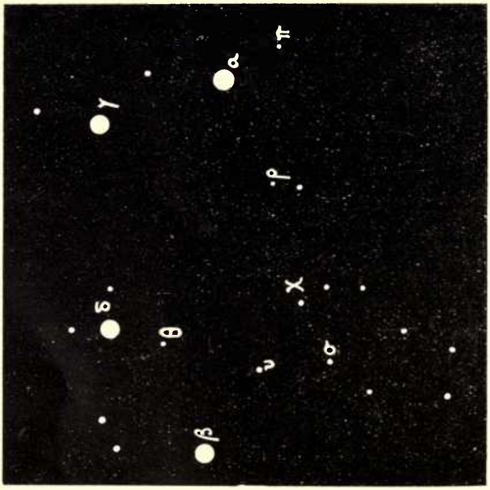
Eridanus is a very long, straggling constellation, reaching from the Equator to 60° of S. Declination. Its important stars are invisible in England. They are: α (Achernar) 1; θ, $2\frac{1}{2}$; β and γ, 3; v^4 and ϕ, $3\frac{1}{2}$; together with ϵ, δ, Flamsteed's 12, v^7 and τ^4, all about $3\frac{3}{4}$.

Taurus (The Bull). This is a large and interesting constellation comprising naked-eye and telescopic objects in great variety. Amongst the former are the celebrated groups of the Pleiades and the Hyades and the beautiful 1st-magnitude star Aldebaran. The other bright stars are: β2, η, ζ, 3, λ, θ^2, $3\frac{1}{2}$; together with ϵ, o, ξ, and Flamsteed's 17 and 27, all of about $3\frac{3}{4}$. Besides these there are no fewer than 48 stars ranging from mag. 4 to $5\frac{1}{4}$.

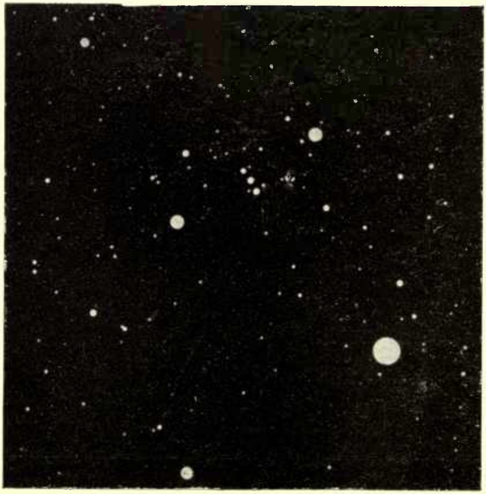
Cælum (The Graving Tool) is a small southern constellation, the two brightest stars of which, α and γ, are only $4\frac{1}{2}$.

Dorado (The Sword-fish), a southern constellation, has for its chief stars: α 3, and β 4. This constellation contains a celebrated cluster of stars.

Central Portion of Orion (*F. W. Longbottom*).



" The Sickle " in Leo.



The Constellation Orion and Neighbourhood.

Orion. This, though not in area the largest, is by far the most brilliant and interesting of all the constellations, both as regards its naked-eye stars and its telescopic objects. Its position, too, is very good for observers in England, as it comes to the meridian in the winter at a very convenient altitude. Its 2 brightest stars, β (Rigel) and α (Betelgeuse), are both, especially the former, brighter than the average 1st-magnitude stars; then, besides, there are 4 of the 2nd magnitude, ϵ, γ, ζ, κ. Next follow δ $2\frac{1}{2}$, ι 3, π^1 $3\frac{1}{4}$, η, λ, τ, $3\frac{1}{2}$, and σ $3\frac{3}{4}$, with 45 stars of mags. 4 to $5\frac{1}{4}$.

Lepus (The Hare) is a small constellation immediately S. of Orion, with the following conspicuous stars: α $2\frac{3}{4}$, β 3, ϵ and μ $3\frac{1}{4}$, and ζ, η, γ, $3\frac{3}{4}$.

Pictor (The Painter) is a southern constellation with the following as its chief stars: α $3\frac{1}{2}$, β 4.

Mons Mensa (The Table Mountain), in the Southern Hemisphere, is one of the least important of all the accepted constellations, and has no star brighter than $5\frac{1}{4}$.

Columba Noachi (Noah's Dove), generally called Columba, is a small constellation to the S. of Lepus, and only partly visible in England. Its chief stars are: α $2\frac{3}{4}$, β 3, and ϵ $3\frac{3}{4}$.

Camelopardus (The Camelopard) is a long, straggling constellation with a large number of 4th-magnitude stars, but nothing brighter.

Auriga (The Charioteer) is a constellation occupying a large area, and with one star in particular, α (Capella), which is very brilliant, being indeed in the judgment of some the second brightest star visible in England, ranking after Sirius. The other bright stars are: β, 2; θ, ι, $2\frac{3}{4}$; ϵ, η, $3\frac{1}{4}$; and δ, $3\frac{3}{4}$.

Canis Major (The Greater Dog). This, though quite a small constellation as regards its area, contains a large number of conspicuous stars, including the brightest of all, Sirius. The other bright stars are: ϵ $1\frac{1}{2}$, δ $1\frac{3}{4}$, β 2, η $2\frac{1}{2}$, ζ, o^2, 3, and Flamsteed's 22 and 28, both about $3\frac{1}{2}$.

Gemini (The Twins) has 2 stars with familiar names as leaders, together with several others of lesser magnitude. The chief stars are: β (Pollux) 1, α (Castor) $1\frac{1}{2}$, γ 2, μ and ϵ $3\frac{1}{4}$, ξ, s, λ, δ and κ all about $3\frac{1}{2}$, and θ $3\frac{3}{4}$.

Monoceros (The Unicorn) has 2 stars of mag. 4 and nothing larger; it is, however, not an unimportant constellation, being rich in telescopic objects owing to its position in the Milky Way.

Canis Minor (The Lesser Dog), though a small constellation, will always be readily found by its α (Procyon), one of the largest of the 1st-magnitude stars. The next star, β, is only of mag. 3.

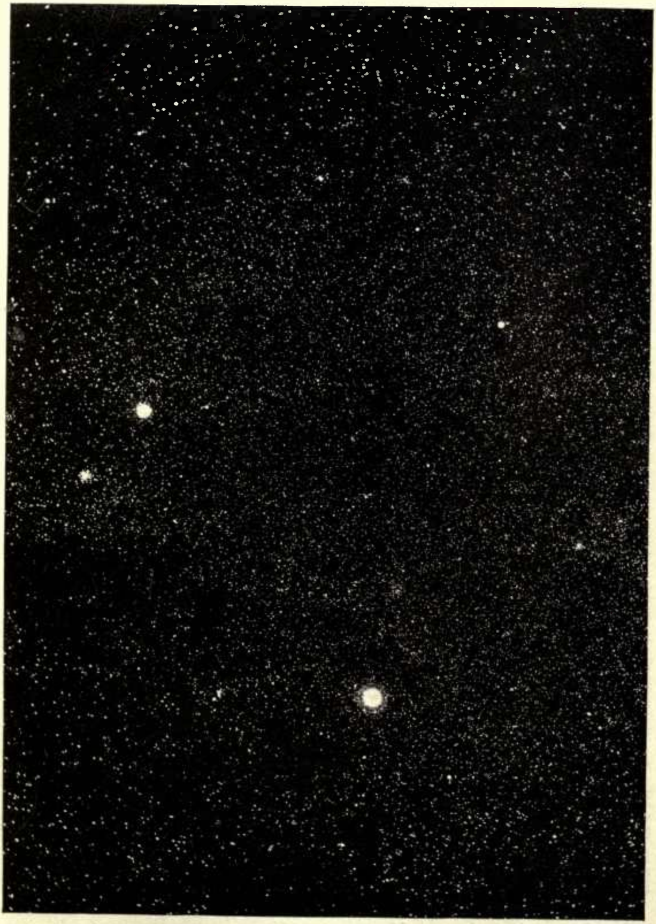
Argo (The Ship Argo) is not an easy constellation to describe because of its great extent, and, by way of facilitating work in its confines, it has been by common consent cut up into 4 divisions, respectively called *Carina* (The Keel), *Malus* (The Mast), *Puppis* (The Poop), and *Vela* (The Sails), to which some add a 5th, *Pyxis Nautica*, a part of Malus. The conspicuous stars are: α (Canopus), a very bright 1st-mag.; then follow β, ϵ, δ, 2; ι, ζ, λ, $2\frac{1}{2}$; κ, ϕ, $2\frac{3}{4}$; θ, μ, ρ, γ, 3; τ, υ, $3\frac{1}{4}$; ξ, ν, σ, ω, $3\frac{1}{2}$; χ, ψ, $3\frac{3}{4}$. These stars will be found scattered all over the constellation. Canopus is the second brightest star in the heavens, being but slightly inferior to Sirius, which it only precedes in R.A. by about 18 m.

Lynx is a troublesome constellation to find, its brightest star, α, being only $3\frac{1}{2}$; and the next one, Flamsteed's 38, only $3\frac{3}{4}$.

Cancer (The Crab). The most conspicuous star is β, only $3\frac{3}{4}$; but the cluster "Præsepe" will indicate this constellation to the naked-eye observer.

Volans. The proper name of this southern constellation is Piscis Volans (The Flying Fish); but, as there are 2 other Fishes in the heavens (Pisces, the Zodiacal constellation, and Piscis Australis), it has been agreed to drop the 3rd Piscis and use only the word "Volans." Its chief stars are: γ and β, both about $3\frac{3}{4}$.

Antlia Pneumatica (The Air-pump). The brightest star is α only of mag. $4\frac{1}{2}$.



The "Southern Cross."

The Spiral Nebula, 51 M. Canum Venaticorum (*Earl of Rosse*).

Sextans (The Sextant) is an insignificant constellation, and its brightest star only $4\frac{1}{2}$.

Leo Minor (The Lesser Lion) lies to the N. of Leo Major; its brightest star is Flamsteed's 46, of mag. 4.

Leo (The Lion). The prominent feature of this constellation is the group of stars known as "The Sickle." The chief stars are: α (Regulus), $1\frac{1}{2}$; ν, β, $2\frac{1}{4}$; δ, $2\frac{3}{4}$; ϵ, 3; θ, η, ζ, all $3\frac{1}{2}$; and o, $3\frac{3}{4}$.

Chamæleon. This is a small and unimportant constellation not far from the S. Pole, and with no star brighter than α, $4\frac{1}{2}$.

Hydra (The Water-snake). A long-straggling constellation extending through more than 6 hours of R.A. Chief stars: α, 2; ζ, ν, γ, π, ϵ, all about $3\frac{1}{2}$.

Ursa Major (The Great Bear). This has already been somewhat fully described on a previous page. Its chief stars are: ϵ (Alioth), $1\frac{3}{4}$; α (Dubhe) and η (Benetnasch), both 2; ζ (Mizar), β and γ, all $2\frac{1}{2}$; μ, ψ, ι, θ, all 3; o, ϵ, λ, $3\frac{1}{2}$; κ, h, ξ, ν, $3\frac{3}{4}$.

Crater (The Cup) is a small constellation sometimes treated as part of Hydra. Its 2 principal stars are: Flamsteed's 19, and δ, both of them scarcely of mag. 4.

Crux (The Cross). This is a southern constellation, small in size, but with 4 conspicuous stars which suggested its name. Opinions seem much divided as to whether it really is a striking group. The chief stars are: α $1\frac{1}{4}$, β $1\frac{3}{4}$, γ 2, and δ $3\frac{1}{4}$. The following is the opinion of Mr. W. B. Gibbs, F.R.A.S.:—

"The Southern Cross" is formed by five stars, of which only one is of the 1st magnitude, the others are of the 2nd and lower magnitudes. Closely following, a few degrees away, are the two bright stars α and β Centauri, which are sometimes called "The Pointers." When the cross is vertical its longer diagonal points to the S., and at any other time the South Pole may be approximately found by prolonging this diagonal $4\frac{1}{2}$ times its own length in the direction of the South Pole. Altogether these two stars of the Centaur and those of the Southern Cross make a most notable group, the most characteristic star-group of the Southern Hemisphere."

Corvus (The Crow). A small constellation with some very bright stars, several of which are suspected to be variable. The 4 chief stars, γ and β, both $2\frac{3}{4}$, and ϵ and δ both 3, form a trapezium.

Musca Australis (The Southern Fly) is a southern constellation. Chief stars: α 3, β $3\frac{1}{4}$, δ and B.A.C. 3984, both $3\frac{3}{4}$.

Coma Berenices (Berenice's Tresses) is a small constellation of medium-sized stars distributed at somewhat even intervals. The brightest, β, is only $4\frac{1}{2}$, but there are 17 as bright or brighter than $5\frac{1}{4}$.

Canes Venatici (The Hunting Dogs). This constellation has but one bright star, α, called also "Cor Caroli." Hevelius desired to form this into a separate constellation to commemorate Charles II.

Centaurus (The Centaur) is a large and important southern constellation with many bright stars, none of which are visible in England. These are: α^2, β, both of mag. 1; θ $1\frac{3}{4}$; ν, η, ϵ, $2\frac{1}{2}$; ζ, δ, $2\frac{3}{4}$; ι, 3; κ, $3\frac{1}{4}$; λ, μ, α^1, $3\frac{1}{2}$, and ν, $3\frac{3}{4}$.

Virgo (the Virgin) has one very bright star, α (Spica), but is a constellation chiefly noted for its many nebulæ. The other chief stars are: ν, ϵ, 3; ζ, $3\frac{1}{2}$; β, δ, Flamsteed's 109, all $3\frac{3}{4}$.

Boötes (The Bear Leader). This is one of the largest of the northern constellations, and possesses in α (Arcturus) one of the most brilliant of the northern stars, its rivals being α Aurigæ, and α Lyræ. Its other chief stars are: ϵ, $2\frac{1}{2}$; η, γ, 3; δ, β, ρ, $3\frac{1}{2}$; ζ, $3\frac{3}{4}$.

Circinus (The Compasses) is a very small southern constellation, the brightest star of which is α, $3\frac{1}{2}$.

Lupus (The Wolf) is a southern constellation, a mere fragment of which is visible in England. The bright stars are: α, β, $2\frac{3}{4}$; γ, 3; ζ, ϕ^1, $3\frac{1}{2}$; δ, ϵ, η, ι, all $3\frac{3}{4}$.

Libra (The Balance) is so low down in the southern horizon that it is not easy to get hold of it, especially as its visibility coincides with the short nights of the English summer. Its principal stars are: β, $2\frac{3}{4}$, and α and Flamsteed's 20, both about 3.

Apus (sometimes called Avis Indica, The Bird of Paradise) is a small constellation not far from the South Pole, and its brightest star, α, is only about mag. 4.

Serpens (The Serpent) is a straggling constellation, much mixed up with Ophiuchus. The chief stars are: α, $2\frac{3}{4}$; η, μ, $3\frac{1}{2}$; and ϵ, ξ, β, all about $3\frac{3}{4}$.

Corona Borealis (The Northern Crown) bears more resemblance to its name than most of the constellations do. Chief stars: α, $2\frac{1}{2}$, and β, $3\frac{3}{4}$; with 13 stars between 4 and $5\frac{1}{4}$.

Triangulum Australe (The Southern Triangle) is a small southern constellation, with several bright stars: α, $2\frac{1}{4}$, and γ, β, each 3.

Ursa Minor (The Little Bear) is often spoken of as being a facsimile of the Great Bear, but the idea is rather far-fetched. The real importance of this constellation is due to the Northern Polar point and the Pole Star being within its boundaries. Its chief stars are: β (Kochab), and α (Polaris), both about 2; and γ, $3\frac{1}{4}$.

Norma (The Rule) is an unimportant southern constellation, whose brightest star (γ^2) is only of mag. $4\frac{1}{2}$.

Draco (The Dragon) is a constellation which may almost be said to extend everywhere, for it reaches through nearly 12 hours of R.A., and is circumpolar in England. The difficulties of studying it are aggravated by the fact that when on the meridian it is absolutely in the zenith. Chief stars: γ, $2\frac{1}{2}$; η, $2\frac{3}{4}$; β, 3; ζ, $3\frac{1}{4}$; ι, α, $3\frac{1}{2}$; χ, κ, $3\frac{3}{4}$; with 43 stars ranging from 4 to $5\frac{1}{4}$.

Scorpio (The Scorpion) is a zodiacal constellation, rather unfavourably placed for observers in England. Its principal star, α, of mag. 1, is known as Antares (= the "rival of Mars"), a name given to mark its red colour. The other chief stars are: λ, $1\frac{3}{4}$; θ, ϵ, 2; δ, κ, $2\frac{1}{2}$; υ, $2\frac{3}{4}$; β^1, τ, σ, π, all 3; ι^1, $3\frac{1}{4}$; μ^1, ζ^2, η, all $3\frac{1}{2}$.

Ara (The Altar) is a small constellation, but with a good share of medium-sized stars. These are: β, $2\frac{3}{4}$; α, 3; ζ, $3\frac{1}{4}$; γ, $3\frac{1}{2}$; δ, η, $3\frac{3}{4}$; θ, ϵ^1, both about 4.

Ophiuchus, sometimes called *Serpentarius* (The Serpent-bearer), is much mixed up with Serpens, the animal carried, and with Hercules. The chief stars are: α, $2\frac{1}{4}$; η, $2\frac{1}{2}$; δ, ζ, $2\frac{3}{4}$; β, 3; ϵ, κ, θ, ν, all about $3\frac{1}{2}$; γ and Flamsteed's 72, both $3\frac{3}{4}$.

Hercules is a large and important constellation, with a great variety both of naked-eye and of telescopic objects. Its principal stars ars: β, $2\frac{3}{4}$; ζ, 3; α, δ, $3\frac{1}{4}$; π, μ, $3\frac{1}{2}$; η, γ, $3\frac{3}{4}$; with 41 stars from 4 to $5\frac{1}{4}$.

Corona Australis (The Southern Crown) is a southern constellation with no stars brighter than mag. 4. It is to be noticed that 6 of its naked-eye stars are disposed in a curved line.

Scutum Sobieskii is sometimes called *Clypeus Sobieskii*, but the single word *Scutum* (The Shield) is its more usual designation. Its brightest star is B.A.C. 6325 of mag. 4.

Telescopium (The Telescope) is a small southern constellation, the brightest star of which is α, $3\frac{1}{2}$.

Lyra (The Lyre) is a constellation small in size, but it possesses in its α (Vega) a very brilliant 1st-magnitude star, and a great variety of important telescopic objects. After Vega come γ, $3\frac{1}{4}$; and β, $3\frac{1}{2}$.

Sagittarius (the Archer), by reason of its low altitude in England, is not generally appreciated, but it contains a considerable number of important stars. Thus: ϵ, 2; σ, $2\frac{1}{4}$; δ, $2\frac{3}{4}$; ζ, γ^2, η, λ, π, all 3; ϕ, $3\frac{1}{4}$; ξ^2, τ, $3\frac{1}{2}$; β^1, $3\frac{3}{4}$; with 36 stars from 4 to $5\frac{1}{4}$.

Pavo (The Peacock) is a small southern constellation with some conspicuous stars: α, 2; β, $3\frac{1}{4}$; δ, $3\frac{1}{2}$; η, $3\frac{3}{4}$.

Aquila (The Eagle), though only a small constellation, is rich in bright and double stars. The chief stars are: α, 1; γ, $2\frac{3}{4}$; ζ, 3; θ, δ, λ, $3\frac{1}{2}$; whilst η, is a bright 4.

Sagitta (The Arrow) is a small but ancient constellation, with 2 stars, γ, δ, both of them about $3\frac{3}{4}$.

Vulpecula et Anser.– As a fox and a goose were 2 things which formerly were supposed to go together (for a short time), so Vulpecula had an Anser associated with him; but the Anser has long since disappeared down the Fox's throat, and astronomers only talk now of the Fox. The brightest star is α, $4\frac{1}{2}$; but there are no fewer than 14 stars ranging from $4\frac{3}{4}$ to $5\frac{1}{4}$.

Cygnus (The Swan) is a large and important constellation, with much in it to interest all classes of students. A rich part of the Milky Way occupies a considerable area of it, and a large number of prominent red stars are also among its special features. The chief stars are: α (Deneb) $1\frac{1}{2}$; γ, $2\frac{1}{4}$; ϵ, $2\frac{3}{4}$; δ, β (Albireo), 3; ζ, $3\frac{1}{2}$; ξ, ω^1, $3\frac{3}{4}$; together with no fewer than 53 stars between 4 and $5\frac{1}{4}$.

Delphinus (The Dolphin) is an unimportant northern constellation, the brightest star of which is β, $3\frac{3}{4}$.

Capricornus (The Goat) is a constellation low down in England, with not much to attract the naked eye. Its chief stars are: δ, 3; β, $3\frac{1}{2}$; α^2, ζ, γ, all $3\frac{3}{4}$.

Microscopium (The Microscope) is a small southern constellation whose brightest star, θ^1, is only $4\frac{3}{4}$.

Equuleus (The Little Horse) is a small constellation whose brightest star, α, is only 4.

Indus (The Indian) is a small southern constellation whose brightest stars are: α, 3, and β, $3\frac{3}{4}$; but ϵ of mag. $5\frac{1}{4}$ is distinguished for its remarkably large proper motion.

Piscis Australis (The Southern Fish) has only one bright star, α (Fomalhaut), $1\frac{1}{4}$.

Cepheus is a large and straggling constellation which reaches nearly to the North Pole. Its chief stars are: α (Alderamin) $2\frac{1}{2}$; β, γ, ζ, η, ι, all about $3\frac{1}{2}$.

Grus (The Crane) is a southern constellation which, though small, contains a considerable number of important stars. These are: α, 2; β, $2\frac{1}{4}$; γ, 3; ϵ, $3\frac{1}{2}$.

Aquarius (The Water-bearer) has for its 2 principal stars β and α, both about 3; δ, c^2, $3\frac{1}{2}$; and ϵ, ζ, $3\frac{3}{4}$.

Lacerta (The Lizard) is a small northern constellation, of which the largest star, α, is only 4: but there are 15 other stars up to $5\frac{1}{4}$.

Pegasus (The Winged Horse). The so-called "Square of Pegasus" (of which α Andromeda, sometimes called δ Pegasi, is one member) is familiar to most star-gazers. The chief stars of Pegasus are: ϵ, α (Markab), β (Scheat), all about $2\frac{1}{2}$; γ (Algenib), η 3; ζ $3\frac{1}{2}$; and μ, θ, $3\frac{3}{4}$. There are 30 stars 4 to $5\frac{1}{4}$.

Toucan (The American Goose). This southern constellation only includes one bright star, α $2\frac{3}{4}$.

Octans (The Octant) is the constellation which includes the South Pole. The brightest star is μ, $3\frac{3}{4}$; but the nearest star to the Pole is σ, $5\frac{3}{4}$.

APPENDIX I.

STATISTICS RESPECTING THE PLANETS AND THEIR SATELLITES.

SOME STATISTICS OF THE PLANETS.

Name.	Symbol.	Semi-axis Major. ⊕ = 1	Mean Distance from Sun. Miles.	Sidereal Period in Days.	Sidereal Period in Years.	Eccentricity of Orbit.	Diameter as seen from the Earth.	Diameter in Miles.	Axial Rotation. d. h. m.
Mercury .	☿	0·387	35,958,000	87·9	0·24	0·205	5″—13″	3,008	24 5 30
Venus .	♀	0·72	67,190,000	224·7	0·61	0·006	11″—67″	7,480	23 21 23
The Earth	⊕	1·00	92,890,000	365·2	1·00	0·016	—	7,926	23 56 4
Mars .	♂	1·52	141,536,000	686·9	1·88	0·093	3·6″—24·5″	4,999	24 37 23
Jupiter .	♃	5·20	483,288,000	4332·5	11·86	0·048	32″—50″	88,439	9 55 21
Saturn .	♄	9·53	886,065,000	10759·2	29·45	0·056	14″—20″	75,036	10 14 24
Uranus .	♅	19·18	1,781,944,000	30686·8	84·01	0·046	3·8″—4·1″	30,875	9 30 ?
Neptune .	♆	30·03	2,791,750,000	60126·7	164·62	0·008	2·7″—2·9″	37,205	?

SOME STATISTICS OF THE SATELLITES OF THE PLANETS.

Name or Number.	Inclination of Orbit.	Eccentricity.	Mean Daily Motion.	Sidereal Period.	Mass.
THE SATELLITE OF THE EARTH.					
	° ′ ″		° ′ ″	d. h. m.	
The Moon	5 8 47	0·0549	13 10 35	27 7 43	0·012552
THE SATELLITES OF MARS.					
	° ′		°	d. h. m.	
Phobos .	27 28	0·0217	1128·8	0 7 39	?
Deimos .	27 24	0·0031	285·1	1 6 17	?
THE SATELLITES OF JUPITER.					
	° ′		°	d. h. m.	
V . .	2 20	0·0050	722·6	0 11 57	?
I . .	2 8	?	203·4	1 18 27	0·00001
II . .	1 38	?	107·3	3 13 13	0·00002
III . .	1 59	0·0001	50·3	7 3 42	0·00008
IV . .	1 57	0·0072	21·5	16 16 32	0·00004
VI . .	28 56	0·156	1·43	251	?
VII . .	31 0	0·024	1·35	265	?
VIII . .	148 52	0·33	0·45	26 months	?
THE SATELLITES OF SATURN.					
	° ′		°	d. h. m.	
Mimas .	27 29	0·019	381·9	0 22 37	0·00000007
Enceladus	28 4	0·004	262·7	1 8 53	0·0000002
Tethys .	28 40	?	190·6	1 21 18	0·0000011
Dione .	28 4	0·002	131·5	2 17 41	0·0000018
Rhea . .	28 22	0·0009	79·6	4 12 25	0·0000040
Titan . .	27 39	0·028	22·5	15 22 41	0·0002127
Themis .	39 6	0·23	17.27	20 20 24	?
Hyperion.	27 14	0·129	16·9	21 6 38	?
Iapetus .	18 28	0·028	4·5	79 7 56	0·00001
Phœbe .	175 5	0·165	0·6	550 10 34	?
THE SATELLITES OF URANUS.					
	° ′		°	d. h. m.	
Ariel . .	97 5	0·02	142·8	2 12 29	Between 0·00001 and 0·00005
Umbriel .	98 2	0·01	86·8	4 3 27	
Oberon .	98 1	?	41·3	8 16 56	
Titania .	98 17	?	26·7	13 11 7	
THE SATELLITE OF NEPTUNE.					
	° ′		°	d. h. m.	
	142 40	0·007	61·2	5 21 2	?

(From the *Connaissance des Temps*, 1912.)

APPENDIX II.

CATALOGUE OF CELESTIAL OBJECTS EASY FOR SMALL TELESCOPES.

THE following Catalogue includes, with objects already mentioned, others which may be seen without difficulty in small telescopes; though, to bring out their specially attractive features, large telescopes may often be necessary.

PLANETS.

MERCURY. CERES.
VENUS. JUPITER.
MARS. SATURN.

DOUBLE STARS, CLUSTERS, AND NEBULÆ.[1]

No double star is included unless bright enough to be easily found (as a single star) with the naked eye, and unless the two components are at least 4″ or 5″ apart.

No.	Name.	R.A.	Decl.	Description.
		h. m. s.	° ′	
1	47 Toucani . .	0 19 36	−72 38	Superb globular cluster.
2	31 M Andromedæ . . .	0 37 19	+40 43	"The Great Nebula."
3	η Cassiopeiæ .	0 43 3	+57 17	Double star, mags. 4, $7\frac{1}{2}$: dist. 5″.

[1] Extracted from *The Cycle of Celestial Objects* by Smyth and Chambers, 2nd ed., price 6s. An indispensable companion to every telescope.

No.	Name.	R.A.	Decl.	Description.
		h. m. s.	° ′	
4	Nubecula Minor	0 49 8	−73 55	Mass of nebula.
5	γ Arietis . . .	1 48 2	+18 18	Double star, mags. $4\frac{1}{2}$, 5 : dist. 8″.
6	γ Andromedæ .	1 57 45	+41 51	Double star, mags. $3\frac{1}{2}$, $5\frac{1}{2}$: dist. 10″.
7	33 ♅ VI Persei.	2 12 2	+56 41	Double cluster in fine field.
8	o Ceti . . .	2 14 17	− 3 25	Celebrated variable, max. mag. 2 : fiery red, invisible at min.
9	α Ceti . . .	2 57 3	+ 3 41	Orange star, mag. $2\frac{1}{2}$.
10	β Persei . . .	3 1 39	+40 34	Variable star, max. 2, min. 4.
11	η Tauri . . .	3 41 32	+23 47	Chief star in the "Pleiades."
12	δ Orionis . .	5 26 53	− 0 22	Double star, mags. 2 and 7 : dist. 53″
13	1 M Tauri . .	5 28 27	+21 57	"The Crab" nebula.
14	42 M Orionis .	5 30 20	− 5 27	"The Great Nebula in Orion" surrounding the star θ.
15	σ Orionis . .	5 33 33	− 2 37	Multiple star, mags. 4, 8, and 7 : dist. 12″ and 42″ : other stars.
16	30 Doradûs . .	5 39 29	−69 9	In the Nubecula Major.
17	35 M Geminorum	6 2 40	+24 21	Fine cluster of stars.
18	5 Lyncis . . .	6 18 6	+58 28	Fiery red star, mag. $5\frac{1}{2}$.
19	41 M Canis Majoris . .	6 42 39	−20 37	Cluster of stars.
20	μ Canis Majoris	6 51 32	−13 55	Fiery red double star, mags. $5\frac{1}{2}$ and $9\frac{1}{2}$: dist. 3″.
21	α Geminorum .	7 28 13	+32 6	Double star, mags. 3 and $3\frac{1}{2}$: dist. 5″.
22	γ Argûs . . .	8 6 26	−47 0	Double star, mags. 2 and 6 : dist. 42″.
23	44 M Cancri .	8 34 30	+20 17	Loose cluster, "Præsepe."
24	η Argûs . . .	10 41 10	−59 9	"The Great Nebula in Argo," surrounding the star η.

No.	Name.	R.A.	Decl.	Description.
		h. m. s.	° ′	
25	54 Leonis . .	10 50 12	+25 17	Double star, mags. $4\frac{1}{2}$ and 7 : dist. 6″.
26	α Crucis . . .	12 21 0	−62 33	Quintuple star, mags. $1\frac{1}{2}$, 2, and 5 : dist. 5″, 90″.
27	γ Crucis . . .	12 25 36	−56 33	Star, mag. 2, Companion, mag. 5 : dist. 120″.
28	γ Virginis . .	12 36 36	− 0 54	Binary star, both mag. 4 : dist. 6″.
29	κ Crucis . . .	12 47 42	−59 48	Remarkable cluster.
30	α Canum Venat.	12 51 20	+38 51	Double star, mags. $2\frac{1}{2}$ and $6\frac{1}{2}$: dist. 20″.
31	ζ Ursæ Majoris	13 19 54	+55 27	Double star, mags. 3 and 5 : dist. 14″ : Alcor, mag. 5, is distant $11\frac{3}{4}$′.
32	ω Centauri . .	13 20 45	−46 48	Large globular cluster.
33	α Centauri . .	14 32 47	−60 26	Double, mags. 1 and 2, dist. 22″.
34	π Boötis . . .	14 36 2	+16 50	Double star, mags. $3\frac{1}{2}$ and 6 : dist. 6″.
35	β Libræ . . .	15 11 37	− 9 0	Mag. $2\frac{1}{2}$: pale green colour.
36	5 M Libræ . .	15 13 27	+ 2 28	Loose cluster.
37	ξ Scorpii . . .	15 58 52	−11 6	Double star, mags. $4\frac{1}{2}$ and $7\frac{1}{2}$: dist. 7″ ; A also double.
38	β Scorpii . . .	15 59 37	−19 31	Double star, mags. 2 and $5\frac{1}{2}$: dist. 13″ ; A also double.
39	ν Scorpii . . .	16 6 11	−19 12	Double star, mags. 4 and 7 : dist. 40″; both stars also double.
40	α Scorpii . . .	16 23 16	−26 12	Double star, mags. 1 and 7 : dist. 3″; fiery red star.
41	13 M Herculis .	16 38 6	+36 37	Very bright globular cluster.
42	α Herculis . .	17 10 5	+14 30	Double star, mags. $3\frac{1}{2}$ and $5\frac{1}{2}$: dist. 5″.
43	92 M Herculis .	17 14 4	+43 14	Globular cluster.
44	8 M Sagittarii .	17 57 45	−24 22	Bright irregular nebula.

No.	Name.	R.A.	Decl.	Description.
		h. m. s.	° ′	
45	17 M Scuti Sobieskii . . .	18 14 50	−16 14	"The Omega Nebula."
46	ϵ Lyræ . . .	18 41 1	+39 34	Double-double and multiple star.
47	11 M Antinoï .	18 45 45	− 6 23	Loose cluster.
48	57 M Lyræ . .	18 49 50	+32 54	Annular Nebula.
49	θ Serpentis .	18 51 15	+ 4 5	Double star, mags. 4½ and 4: dist. 21″.
50	β Cygni . . .	19 26 41	+27 45	Double Star, mags. 3 and 7: dist. 34″.
51	χ Cygni . . .	19 46 44	+32 40	Variable star, max. mag. 4, and red: invisible at minimum.
52	27 M Vulpeculæ	19 55 14	+22 26	"The Dumb-bell" Nebula.
53	α^2 Capricorni .	20 12 30	−12 51	Wide pair of stars, mags. 3 and 4: dist. 376″; a multiple object.
54	β^2 Capricorni .	20 15 24	−15 5	Wide pair of stars, mags. 3½ and 7: dist. 205″.
55	γ Delphini . .	20 42 1	+15 46	Double star, mags. 4 and 6½: dist. 11″.
56	15 M Pegasi .	21 28 15	− 1 16	Globular cluster.
57	β Cephei . . .	21 27 22	+70 7	Double star, mags. 3 and 8: dist. 13″.
58	2 M Aquarii .	21 28 15	− 1 16	Fine globular cluster.
59	μ Cephei . . .	21 40 26	+58 19	Variable star, max. mag. 4, min. 6: deep garnet in colour.
60	δ Cephei . . .	22 25 27	+57 54	Variable star, max. mag. 3¼, min. 4½; also double, Companion mag. 7: dist. 40″.
61	8 Andromedæ .	23 13 7	+48 27	Fiery red star, mag. 5.
62	30 Piscium . .	23 56 49	− 6 34	Fiery red star, mag. 4½.

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*** *The titles of the chapters are in small capitals.*

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