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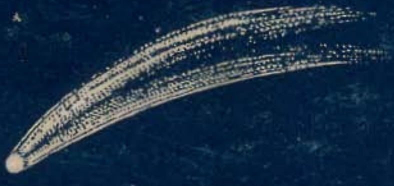

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ASTRONOMY.

MAP OF THE MOON.

Seas, Gulfs, and Marshes.

A. Mare Crisium.
B. Mare Humboldtianum.
C. Mare Frigoris.
D. Lacus Mortis.
E. Lacus Somniorum.
F Palus Somnii.
G. Mare Tranquillitatis.
H. Mare Serenitatis.

I. Palus Nebularum.
K. Palus Putredinis.
L. Mare Vaporum.
M. Sinus Medii.
N. Sinus Æstuum.
O. Mare Imbrium.
P. Sinus Iridum.
Q. Oceanus Procellarum.

R. Sinus Roris.
S. Mare Nubium.
T. Mare Humorum.
V. Mare Nectaris.
X. Mare Fœcunditatis.
Z. Mare Australe.

Mountains and Crater Rings.

1. Grimaldi.
2. Letronne.
3. Gassendi.
4. Euclides.
5. Bullialdus
6. Pitatus.
7. Schickhard.
8. Longomontanus
9. Tycho
10. Maginus.
11. Clavius.
12. Newton.
13. Maurolycus.
14. Stöfler.
15. Walter.
16. Regiomontanus.
17. Purbach.
18. Arzachel.
19. Alphonsus.
20. Ptolemaus.
21. Hipparchus.
22. Albategnius.
23. Theophilus.
24. Cyrillus.
25. Catharina.
26. The Altai Mts.
27. Piccolomini.
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29. Langrenus.
30. Proclus.
31. Cleomedes.
32. Atlas.
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34. Posidonius.
35. Plinius.
36. Menelaus.
37. Manilius.
38. The Caucasus Mts.
39. Eudoxus.
40. Aristotle.
41. The Alps.
42. Plato.
43. Archimedes.
44. The Apennines.
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46. Copernicus.
47. The Carpathian Mts.
48. Timocharis.
49. Lambert.
50. Euler.
51. Aristarchus.
52. Kepler.
53. Flamsteed.

ASTRONOMY

FOR GENERAL READERS.

BY

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

Author of "A Handbook of Descriptive and Practical Astronomy," &c., &c.

POPULAR EDITION.

WITH A NEW CHAPTER ON TWENTIETH CENTURY ASTRONOMY.

WITH 134 ILLUSTRATIONS.

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> "That which we know is little but
> that which we know not is immense."
>
> LAPLACE.

PUBLISHERS' NOTE.

THIS book is written with the idea of giving English readers some general conceptions of this fascinating science.

The author's well-known reputation as a writer upon the subject, together with the many flattering notices the work received when issued at a higher price, assure to the public a work which is both entertaining and instructive and at the same time scientifically accurate.

The publishers, therefore, hope that in its new form the work will be the means of stimulating a taste for scientific work and study.

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PREFATORY CHAPTER ON TWENTIETH CENTURY ASTRONOMY.

ASTRONOMY, like all other branches of knowledge, progresses with the times. But its fundamental principles are more unchanging than those of most other sciences. For instance, its nomenclature has not undergone in its backbone such a revolution as has taken place in the science of Chemistry, and the changes which a chronicler of astronomical progress during the last quarter or half a century would be in duty bound to take note of would have reference much more to an increased knowledge of details than of fundamentals. It is easy to explain why this should be so. It is due primarily to the increase in the size of the telescopes brought to bear on the survey of the Heavens, and the multiplication of observers on the watch to record the things which they see happening, though it is not often that these things involve changes which are wholly unprecedented.

The reader will realize from the foregoing statement that no necessity has arisen for any reconstruction of the text of this little volume, although several years have elapsed since it was first given to the world. The most important new points which need any consideration in this summary review concern the Sun and what has been learnt from several total eclipses; the increase in the number of the minor planets; the discovery of new satellites of some of the major planets; and the question of an unknown new planet revolving outside the orbit of Neptune.

Spectroscopic observations have thrown further light on the constitution of various heavenly bodies, especially comets, but with regard to Sidereal Astronomy, which embraces stars, clusters of stars, and nebulæ, there is not much which I can say in the space available for the purpose.

Measured by material, or, if one may be permitted to say so, by commercial results, by far the greatest visible developement in connection with Astronomy has been the remarkable multiplication of observers and telescopes, and this not in England alone but in all parts of the world and amongst all ranks of society. It is evidenced by the multiplication of books on Astronomy and the apparently unchecked demand for such books; by the increase in the number of societies and organizations devoted to the study of Astronomy; and by the increased attention shown by that newly developed *savant*, the man-in-the-street, which last named fact is indicated by the attention so freely given to current Astronomical topics by the daily and weekly political and general newspapers.

One effect of the general progress of things in the world of late years has been the greatly increased facilities for travel, and this has had a not inconsiderable effect on observations of eclipses of the Sun. Accordingly, eclipse expeditions from all parts of the civilized world to many uncivilized parts have been much more frequent than during former years. During the period now under review there have been three eclipses marked by great expeditionary efforts which stand out before all others,

namely, those planned to view the eclipses of 9th August, 1896, especially known as the Norway Eclipse; that of 28th May, 1900, known as the Portugal Eclipse; and that of 30th August, 1905, known as the Spanish Eclipse. It must not be supposed that these names define precisely the limits within which the eclipses were visible, but only the more prominent centres to which the greater number of astronomical tourists gravitated. Bad weather spoilt nearly all the efforts made to study the 1896 eclipse, but Shackleton, one of Sir G. Baden Powell's party who went to Nova Zembla, obtained the important result of a photograph of the so-called "flash" spectrum at the beginning of totality. This was the first successful attempt to secure a record of this phenomenon after many previous failures. The eclipse of May, 1900, conveniently visible as it was in a country so near to England as Portugal, drew thither a large number of observers; and many others went to the south of Spain and Algiers. By the aid of a large number of prismatic cameras a great quantity of photographs were obtained, but the observations taken as a whole did not yield any striking additions to our knowledge. They are not on that account, however, to be despised, because they served to confirm certain previous conclusions connected with the Sun's Corona. The central line of eclipse in 1905 passed from Labrador across to Spain and Egypt. It was hoped that observations taken in countries so remote as Labrador and Egypt (which meant in the latter case at an absolute interval of more than two hours after observations taken at the former station) would have enabled Astronomers to ascertain whether during such an interval as two hours of absolute time any material change or transformation took place in the Solar Corona. The attempt to obtain information on this point was, however, frustrated by the unfortunate failure of the weather in Labrador. The expeditions to view this eclipse were on an unusually large scale, no less than eighty different places being occupied as observing stations. The weather was very generally unfavourable, more or less, a fact to be regretted, especially because many years will elapse before any other eclipse occurs, visible in a locality easily accessible to English, or indeed to European, Astronomers.

The sum total of the minor planets continues to grow, I will say boldly, with undesirable rapidity, and the total number is now approaching 600. They have, with some half-a-dozen exceptions, long ceased to be of any individual interest, and it is marvellous that the stolid German mind can continue to take note of them, for it must be freely confessed that the credit of their discovery and calculation now rests almost wholly with the Germans. It is, moreover, no wonder that many of them have been lost, and that now and again a new discovery turns out to be an old one.

Far more interesting than the minor planets are the new satellites of Jupiter and Saturn. Astronomers were so long accustomed to consider the satellites of the major planets to be limited to the 4 belonging to Jupiter, the 8 belonging to Saturn, the 4 belonging to Uranus, and the one belonging to Neptune, that when in 1877 the discovery was announced of 2 satellites to Mars, quite a shock was given to the astronomical world. But there have been more serious shocks since; and Jupiter with 8 satellites instead of 4, and Saturn with 10 instead of 8 may now be regarded as recognized facts.

As a complete statement of Jupiter's satellites is not readily met with, the following table may interest many readers. It is to be remarked that a very haphazard system of nomenclature has come into use, though perhaps this was, in a sense, unavoidable. It is to be hoped, however, that names will soon be provided by the discoverers of these satellites.

THE SATELLITES OF JUPITER.

DESIGNATION	DISCOVERER AND DATE OF DISCOVERY	MEAN DISTANCE	SIDEREAL PERIOD	
		Radii of Jupiter	d.	h.
V	Barnard, Sept. 9, 1892	1·2	0	12
I Io	Galileo, Jan., 1610	6·0	1	18
II Europa	Galileo, Jan., 1610	9·6	3	13
III Ganymede	Galileo, Jan., 1610	15·3	7	4
IV Callisto	Galileo, Jan., 1610	26·9	16	18
VI	Perrine, Dec. 3, 1904		250	12
VII	Perrine, Feb., 1905		259	17
VIII	Melotte, Feb. 28, 1908		790	±

The 8 old satellites of Saturn have recently been increased to 10 by two discoveries made in America, both by means of photography in the first instance. Satellite IX, which has been named Phœbe, was found on a plate taken on August 16, 1898. It revolves round its primary in 546 days, at a distance which may vary from 6,210,000 to 9,740,000 miles. This great variation is owing to the remarkable eccentricity of the satellite's orbit, which is 0·22, an eccentricity greater than that of any other planetary satellite or major planet, and equalled only by a few minor planets. Phœbe's diameter has been estimated at 200 miles. Its brightness is less than that of a 16th magnitude star. Satellite X, which has been named Themis, was found on a plate taken in 1905. Not much is known of the character of its orbit, except that it revolves round its primary in the short period of 21 days, which is nearly the same as the period of Hyperion, the seventh satellite, discovered in 1848.

Since January, 1890, no fewer than 95 comets have appeared, but none of them of special size and importance. Two of them, Holmes's (1892, iii) and Morehouse's (1908, iii), underwent extraordinary transformations of appearance indicative it would seem of the operation of forces, inherent or external, or both, as to which we shall no doubt know more, sooner or later, and have much to learn. The great comet event of 1910 is, of course, the return of Halley's comet, celebrated alike in astronomical and in political history.

As regards the supposed trans-Neptunian planet, little can be said because nothing is known; but Forbes in Scotland and Flammarion in France have agreed very definitely in favour of the existence of such a planet.

It has been suggested to me that the usefulness of this book would be enhanced if it contained a little more information on the subject of Telescopes and their use. I will therefore deal with this matter by way of supplement to the chapter which appears elsewhere.[1] It so happened that only two or three days before I began writing these remarks, I accidentally fell in with a gentleman who, interested in Astronomy, told me that he possessed two telescopes, but never used them, and did

---

[1] See chap. xiii, *post.*

not know how to use them. I fear that some such confession as this might often be made, and it has stimulated me to write what I am now going to write.

The most common mistake made by everybody is that Astronomy cannot be studied instrumentally except a large telescope is at command. There is no greater mistake imaginable. Even with an opera-glass something can be done. Indeed, the use of an opera-glass combined with a set of star maps, and so used for twelve months, is itself an important preliminary training for more work on a larger scale when the telescope arrives.

To a young student who intends to take up Astronomy systematically as a pursuit, I would say "Do not buy your telescope until at least you have given twelve whole months to a study of what I must call, for convenience' sake, the Geography of the Sidereal Heavens. You will then start work with your telescope with much greater zest." The books wanted for such a purpose are an almanac and a star atlas. As an almanac *Whitaker's* is unrivalled, and the old *British* very good. The best English atlases for this purpose are *McClure's*, published by the S.P.C.K. and *Hind's*, published by Keith Johnston; but of course there are others available, amongst which I may single out *Peck's Handbook and Atlas* as very good. McClure's book has the additional advantage that it contains a catalogue of celestial objects suited for small telescopes.

The most important caution to be given to the tyro in Astronomy is "Do not concentrate too much of your thoughts and money on the size of the telescope which you are proposing to buy, as distinct from its stand." With a smaller telescope on a well-mounted stand, more work can be done, and it can be more pleasantly done, than with a much larger telescope on an inefficient stand. The only right sort of stand is an equatorial, however coarse may be the graduation of its circles. A 3-inch telescope equatorially mounted is a far more useful appliance than a 4-inch mounted in altazimuth fashion on the exploded pillar-and-claw stand to be placed on a table, which was affected by our forefathers fifty or one hundred years ago. Another serious mistake into which young or inexperienced amateurs generally fall, is an undue partiality for eye-pieces of high power. It may be taken for granted that one-half of the eye-pieces (being of course those of the highest power) commonly supplied by opticians with new telescopes, are not of the slightest use for general purposes; and this is peculiarly true in the case of telescopes which are not equatorially mounted. I suggest the following as an ample supply of powers for the smaller sizes of telescopes intended to be dedicated to what I may call general star-gazing use:

3 inches of aperture: 20, 55.
4 inches of aperture: 25, 65, 140.
5 inches of aperture: 30, 85, 170.

Whilst of course it is desirable that all the lenses and the object glass of a telescope should be as clean as possible, this condition of things should be obtained rather on the principle of prevention being better than cure; that is to say, when suitable care is exercised the glasses of a telescope ought not to get dirty or dusty except at long intervals of time. When they have got into condition to need systematic cleaning, the cleaning process should be carried out very delicately, with a light hand and very soft materials. As regards the latter there is nothing so suitable as an antiquated cambric or silk pocket handkerchief. No water should be used, but in cases of real necessity to use liquid it should be spirits of wine applied with a camel's-hair brush and then very gently rubbed.

The foregoing remarks obviously apply more particularly to refractors, but in spirit may be considered applicable *mutatis mutandis* to reflectors. I do not, however, recommend reflecting telescopes for amateurs financially limited to small sizes of aperture. It is true that inch for inch they are cheaper than refractors, but they are very unhandy, and the mirrors, whether metallic or silvered glass, soon get out of condition, and are not easily or inexpensively rehabilitated.

Some means of ascertaining sidereal time is, of course, indispensable to the amateur, and is best met by a clock directly regulated to sidereal time which gains about four minutes a day on common time. An expensive, highly finished clock of great scientific accuracy is wholly unnecessary; and any fairly good English or French clock costing £2 or £3, or even less, will suffice. Indeed, it is easy enough for the amateur observer to calculate sidereal time by means of the almanac for himself every day, as he wants it, and carry on his work with a clock or watch not set to sidereal time. This may be a little awkward in practice, and a simple, easy remedy is to use any sort of a clock to fulfil the rôle of a journeyman clock, starting it to sidereal time every evening before beginning work.

An obviously important factor in the conduct of astronomical observations is the weather. As to this the amateur must not be too fastidious. He must not disregard a day for viewing the Sun, or a night for viewing stars because there seem to be too many clouds about, or because the stars look dull. When there are broken clouds about, especially after some showers of rain, it will often happen that the stars will be very clearly and sharply defined; and paradoxical as it may sound it often happens that when the stars are not sharply defined to the naked eye, but seem dimmed as if by a veil of haze, the definition may be fairly, or even very, good. This probability especially applies to the observation of planets.

A small telescope, if of good quality and mounted on a steady stand, will often render visible planetary features which are very interesting: under this head I may enumerate the horns of Venus, the coloured patches and polar snows of Mars, the belts and larger satellites of Jupiter, and the rings of Saturn. Jupiter in particular affords endless interest in the movements of its 4 old satellites, their transits across the planet, and eclipses, and occultations. Nor must the Moon be forgotten. Its mountains and their similarity of formation to terrestrial volcanoes are most interesting. And incidentally the occultations of stars by the Moon should not be forgotten. The best time for viewing the Moon is when it is rather young, or very old, because the shadows of the mountains then come out in their most striking form. The Moon when full should be avoided because the mountains cast no shadow, and a straight front view of them is not of much good.

In looking at the Sun and its spots care must be taken to use dark glasses: and whatever the size of the telescope, however small, a diagonal reflector. This reflects the light rays only and disperses the heat rays. This precaution is very important, or accidents to glasses and eyes alike may occur.

ASTRONOMY.

CHAPTER I.

PRELIMINARY CONSIDERATIONS.

ASTRONOMY may be regarded as one of the most comprehensive of the intellectual sciences cultivated in the present day. It embraces matters of the greatest popular interest to the general public, whilst it also calls to its aid, for certain purposes, mathematical calculation and analysis of the most difficult and abstruse character. Astronomy as a matter of study may be conveniently regarded as embracing three main branches, each tolerably distinct from the other.

That branch which we study with the sense of vision, that is, which requires the eye or a telescope to be brought to bear on it, and which must be pursued more or less in the open air, may be called simply "Descriptive Astronomy."

That branch which investigates causes and effects and the laws which govern the universe, and which is chiefly a matter for indoor study in the daytime, so to speak, is known as "Theoretical," or sometimes "Physical," Astronomy.

That branch which relates to instruments and methods of employing them, and, to some extent at least, of drawing useful conclusions from the results which they place us in possession of, is known as "Practical Astronomy."

The terms "Descriptive Astronomy" and "Theoretical Astronomy" may, in the light of what has just been stated, be said sufficiently to explain themselves, but "Practical Astronomy" seems to require a little more expansive definition. It includes various processes and operations, and the ways of obtaining a knowledge of certain facts which justify us in regarding the science as a useful one. Practical astronomy may be said, in fact, to embody the commercial or utilitarian aspect of the science, for unfortunately in these days people are not always ready to disregard the money-making opportunities afforded by objects of study which are primarily of an elevating or intellectual character.

The great changes which of late years have come over the methods of presenting science to general readers find illustrations in astronomy just as they do in such sciences as geology and chemistry, and readers and students can now pursue their work and researches under circumstances vastly different from those which prevailed at the beginning of the present century, and indeed up till about the year 1850. Up to about that period it may be said that the books obtainable were few in number, and often repulsive in form. Their engravings or illustrations were likewise few, and these were generally coarse and often grotesque—mere caricatures of the objects supposed to be represented. Scarcely anything had been done in the way of applying colour to scientific printing. Telescopes were rare, small, of inferior workmanship, and very

expensive. In every one of these points we of the present generation possess advantages over the last and preceding generations, the nature and extent of which many of us scarcely realize. Perhaps if I mention only the one subject of photography, the reader will be able to form a slight idea of the progress by which he is now profiting. It is not easy to describe the service which photography has rendered in securing exact records of astronomical facts and events.

Some other ideas seem to deserve brief notice in this place, in connection with the foregoing statement of the improved facilities which now exist for enabling the general public to obtain some insight into the wonders of creation included in the domain of astronomy. The books and methods of half a century ago were generally based on an elaborate series of definitions, often stated in a dry and repulsive form, and on diagrams of complex and forbidding aspect. When it was a matter of the personal teaching of astronomy, no teacher could do anything without a great globe, and a vast amount of explanation respecting this (for astronomical purposes) extremely doubtful toy. He would dwell so much upon preliminary details, that by the time he arrived at his astronomy properly so called, he had reached nearly the end of his available time, however many lectures or lessons his course might consist of. We have in the present day outgrown most of these antiquated methods of doling out astronomical facts, whether for the student or for the general reader. Moreover the books on all subjects claiming attention nowadays are so numerous, that conciseness of diction and clearness of style, both in the statements made, and in the manner of making them, are important to a degree which formerly would not have been realized.

The foregoing general remarks will, in their way, afford a clue both to the scope and to the intention of the present work, and also to the manner in which it is proposed to exhibit the information which will be given.

CHAPTER II.

THE SOLAR SYSTEM.

THE expression "Solar system" is in common use to express collectively those various heavenly bodies which revolve round the Sun as a centre, and which depend upon the Sun in various ways, some of which we shall in due course consider. The bodies here to be included are especially the planets (with their satellites, often spoken of as "moons"), comets, and meteors. Yet in strictness, perhaps, only some of the comets should be ranked as members of the Solar system; whilst as regards the meteors, their origin being unknown, and their movements irregular and uncertain, the propriety of treating them as members of the Solar system is by no means free from doubt. Perhaps, however, we may best define the Solar system as that series of created celestial objects which depend on the Sun, the largest and most important of them.

We nowadays perfectly comprehend that the Sun is the centre to which we look, and that all the planets and many of the comets circulate round this centre; but conclusive knowledge of these facts is comparatively a thing of modern times. In ancient times, and down to within three or four centuries ago, ideas altogether different were current, and several contradictory theories had at different periods been put into circulation regarding the centres round which the several planets revolved, and the order in which they did so. As to the comets, it may be said that nobody in days gone by seriously considered them as in any way belonging to the Sun or to the planets. The Moon was regarded as being simply a very bright planet, distinguishable, say, from Venus or Jupiter, only by its greater size and more rapid motions.

As several distinguished men, who are such on account of their general eminence as astronomers, are associated with some of these incorrect theories of the Solar system, it may be worth while to state briefly the principal features of these erroneous systems.

The "Ptolemaic System," though bearing the name of Ptolemy, was not perhaps actually suggested by that philosopher. It makes the Earth the centre of the system round which the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, all regarded as planets, revolve, and in the order stated. The "Egyptian System" slightly differed from the Ptolemaic in treating Mercury and Venus as satellites of the Sun, and not independent planets.

The "Pythagorean System" contemplated the existence of a central fire, around which, as the hearth or high altar of the universe, 10 heavenly bodies revolved. All these theories were of course erroneous, not to say ridiculous; but it is certain that more than one Greek philosopher had an inkling of the fact that the Sun was the real centre of everything, and that the Earth and planets in some mysterious way depended upon it.

Next in point of time was the theory put forth by Copernicus, which, as developed by Sir I. Newton, is now the accepted theory of the universe. Nevertheless, it had one powerful opponent in Tycho Brahe, who, eminent as an observer, utterly failed as a theorist when

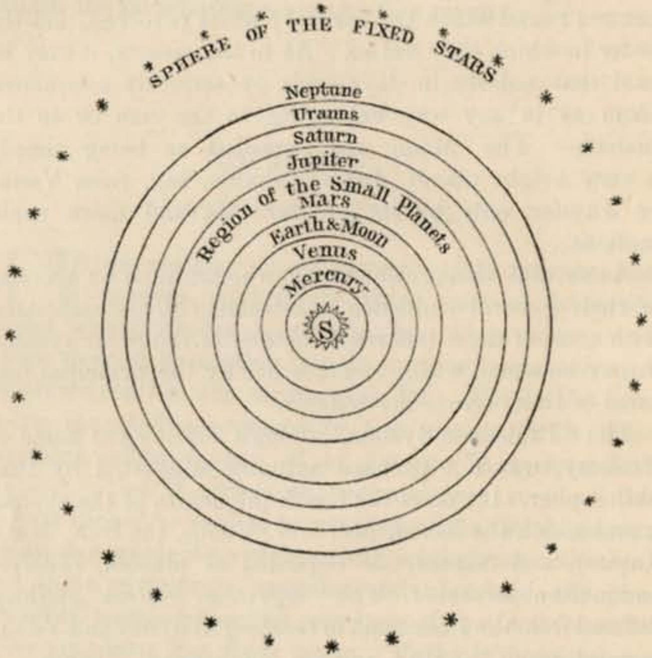

FIG. 1.—THE COPERNICAN THEORY OF THE UNIVERSE.

he insisted that the Earth was the immovable centre of everything.

Tycho Brahe, who died in 1601, and who was a very hard-working, and, in other respects, able astronomer, put forth a theory which suggested the Earth as the centre of the universe, with the Moon as the Earth's nearest satellite, the Sun being another and more distant satellite, around which the major planets circulated, they themselves being solar satellites. Tycho marred the credit of a long and useful life as a working observer by

FIG. 2.—TYCHO BRAHE'S HOUSE AND OBSERVATORY, "URANIBERG," IN THE ISLAND OF HUEN.

lending himself (apparently from religious motives) to this theory, which Copernicus had in effect demonstrated to be untrue and impossible half a century previously.

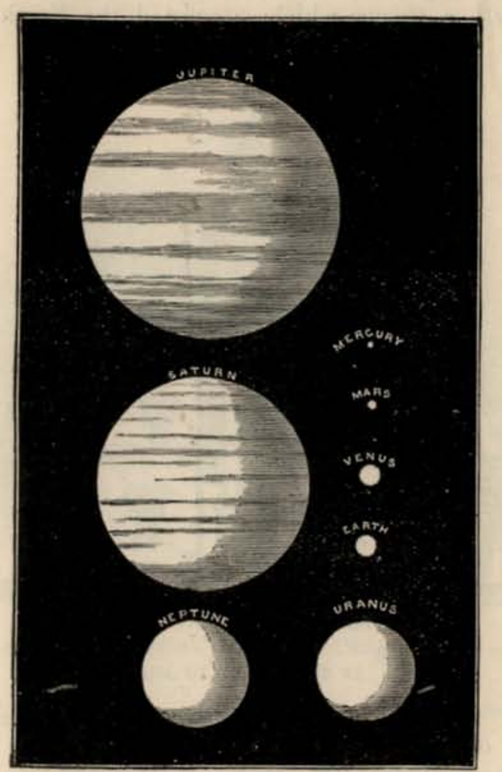

FIG. 3.—COMPARATIVE SIZES OF THE PLANETS.

The Solar system, as we now accept it, consists of the Sun and the following bodies revolving round it:—

(1) Mercury.
(2) Venus.
(3) The Earth (with its satellite the Moon).
(4) Mars (with its 2 satellites).
(5) The Minor Planets (about 300 in number).
(6) Jupiter (with its 4 satellites).
(7) Saturn (with its 8 satellites).
(8) Uranus (with its 4 satellites).
(9) Neptune (with its 1 satellite).
(10) Certain comets known as "periodical comets."

Of the above, Mercury and Venus being within the Earth's orbit, are called "inferior planets," whilst Mars and all the others, because they are outside the Earth's orbit, are called "superior planets."

Tabular details respecting the several major planets, the minor planets, and the satellites, will be given subsequently in the Appendix.

One of those happy inspirations which one meets with now and again in literature, led Sir John Herschel to frame a comparative statement of the objects comprising the Solar system, which, with some modifications and extensions, is reproduced in the following table. His idea was to start with a level field or open common, and on it to place certain objects at certain distances to represent the Sun and planets, thus:—

Sun in the centre, 2 feet in diameter.

	Distance from the Sun.	Ideal Size.
Mercury	82 feet	a mustard seed.
Venus	142 feet	a pea.
The Earth	215 feet	a pea.

	Distance from the Sun.	Ideal Size.
Mars	327 feet	a small pepper-corn.
The minor planets	500-600 feet	grains of sand.
Jupiter	¼ mile	an orange.
Saturn	⅖ mile	a small orange.
Uranus	¾ mile	a cherry.
Neptune	1¼ mile	a plum.
Encke's comet (Aphelion)	290 yards	—
Donati's comet (Aphelion)	6 miles	—
Nearest fixed star	7500 miles	—

It needs hardly to be affirmed that the planets perform their movements in obedience to definite laws, and indeed no science more often furnishes illustrations of the existence of Order and Design in nature than does astronomy.

Whilst we shall come across proofs of this in many places, it is expedient here to call attention to the laws commonly called "Kepler's Three Laws," being the most important and best known of all the laws which astronomy presents us with.

Copernicus, in making the Earth and the planets move round the Sun, allotted to the Sun the eminent position in the universe which belongs to it. But he could not determine the laws which governed the motions of the planets. This was reserved for the genius of Kepler In calculating the different positions of Mars, and comparing his own observations with those of Tycho Brahe, Kepler was astonished at finding numerous apparent irregularities in Mars's orbit, and still more in its distance from the Earth. He soon saw that the orbit could not be circular, that it must be some other closed curve, and eventually he recognized that it must be an ellipse, with the Sun occupying one of the two foci. This was a foreshadowing of his First Law.

It was not, however, enough to have discovered the true form of planetary orbits ; he desired to ascertain the reason of that form, and he concluded that it depended upon some influence exerted by the Sun. Thus he obtained an inkling of what Newton was able to demonstrate some three-quarters of a century later.

The path of a planet once traced, the next thing to determine was what regulated the irregularities observed in its course. Kepler having remarked that the velocity of a planet seemed to be greatest when it was nearest to the Sun, and least when it was most remote from the Sun, proceeded to suggest that an imaginary line joining the centre of a planet and the centre of the Sun would pass over equal areas in equal times, an important discovery which resulted in his Second Law.

He did not stop there, but proceeded to apply his two first laws to other planets besides Mars, and to the Earth itself. Then noticing that the revolutions of these planets were so much longer as the orbits were larger, he sought to discover if any relation subsisted between the diameters of the orbits and the times occupied by the planets in traversing them. After 27 years of laborious research he found out that a relationship did subsist, and thus was able to assert his Third Law.

These laws are commonly set forth in some such terms as the following :—

(1) The orbit described by every planet is an ellipse,

of which the centre of the Sun occupies one of the foci.

(2) Every planet moves round the Sun in a plane orbit, and the radius vector or imaginary line joining the centre of the planet and the centre of the Sun describes equal areas in equal times.

(3) The squares of the periodic times of any two planets are proportional to the cubes of their mean distances from the Sun.

The first of these laws explains the variations in the distance of the Earth from the Sun, and likewise of the planets from the Sun. The second accounts for the regularity which observation enables us to discover in the angular velocity of the Sun in its apparent movement round the Earth; or, as it should be more properly put, in the angular velocity of the Earth round the Sun. Whilst the third law enables us, knowing the distance of the Earth from the Sun, and its period and the period of any given planet, to calculate at once the mean distance of that planet, expressed in the same terms as the distance of the Earth is expressed in, be it radii of the Earth's orbit, or miles, or what not.

Fig. 4 will serve to fix in the reader's mind the principles enunciated in Kepler's First and Second Laws.

The ellipse A B C P Q represents the Earth's orbit. S is the Sun, at one of the two foci of the ellipse. It is obvious at a glance that the Earth is not at the same distance from the Sun at all parts of its annual path. It is nearest the Sun when at P ("perihelion"); farthest at A ("aphelion"). The line A S P, being the line bisecting the ellipse and passing through the two foci (one of which, S, is marked, and the other not marked), is called the "line of apsides." All the foregoing expressions apply to planetary orbits generally.

At the time when the Earth is nearest the Sun, or in perihelion, it is clear that the Sun is nearest to the Earth, but to express this directly, another word, "perigee," is in use. Similarly the word "aphelion" has for its correlative "apogee." These two words are often used to refer to the greatest and least distances of any planet from the Earth.

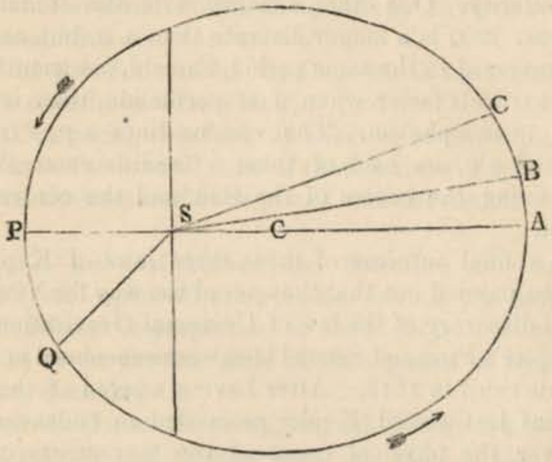

FIG. 4.—DIAGRAM ILLUSTRATING KEPLER'S FIRST AND SECOND LAWS.

The same diagram will serve to explain Kepler's Second law, of equal areas being described in equal times. Suppose a planet moves from its perihelion, P, to Q, in one month. It will have described the area P S Q, that is to say, the triangular space included between the imaginary lines S P, S Q, and its actual orbit P Q. Suppose again, on the other side, it moves from its aphelion, A, to B, in one month; it will then have described the area A S B, that is to say, the triangular space included between the imaginary lines S A, S B, and its actual orbit A B. Kepler's Second law is to the effect that, as the areas P S Q and A S B both represent one month, therefore those areas are equal, notwithstanding their seeming dissimilarity. One other conclusion is also sufficiently obvious. P Q is a longer distance than A B, but as both are traversed in the same period, namely, one month, the planet travels faster when near perihelion than it does when near aphelion. The various lines S P, S Q, S A, S B, and S C, are each of them a "radius rector," or a line joining the centre of the Sun and the centre of a planet.

As a final outcome of these three laws of Kepler, it may be pointed out that they paved the way for Newton's grand discovery of the law of Universal Gravitation.

Kepler's First and Second laws were announced in 1609, and his third in 1618. After having arrived at the conclusions just stated, Kepler proceeded to endeavour to discover the physical cause of the movements of the planets. His investigations as to this often exercised his active imagination, but at his epoch (he died in 1630) the time had not come for the solution of this great problem, which needed the assistance of advanced mathematical analysis, then only in process of development. Kepler indeed altogether failed to approach his goal; on the contrary, he drifted quite away from it in vain speculations respecting the motive force which acted on the planets. The honour of making known the general principle of the movements of the heavenly bodies was reserved for Sir I. Newton. In his celebrated *Principia*, published in 1686, this great man, utilizing the observations especially of Galileo and Huygens, ultimately established certain important conclusions, which are now accepted universally as the basis of all physical astronomy. A popular epitome of these conclusions, even in an elementary form, would be entirely beyond the scope of these pages. It must suffice then to sum them all up in a few curt sentences, thus:—

(1) In the Sun resides the force which maintains the planets each in its own orbit.

(2) Comparing this force as affecting any two planets, it varies in the inverse ratio of the square of the distance between the centre of each planet and the centre of the Sun.

(3) All material bodies, and therefore all planets, mutually act upon all other bodies within the scope of their influence in proportion to their respective masses, and also in the inverse ratio of the squares of their respective distances.

These fundamental principles, taken together collectively, may be said to constitute the basis of the Newtonian laws of Universal Gravitation.

CHAPTER III.

THE SUN.

THE Sun may well be said to be worthy of its position as the centre of our system, not only on account of its size, but by reason of the vast and complex influences which it exerts over all the planets under its sway. The mean distance of the Earth from the Sun is the chief standard of celestial distances. A consideration of the methods of ascertaining it belongs to another place. At present let it suffice to say that that distance is probably close upon 93 millions of miles. The apparent diameter of the Sun is rather more than half a degree, or 866,000 miles. The surface of the Sun's globe is nearly 12,000 times that of the Earth, whilst its volume is 1,300,000 times greater. The Sun's mass, or attractive power, is 332,000 times that of the Earth, and about 750 times that of all the planets taken together. One noticeable thing about the Sun is the smallness of its specific gravity. The average weight of a given bulk of earth, say a cubic foot, compared with a similar bulk of water, is about 5½ to 1. That is to say, whilst a cubic foot of water weighs 62 pounds, a cubic foot of earth weighs about 350 pounds; but in the case of the Sun, a cubic foot of its material will weigh no more than half as much again as the like bulk of water: in other words, bulk for bulk, the Sun is only one-fourth the weight of the Earth.

Could we carry on at the surface of the Sun certain philosophical experiments connected with falling bodies, say, for instance, firing a shot out of a cannon, we should observe some striking contrasts as between the behaviour of falling bodies on the Earth and on the Sun. The stupendous magnitude and mass of the Sun would be found to intensify the force of gravity there far beyond anything we can realize. It would be 27 times greater than on the Earth, so that an artillery projectile would have very little movement there, but would fall to the Sun's surface within a few yards of the cannon's mouth.

The Sun is a self-luminous sphere, emitting, as we all know, a vast amount of heat and light. Many calculations have been made with the view of conveying to the human mind numerical ideas as to the amount of this heat and light, but it cannot be said that the conclusions are very expressive, for there is an air of unreality about all of them. However, for those who like such speculations, it may be stated that, whilst one physicist has calculated that the Earth's annual share of the Sun's heat would raise an ocean of fresh water 60 feet deep from freezing point to boiling point, another has calculated that the ordinary daily light of the Sun would be represented by rather more than 5000 wax candles concentrated at a distance of 1 ft. from the observer.

If we look at the Sun, what do we see, or rather, what do we appear to see?—a small, circular, and seemingly 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, for a very slight amount of study shows that it is very large, and not flat, but a sphere or ball.

Moreover, with exceptions too rare to be worth notice in this place, the Sun seems to have the same smooth surface and yellowish colour all over. In the telescope, however, matters are far otherwise ; the surface appears mottled or stippled ; it is brighter in the centre than at the edges, and blackish spots may frequently be seen in certain parts of the disc. The inequality in the brightness of the Sun, as between centre and edges, is a thing which results very naturally from the fact of the Sun being a globe enveloped in a sort of atmosphere, through which luminous rays reach us from below this atmospheric envelope, as we may for the moment, at least, call it.

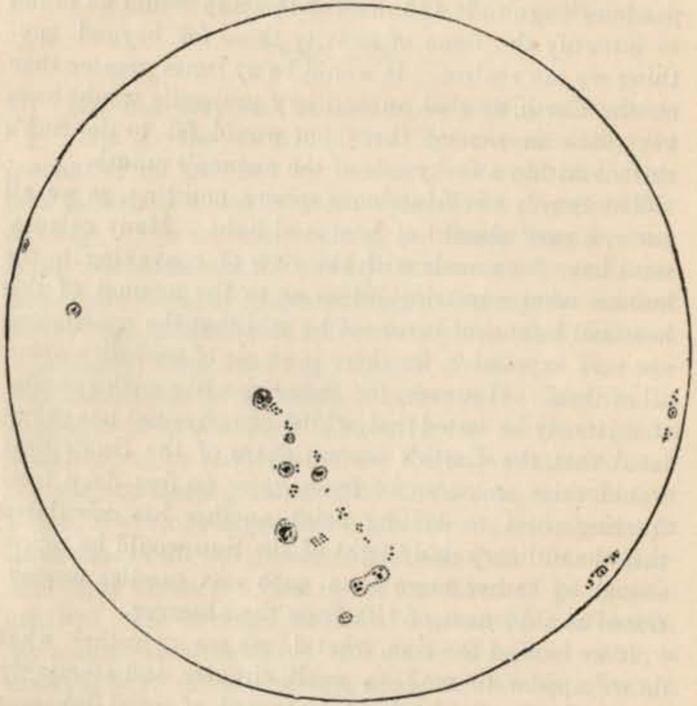

FIG. 5.—THE SUN WITH MANY SPOTS VISIBLE, MAY 15, 1836.

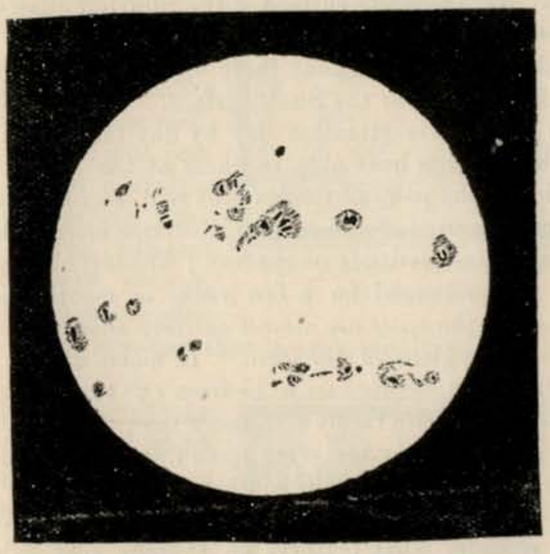

FIG. 6.—THE SUN WITH SPOTS IN BOTH HEMISPHERES.

Experiments made for the purpose of comparing the apparent brilliancy of the Sun at its centre, have yielded very contradictory results, but a fair conclusion seems to be, that near the edges the luminosity is no more than one-fourth or one-sixth of what it is at the centre.

When the Sun is examined with a telescope, it will often happen that small black, or blackish, patches will be seen on different parts of the disc. These are the so-called "spots on the Sun," a term which is probably used by many who do not in the least understand the things themselves. To a casual and inattentive observer these spots will probably be regarded as being promiscuously spread over the whole surface of the Sun, but observation prolonged over a few weeks, or even over a lesser time, will disclose the fact that these spots are not scattered promiscuously over the Sun's surface. On the contrary, when by a little attention day by day for a short time the observer has been able to guess at the approximate position of the poles of the Sun, he will discover that the general direction of these spots conforms more or less to the parallels of latitude on the Sun; whilst if his observations are prolonged for a few weeks or months, he will notice that the spots are almost entirely absent from the equatorial regions of the Sun. In point of fact their favourite latitude appears to be from 15° to 20° north or south, and they are rarely seen more than 30° or 35° from the equator. They are often more numerous and larger in the northern than in the southern hemisphere.

So much for the distribution of the spots. Now we must consider what features an average spot exhibits. The essential feature, especially as seen with a small telescope, is a black patch, small or large, as the case may be. This patch is now scientifically called an *umbra*. Outside it and surrounding it there is generally an edging or fringe; this is called the *penumbra*. On the other hand, inside the umbra there may be sometimes, but not always, visible a smaller patch of decidedly intense blackness; when this exists it is now called the

nucleus. It is to be understood that what I have just described is to be regarded as a perfect or typical spot, but many departures from this type will be noticed by an attentive and habitual observer. For instance, several distinct umbræ are often to be seen within the limits of one penumbra, whilst a nucleus is often wanting altogether. The adjacent woodcuts will convey, however, a better notion of an average Sun-spot than a prolonged verbal description.

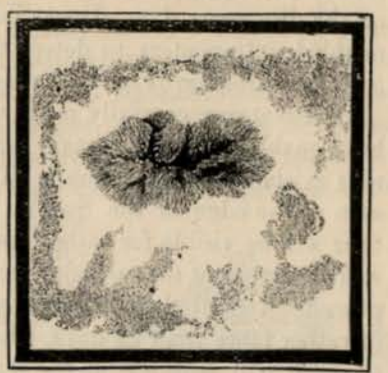

FIG. 7.—SPOT ON THE SUN, JULY 2, 1826 (CAPOCCI).

A spot once found may last for a period short or long, dependent, as far as we know, upon no laws; but a few days or weeks represents their usual duration. It must not be supposed, however, that any one spot will remain continuously visible at the same place on the Sun for days together, or even for one day. On the contrary,

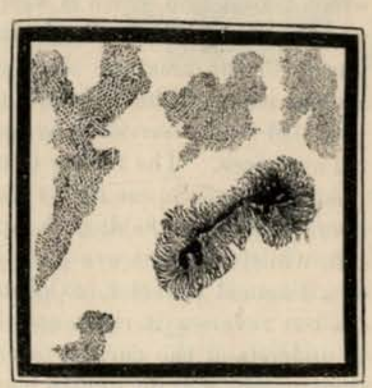

FIG. 8.—SPOT ON THE SUN, SEPTEMBER 29, 1826 (CAPOCCI).

the Sun being a body which, like the planets, rotates upon its axis, every spot occupies a different relative position on the disc every day. It was indeed this fact which first enabled astronomers to detect the axial rotation of the Sun, and afterwards to determine its duration.

Observations carefully made with this object in view have enabled us to ascertain that the Sun rotates on its axis in about 25 days 8 hours. That is to say, that a spot seen at the edge of the Sun on a given day for the first time will be visible for rather more than 12 days, when it will disappear at the opposite limb to that at which it appeared. It will then remain invisible for another period of rather more than 12 days, when if still in existence as a spot it will reappear at the same limb as that at which it was first seen 25¼ days previously. If at its first appearance a spot comes into view on a limb it will be on the eastern limb and it will disappear on the western limb; but which is east and which is west, and which is north and which is south on the Sun's disc, will often at first be a puzzle to the amateur observer, because any one point, say the east, will be different according as his telescope is provided with a terrestrial eye-piece or with an astronomical eye-piece. The former of course exhibits the cardinal points as they appear to the naked eye; the latter, however, inverts the field, both upside down and right and left, whilst a certain eye-piece in common use, and known as a diagonal reflector, exhibits the image the right way up, but reverses it right and left. In order, therefore, to understand the correct orientation of the Sun's limb, the amateur will do well to learn the bearings of his eye-piece by means of some convenient terrestrial objects. The varying position of the Earth with reference to the Sun, arising out of the Earth's successive seasons, also leads to slight apparent changes in the tracks pursued by spots in crossing the Sun.

Sun-spots vary very greatly indeed in size, both as regards one spot compared with another, and as regards the same spot at different stages of its existence. It is now generally admitted that a spot on the Sun is not a spot properly so called, in the sense in which we speak of a spot of dirt on a glass, but that it is an aperture or rift in the visible surface of the Sun brought about by disruptive forces operating below. Accordingly a spot exhibits at the beginning the appearance of a very minute aperture, which gradually widens in each direction, so that however large it eventually becomes its general outline nearly always is slightly symmetrical, approximating, say, to a polygon, though of course this statement must be taken in a very loose sense. Having reached its maximum development of size, the spot remains somewhat unchanged both in shape and size for, it may be, a few days, or even a week or two; eventually the spot begins to close up, and at last ceases to exist. These changes will sometimes occupy a few weeks, or even longer, during which time the spot, slightly altering from day to day, may yet be identifiable for a considerable time.

FIG. 9.—SPOT ON THE SUN, MAY 6, 1871.

On the other hand, there are spots exhibiting no symmetry of form, which break out with great suddenness, and after undergoing rapid and violent changes suddenly disappear.

As regards number, there may be visible at the same time no more than one or two spots, or several dozen spots of different sizes may be visible. These diversities do not, however, depend upon chance, but upon a law of a very singular and striking kind, the discovery of which is one of the most interesting incidents in the history of modern astronomy. In 1826 a German amateur, named Schwabe, who lived at Dessau, began daily observations on the Sun. Having completed a 12 years' series of such observations, he noticed distinct traces that the spots varied in number from year to year in a gradually changing manner, that is to say, if during some one year he saw many, then there might be fewer the next year, and fewer still the year after, and so on down to an evident minimum. He carried on these observations year after year for 30 years, when he succeeded in convincing the world that his ideas as to the reality of these changes were well founded. Schwabe himself put the period at about 10 years, but later observations on much the same footing, prolonged to the present time, and indeed still in progress, have led astronomers slightly to enlarge Schwabe's period, and the true value is now recognized as being a few weeks over 11 years. The following were years of maxima:—1829, 1837, 1848, 1860, 1870, 1883. It will be observed that the intervals are not quite identical. This is admitted. The figure of 11 years is derived by working on a long average of observations, which in a broken (and therefore in some

sense unsatisfactory) shape begins as far back as 1610, in fact with the invention of the telescope.

Two remarkable coincidences have been ascertained, both of them growing out of Schwabe's discovery of the periodicity of the solar spots. Changes take place periodically in the diurnal variation of the magnetic needle, and in the prevalence of auroras, which not only occupy a period of 11 years, but are of such a character that the epochs of maxima and minima for each phenomenon are nearly simultaneous with one another and with the Sun-spots.

It is probable that besides the 11-year period, there is another period 5 times as long, or 55½ years, and a third period 3 times the length of this, or 166 years; but it is evident that we must wait for another half century or more before the truth of these surmises can be established beyond question. Besides these periods, it has been thought that there exist minor periods in the prevalence of Sun-spots, traceable to certain of the planets, especially Venus and Jupiter.

Many theories have been broached suggestive of a relationship between the prevalence of Sun-spots and clouds and rainfall on the earth, but the evidence is at present not definite enough to deserve notice here.

As regards the physical cause of Sun-spots, we know very little. The spectroscope, whilst it has disclosed to us much information respecting the existence on the Sun of various terrestrial elements, and in particular of hydrogen gas, still leaves us very much in the dark as to the physical cause of the spots. It is, however, open to no doubt that they are funnel-shaped apertures in the Sun's "photosphere," as the envelope of the Sun which is the visible source of the light which comes to the Earth, is termed. Above the photosphere is the "chromosphere," a thin casing of self-luminous gaseous matter in an incandescent condition. Rising above the chromosphere again, comes the "corona," a vast shell of unknown vapours, highly attenuated, and many thousands of miles thick, extending indeed to at least half a degree from the visible edge of the Sun.

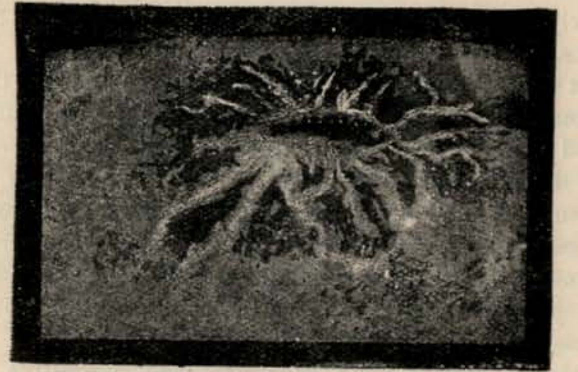

FIG. 10.—FACULÆ ON THE SUN.

Besides the spots, certain streaks of light called *faculæ* are sometimes visible on the Sun towards the limbs at or near the equator. They are of irregular form, and appear to be elevations or corrugations in the photosphere. Fig. 10 will serve in some degree to convey an idea of the visible structure of the Sun in regions where *faculæ* exist.

The value of the Sun's rays to the inhabitants of the Earth is well pictured in the following extract:—

"Equally delicate and mysterious is the relation which our bodies bear to the passing light. How our feelings, and even our appearance, change with every change of the sky! When the sun shines, the blood flows freely, and the spirits are light and buoyant. When gloom

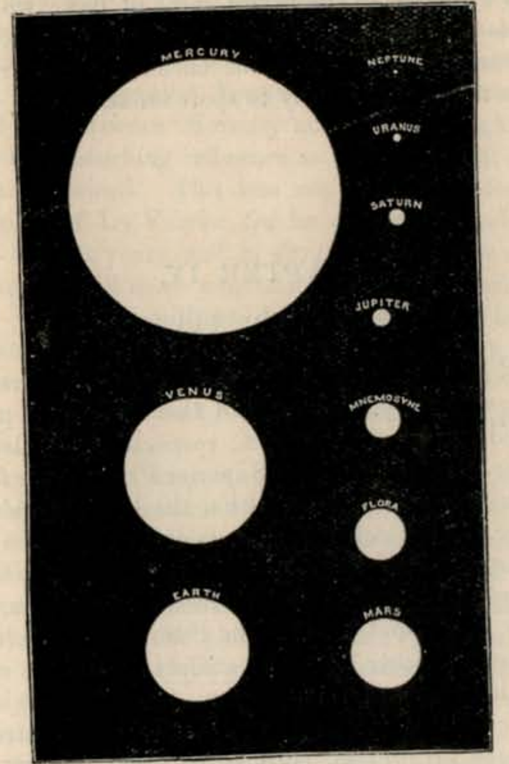

FIG. 11.—APPARENT DIAMETER OF THE SUN AS SEEN FROM DIFFERENT PLANETS NAMED.

overspreads the heavens, dullness and sober thoughts possess the mind. The energy is greater, the body is actually stronger, in the bright light of day; while the health is manifestly promoted, digestion hastened, and the colour made to play on the cheek, when the rays of sunshine are allowed freely to sport around us."[1]

CHAPTER IV.

THE INFERIOR PLANETS.

WE have already seen that, as regards their relative positions compared with the Earth, the planets are divided into two classes, respectively called the "Inferior Planets" and the "Superior Planets," the former being those which revolve within the Earth's orbit, and the latter those which revolve outside it.

Mercury and Venus are at present the only known inferior planets. It is an interesting question, "Is Mercury the planet nearest the Sun, or are there any other planets nearer?" No satisfactory answer can at present be given to this question, but there are to be found a considerable number of indications (no stronger term seems at present permissible) that one or more planets do exist within the orbit of Mercury.

The main justification of this, regarded merely as a theory, depends upon the fact that in 1859 a French astronomer named Le Verrier, of whom we shall hear more in connection with the planet Neptune, put forth a statement that he was unable to reconcile the theory of the orbit of Mercury with the observed facts except upon the supposition that some disturbing influences were at work, the nature of which was as yet unknown to astronomers. He suggested, however, that an undiscovered planet lying between Mercury and the Sun might exercise such a disturbing influence as would account for the difficulties noticed. This was not a mere random shot on the part of Le Verrier, for he continued his investigations in later years, and in 1874 reiterated his conclusions, and in still more emphatic language hinted at the cause. "There is without doubt," said he, "between that planet and the Sun matter hitherto unknown. Does it consist of one or several small planets, or of asteroids, or even of cosmic dust? Theory cannot decide this point."

The evidence to support the idea of an intra-Mercurial planet or planet presents itself in three forms:—(1) Recorded instances of black spots seen in motion across the Sun, which were not Sun-spots; (2) a particular black spot seen by a Frenchman in 1859, and much discussed under the name of the planet Vulcan; (3) observations made in America in 1878, which, if genuine and accurate, evidently show that two or more intra-Mercurial planets were seen during the darkness of the total phase of the solar eclipse of July 29 in that year. Here the controversy remains at a standstill, and no fresh materials for throwing light upon it appear to be within reach at present.

Two inferior planets, therefore, only are yet known, namely, Mercury and Venus. But as the apparent mo-

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[1] J. F. W. Johnston, *Chemistry of Common Life*, vol. ii. p. 403.

tions and phases of these two planets are the same, and differ in principle from the apparent motions and phases of the superior planets, it will be well to treat of these motions in this place before describing the planets themselves.

The inferior planets are never visible otherwise than near the Sun, and more or less in the twilight. They are never seen in those parts of the heavens which are on the meridian at midnight, or "in Opposition" to the Sun, to use the proper technical expression. Twice in every revolution an inferior planet is in conjunction with the Sun; it is in inferior conjunction when it comes between the Earth and the Sun, and in superior conjunction when it is beyond the Sun from the standpoint of an observer on the Earth. When at its greatest apparent distance from the Sun, east or west, it is said to be at its greatest elongation, east or west, as the case may be. At its eastern elongation the planet is an evening star; at its western elongation it is a morning star.

The true motion of each of the inferior planets is always in one and the same direction, that is, in the order of the zodiacal signs as viewed from the Sun, but to us on the Earth (a body which is itself always in motion) the apparent movements of these planets will not always be either uniform or regular, for at certain times they will appear to be stationary, and sometimes even to retrograde or move backwards as regards the signs of the zodiac. When an inferior planet is in inferior conjunction it will sometimes (though only at rare intervals) happen that it will pass directly in front of the Sun, and be projected on the Sun's disc. This phenomenon constitutes a "transit," and is made use of, as we shall see later on,

for obtaining a measure of the distance of the Earth from the Sun.

Fig. 12 represents the apparent path of Mercury amongst the stars during an entire revolution round the Sun in 1850. Its bizarre form is so striking that some further explanations seem desirable, and Fig. 13 will be necessary for making the matter clear. S is the Sun, A B C D the orbit of an inferior planet, E F G V the orbit of the Earth, K L M N the orbit of a superior planet. The outermost circle represents the ecliptic, on which celestial longitudes are reckoned, from the first point of Aries. The symbols attached to this outermost circle are the familiar symbols which indicate the twelve signs of the zodiac.

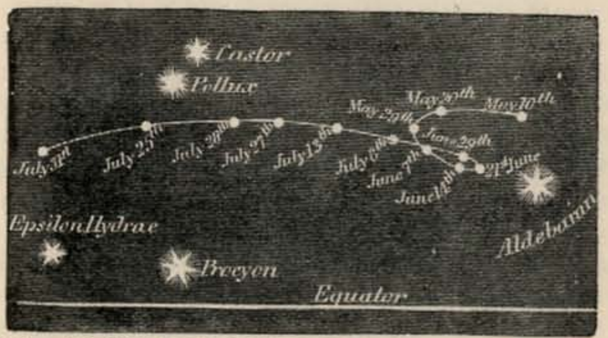

FIG. 12.—APPARENT PATH OF MERCURY DURING A WHOLE REVOLUTION IN 1850.

To an observer on the Earth at E, the inferior planet will be in conjunction with the Sun at B and D. B will be the place of inferior conjunction, and D that of superior conjunction. The places of greatest elongation are near *d* and *e*, whence lines from the Earth to the Sun and to the planet respectively make the greatest possible angle with each other. At *d* the direction of the planet's motion is nearly in a line *towards* the Earth, whilst at *e* it is nearly in a line *away* from the Earth. Accordingly to

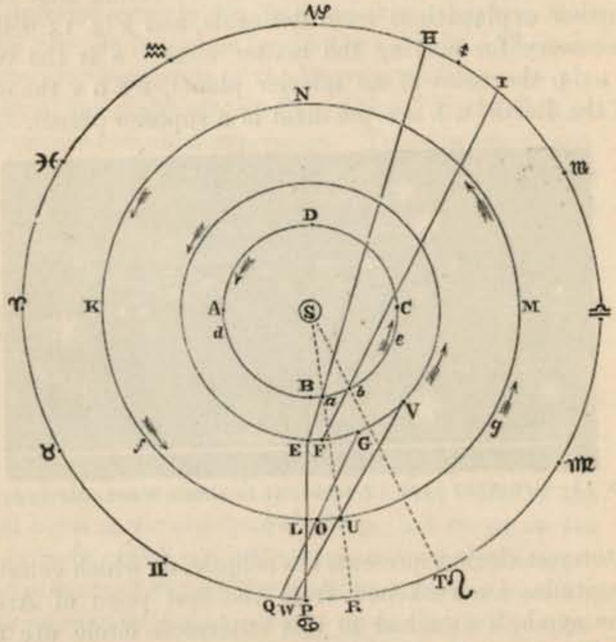

FIG. 13.—DIAGRAM EXPLAINING THE APPARENT MOVEMENTS OF THE PLANETS.

an observer on the Earth the planet will appear for a brief space of time to be motionless. The points in its orbit where this occurs are called its "stationary points."

We have now to consider the apparent retrograde motion of an inferior planet. With the Earth at E, let us suppose the planet to be advancing in its orbit from *a* to *b*, the Earth meanwhile moving to F. The arc *a b* will be longer than the arc E F, because the nearer a planet is to the Sun the greater its absolute velocity. An observer at E looking at the planet at *a* will refer it to the point H in the ecliptic, which in the engraving corresponds to about the seventh degree of the sign Sagittarius. When, however, the observer is carried forwards to F, the apparent place of the planet on the ecliptic will be I, a point less advanced on the ecliptic than H. Hence it follows that during the time the Earth has been going forwards through the space E F, the planet would seem to have gone backwards from H to I, or from Sagittarius into Scorpio. Yet its actual course from *a* to *b* has been forwards in the order of the signs, as would be quite evident to an observer at S, who would regard the motion of the planet from *a* to *b* as being from R to T on the ecliptic.

This diagram further shows the radical difference in the visible position of a planet according as it is treated, as viewed from the Earth or as viewed from the Sun. A planet's place as seen from the centre of the Earth is called its "geocentric" place; as seen from the centre of the Sun its "heliocentric" place.

The phases of the inferior planets must now be considered. So far as appearances go these are precisely the same as those of the Moon, which will be described in a subsequent chapter. Let us consider A, B, C, etc. (Fig. 14), to represent Mercury and Venus in successive parts of their orbits. Then starting from A, which is the place of superior conjunction, at B the planet shines with a nearly full circle of light. By the time it has reached D one half of its disc only is illuminated, and one half is dark. At F nothing remains but a thin crescent of light, which disappears altogether as the planet itself disappears at G, which is the position of inferior conjunction. When, however, a planet is going to perform a transit across the Sun, which sometimes happens at inferior conjunction, though the planet is totally without illumination from the Sun, so far as we are concerned, its existence is rendered manifest as a black ball projected on the bright disc of the Sun.

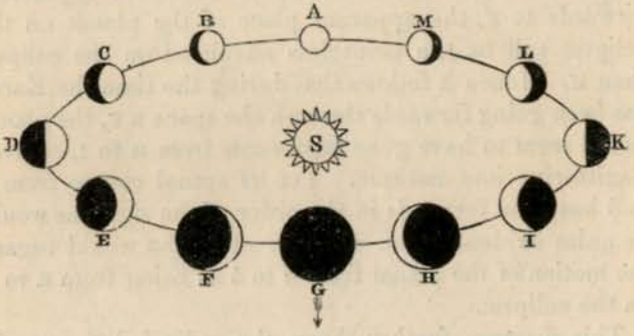

FIG. 14.—PHASES OF AN INFERIOR PLANET.

The diagram suggests (what is indeed the fact) that the apparent diameter of an inferior planet varies much, according to its distance from the Earth. When more than one-half of its disc is illuminated, the planet is in that half of its orbit which is remote from the Earth; its apparent size is then very much smaller than when it is in the half of its orbit nearest to the Earth. That Mercury and Venus exhibit a complete alternation of phases is an incidental proof that their orbits are contained within that of the Earth.

Mercury revolves round the Sun in 88 days, at a mean distance of 36 millions of miles, but the eccentricity of its orbit being considerable (in point of fact greater than that of any of the other major planets), it may approach to within 28½ millions of miles, or recede to more than 43¼ millions of miles. The apparent diameter varies between 4½″ in superior conjunction, and 13″ in inferior conjunction. Its real diameter is about 3000 miles.

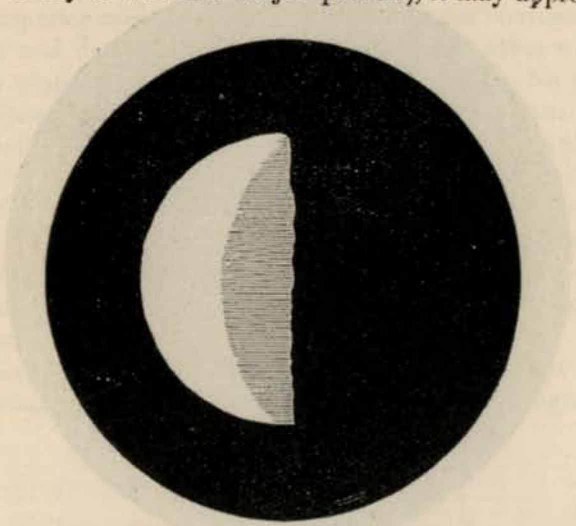

FIG. 15.—VENUS NEAR ITS GREATEST ELONGATION.

It has already been stated that Mercury exhibits phases like those of the Moon. Observations of its physical appearance are obtainable with difficulty, owing to the fact that it is always so near the Sun. No doubt it rotates on its axis, but the period of its rotation is not certainly known. It cannot, however, be rapid, because no flattening of the poles has been made out. A German observer, Schröter, at the end of the last century, thought he could sometimes see the southern horn of the planet truncated or blunted when the planet was near its inferior conjunction, and he suggested that the existence of a mountain might be the cause of this, but no modern observer has confirmed this idea. Indeed Mercury seems to have been almost entirely neglected by the possessors of modern telescopes. Mercury usually shines with a pale rosy hue. It seems not to have an atmosphere, and certainly no satellite.

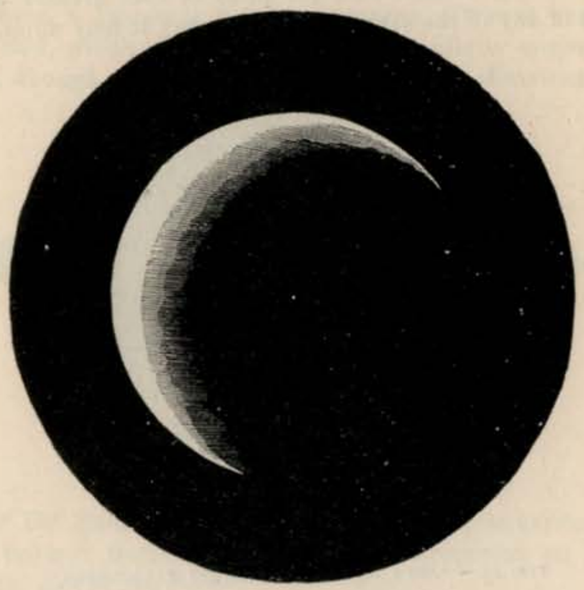

FIG. 16.—VENUS NEAR ITS INFERIOR CONJUNCTION.

Venus revolves round the Sun in 224 days, at a mean distance of about 67 millions of miles. The eccentricity of its orbit is small, and, therefore, the distance varies but little. The apparent diameter varies between 9½″ in superior conjunction, and 62½″ in inferior conjunction. The real diameter is about 7500 miles; in other words, this planet is nearly as large as the Earth. No polar compression is recognizable. The phases of Venus have already been dealt with. The brightness of this planet is often very remarkable, and renders the scrutiny of its surface very difficult. Under certain circumstances its brilliancy is sufficient for it to cast a sensible shadow by night. Spots are sometimes seen, and the existence of mountains has been inferred. It has an atmosphere seemingly of considerable density, but no satellites. The phases of Venus were discovered by Galileo, who communicated the fact to his friend Kepler in an anagram.

CHAPTER V.

THE EARTH, AND VARIOUS PHENOMENA CONNECTED THEREWITH.

THE Earth is in every respect a planet, standing, as such, on the same footing as Venus or Mars, or any other planet; but it is obvious that, as we ourselves are on the Earth, we cannot treat it astronomically in a descriptive sense, as we treat the other planets. But though the astronomer, in that capacity, has not much to say by way of discussing the Earth, yet there are two other men of science who are entitled to be heard on topics involving many semi-astronomical considerations. The geographer studies the Earth's surface and its division into land and water, and into different empires, kingdoms, and states; while the geologist deals with the Earth's crust, and with the stones and minerals of which it is composed

FIG. 17.—PROBABLE APPEARANCE OF THE EARTH FROM THE MOON.

At some period in its history the Earth was no doubt a sphere, but when, under circumstances which the Creator has not disclosed to us, the Earth had imparted to it a motion of rotation on its axis, it was soon transformed from a sphere into an oblate spheroid, the name given to a sphere when it has become flattened at the poles. The polar diameter of the Earth is 7899 miles. Its equatorial diameter is 7925 miles. The difference, 26 miles, represents the compression of the Earth. This difference or excess of the equatorial diameter, expressed as a fraction of its entire length, gives us as the amount of the compression the fraction $\frac{1}{299}$. This is the way we arrive at a measure of the polar flattening of all the planets, when we speak of their respective compressions as being so and so. If we take a globe one yard in diameter to represent the Earth, that diameter will be too long by $\frac{1}{8}$ inch for the true polar diameter of the Earth.

That the Earth generally is a sphere, or something like it, is brought to our notice in various ways. Standing on the seashore and watching a ship sailing away in the distance, it will be seen that first of all the hull disappears, then the lower parts of the rigging, and finally the topmasts. Ships have sailed in a particular direction, and keeping always more or less in the same direction, for instance, always east or always west, the ship has arrived round again at the port from which it started. The curvilinear shadow cast by the Earth on the Moon during a lunar eclipse, and the varying appearances of the constellations as we travel northwards or southwards over the Earth, are also subsidiary proofs of the spherical form of the Earth.

The science which more especially deals with the shape and dimensions of the Earth is called Geodesy, and the men who make the necessary observations are land-surveyors rather than astronomers, yet it is necessary that they should know a good deal about astronomy, and be able to practise it.

The way in which the dimensions of the Earth have been arrived at may be briefly explained thus:—A surveying officer, provided with some such instrument as a transit-theodolite, ascertains the latitude of his station, and so finds the elevation of the pole above his horizon. He then moves northwards or southwards in the line of the meridian to a new station, where he takes a fresh set of observations, so as to ascertain the latitude of the new station. He also finds out by appropriate methods the distance, measured say in miles and yards, on the surface of the Earth between the two stations. The difference

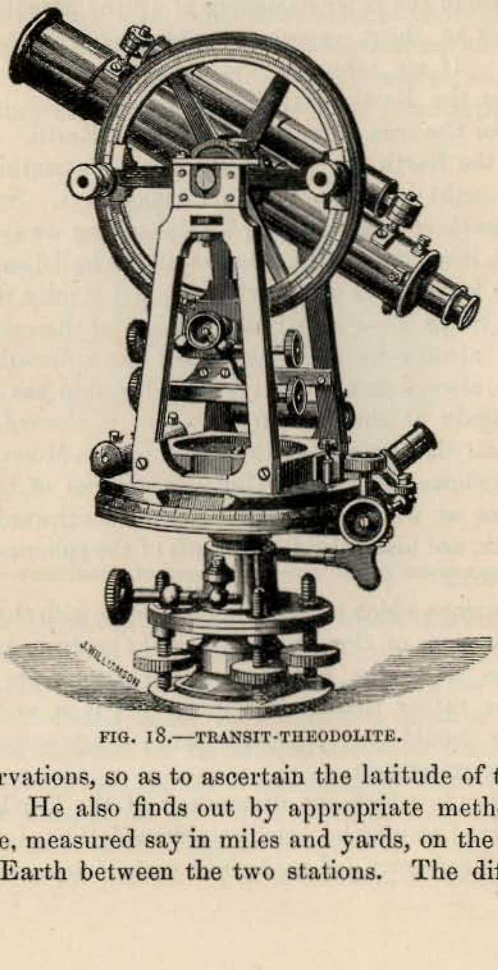

FIG. 18.—TRANSIT-THEODOLITE.

of the latitude in degrees, and the distance in miles, will enable him to ascertain how many miles go to a degree. This is found to be on an average about 69½ British statute miles. The process here described in outline is what is called in scientific language the measurement of an arc of the meridian. By carrying out measurements of this character in different latitudes, and connecting together first of all the different measurements and then the different results, astronomers have arrived at the value in miles of a degree in different latitudes, and so have discovered the exact figure of the Earth, including the amount of the flattening at the poles.

The story of the Ordnance Survey of England (and other civilized nations have carried out operations of the same character) is one of extreme interest, but cannot further be discussed here.[1]

The problem of ascertaining what is the diameter, circumference, and volume of the Earth is a very easy one when once we have obtained the details mentioned above. Knowing that the whole circumference of the circle is 360°, we have only to multiply 360 by 69½, and we get the circumference in miles. Knowing the circumference in miles, and that the circumference of every circle bears a certain ratio (3·1416 to 1) to its diameter, we obtain the diameter by a common division sum.

The marvellous precision which has been reached in these matters is shown by the fact that two great astronomical mathematicians, Airy and Bessel, separately

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[1] Some general particulars, though a little out of date, will be found in Herschel's *Outlines of Astronomy*, whilst a popular account of the business will be found in Col. White's *Ordnance Survey of the United Kingdom*.

working at this problem, arrived at independent estimates which only differed by 55 yards; whilst one of the Ordnance Survey base-lines in Ireland was found by measurement to differ only 7 inches from its calculated length, though that extended over several miles.

To an inhabitant of the Earth (as such), who is also a student of astronomy, certain astronomical facts will from time to time present themselves, which, though not offering much to attract the mere idle gazer, yet involve various matters of importance and interest to one who wishes to dive into the secrets of the universe.

I include in the foregoing statement such matters as the following, and I will briefly deal with some of them so far as is consistent with the limited scope of this volume:—

The Tides.
The Seasons.
Day and Night.
The Rotation of the Earth on its Axis.
The Measurement of Time.
The Precession of the Equinoxes.
Nutation.
The Aberration of Light.
Parallax.
Refraction.
Twilight.

THE TIDES.

The tides of the ocean are caused by the attraction exercised by the Sun and Moon on the water, but the Sun's share is small compared with the Moon's. Fig. 19 is intended to represent the circumstances of a lunar tide. E is the Earth, and M the Moon. The Moon's attraction heaps up the waters at *a*, and draws them away from *b* and *d*; it is "high water" at *a*, and "low water" at *b* and *d*. It is also high water on the side of the Earth opposite to *a*, namely at *c*. This is due to the fact that, although the Earth attracts the Moon because the Moon is the Earth's satellite, yet the Moon exerts a counter pull which affects not only the waters which, as it were, face the Moon, but also the solid body of the Earth, drawing that forwards in the direction of the arrows, and leaving behind the waters immediately near *c*. The principle involved in the tidal movements due to the Sun is very much the same as that just described in the case of the Moon. Fig. 20 will help to fix this in the mind. In this

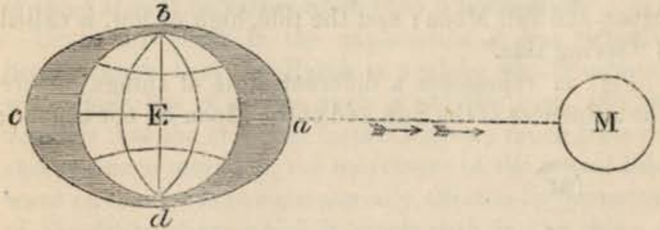

FIG. 19.—THE LUNAR TIDE.

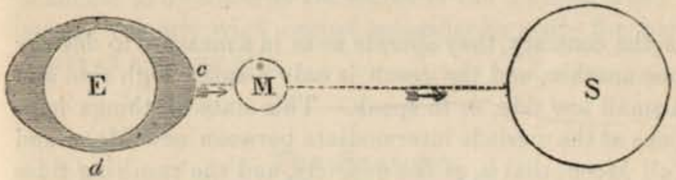

FIG. 20.—THE LUNI-SOLAR TIDE.

diagram S represents the Sun, M the Moon, *c* a point of high water, and *d* a point of low water. In this case the Sun and the Moon pull together, and the resulting high tide is the highest possible, and the corresponding low tide is the lowest possible. This is the state of things which subsists coincidently (or nearly so) with the new Moon and full Moon; and the tide, high or low, is called a "spring tide."

Fig. 21 represents a different state of things. Here the influences of the Sun and of the Moon do not concur; on the contrary, they operate so as in a measure to destroy one another, and the result is only a small high tide and a small low tide, so to speak. This state of things happens at the periods intermediate between new Moon and full Moon, that is, at the quarters, and the resulting tides are commonly and expressively spoken of as the "short" tides, or, sometimes, the neap tides. In the diagram *a* and *c* represent the places of high water, and *b* and *d* the places of low water. Comparing Fig. 21 with Fig. 20, it will be seen that the high water of Fig. 21 is less high, and the low water less low, than in the former case.

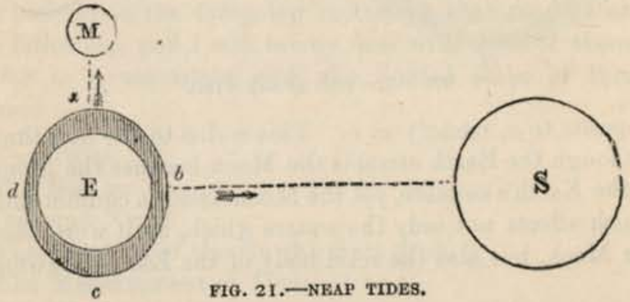

FIG. 21.—NEAP TIDES.

The interval between two successive passages of the Moon over the meridian of a given place, say Greenwich, constitutes a "lunar day." This interval averages 24 hours 50 minutes. From what has gone before it will be understood that during such interval there occur two high waters and two low waters, and that the sub-intervals of these should be rather more than 6 hours each.

Up to this point in the explanation it has virtually been assumed that the Earth is a globe wholly covered with water, but of course such is not the case, and the result is that the observed facts differ very much from the theory above unfolded, the movement of the actual tidal wave on the Earth being materially affected by the nature of the obstructions which it meets with in the shape of land, winds, and so on. Accordingly a statement of tide-facts true of Ireland, which faces the open Atlantic, would not apply to Italy, washed by the Mediterranean Sea, or to Sweden, washed by the Baltic Sea, in which 2 seas the tides are almost imperceptible. The influence of the wind on the tides is often rendered conspicuously manifest to dwellers on the banks of the Thames when a strong easterly wind occurs coincidently with the high water of a spring tide.

THE SEASONS.

The Earth's seasons depend upon the annual motion of the Earth round the Sun, coupled with the fact that the Earth's axis is not perpendicular to the plane of its orbit. If it was, there would be no seasons at all, and the only alternations which we should recognize would be those of day and night. The notion of the axial inclination just spoken of is otherwise conveyed by the phrase "the obliquity of the ecliptic"; which indicates the fact that the plane of the Earth's equator, and the plane in which the Earth travels round the Sun, are inclined to one another at an oblique angle.

In Fig. 22 A, B, C, D, represents four positions of the Earth in its annual orbit; in each case P is the north pole, and Q the south pole, the line P Q being the Earth's axis; E F is the Earth's equator, inclined about 23½° to the plane of its orbit, that is, to the ecliptic. With the Earth at A (summer[1]) the north pole, P, is constantly turned towards the Sun, that is, both by day and by night, as we in England should say; but at the north

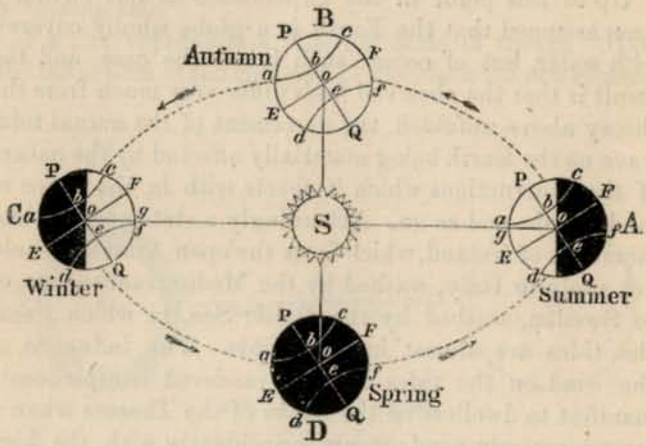

FIG. 22.—THE SEASONS.

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[1] In the northern hemisphere.

pole itself it is all day and no night. The south pole, Q, has at that time correspondingly no day at all; there it is always night.[1] This state of things subsists during our summer (speaking of the northern hemisphere), and attains its maximum effect at the summer solstice (June 21).

The Sun being then at its greatest northern declination, it is vertical (or visible exactly overhead) at all places whose latitude is 23½° north of the equator (*e.g.*, Upper Egypt, Arabia, Central India, Calcutta, Canton, Mexico, and Cuba). We have in England long days and short nights, which become respectively longer and shorter the more north we go, until, reaching the latitude 66½° north, we arrive at the Arctic Circle, all places within which have continuous day, and no night, for 6 months.

Now let us suppose exactly the reverse of all this, with the Earth at C; there the north pole is constantly turned away from the Sun, that is, both by day and by night, as we in England should say, but towards and at the north pole, P, it is all night[2] and no day. The south pole, Q, has at that time correspondingly no night at all; it is there always day. This state of things subsists during our winter (speaking of the northern hemisphere) and attains its maximum effect at the winter solstice (Dec. 21).

The Sun being then at its greatest southern declination, it is vertical (or visible exactly over head) at all places whose latitude is 23½° south of the equator (Zanzibar, Madagascar, Queensland, New Caledonia, and

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[1] This statement ignores the fact that under the circumstances mentioned there is for three months or more a twilight, by reason of the Sun's depressions being less than 18° below the horizon.

[2] The preceding footnote also applies here.

Rio Janeiro). We in England have short days and long nights, which become respectively shorter and longer the more north we travel, until, reaching the latitude 66½° north, and getting within the Arctic Circle, we arrive at places where there is no day at all; nothing but continuous night for 6 months.

In England our longest summer day at mid-summer has for its counterpart in length our longest winter night at mid-winter, or Christmas time, as we may call it. Whilst our shortest summer night has for its counterpart our shortest winter day.

Precisely the reverse of all this occurs in Australia and the southern hemisphere generally, where they have Christmas in June and mid-summer in December.

At the intermediate positions of Fig. 22, namely, B and D, corresponding to the days of the autumnal and vernal equinoxes (September 21 and March 21), the Sun is vertical under the equator, O, and day is equal to night everywhere throughout the world. In both hemispheres the day and the night are each 12 hours in length. But at B the Sun is crossing the equator, going from north to south, under which circumstances the days will (in the northern hemisphere) begin to shorten and the nights to lengthen as between September 21 and December 21. After the latter date, the Earth having passed through the winter solstice at C, the converse will occur, and the days will lengthen and the nights shorten until March 21, the day of the vernal or spring equinox. At this epoch day and night will again become equal, as in September, but as in this case the Sun is crossing the equator from south to north, the days will now continue to lengthen and the nights will continue to shorten till June 21, when the summer solstice arrives from which we started.

THE PRECESSION OF THE EQUINOXES.

In what has just been said it is assumed that the place of each equinox remains the same from year to year, but such is not the case. The equinoxes move backwards amongst the stars, that is, contrary to the order of the signs of the zodiac, at the rate of about 1° in 70 years, or 50" of arc annually. This change is called the "precession of the equinoxes," because the position of either equinox in any given year precedes (reckoning with reference to the order of the signs) the position which is occupied in the previous year.

Precession results from the revolution of the pole of the equator round the pole of the ecliptic, which again is due to the action of the Sun, Moon, and other planets. This revolution involves the pole of the equator travelling round the pole of the ecliptic in a circular path at a distance of 23½°, measured from pole to pole. The time occupied is no less than 25,000 years, in which period the equinox completes an entire circuit of the heavens. One immediate consequence of this movement is that the pole-star for the time being will vary as the polar point varies, and the pole-star of one epoch will not be the pole-star of another epoch.[1]

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[1] Some further allusions to this point will be found elsewhere. (See Chap. XI., *post.*)

NUTATION.

Very closely related to the phenomenon of the precession of the equinoxes is that of the "nutation" of the Earth's axis, which is more immediately due to the attraction of the Moon upon the spheroidal figure of the Earth. Inasmuch as the inclination of the Moon's orbit to the equator varies between 18½° and 28½° in a period of 18·6 years, this is also the period of the inequality in the motion of precession which constitutes nutation. This word literally means "nodding," and is used because that is just the effect produced on the pole of the equator in its endeavours to describe a circle round the pole of the ecliptic in the 25,000 years alluded to above in speaking of precession. The annexed engraving will help to make this clear. Each indent is supposed to represent 18·6 years of time, but the diagram is not drawn to scale, or the indents would be very much more numerous to correspond to 25,000 years.

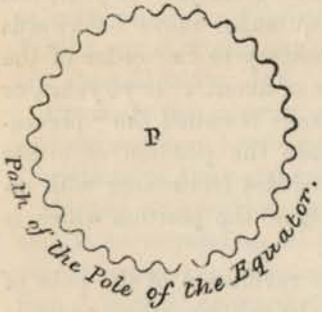

FIG. 23.—THE NUTATION OF THE EARTH'S AXIS.

THE ABERRATION OF LIGHT.

The "aberration of light" is another phenomenon, in virtue of which the apparent places of the stars as viewed from the Earth differ from their true places. It depends conjointly on light not being propagated instantaneously, and on the Earth being in motion. Thus it comes about that the rays of light emanating from a star appear to reach us from a different direction to what they would do were the Earth at rest.

This may be illustrated in a general way by means of Fig. 24. If a ball be dropped from P into the mouth of an inclined tube, C A, and an observer stationed at the bottom of the tube be carried along the horizontal line from A to B at a velocity proportional to that with which the ball descends towards the same line, the ball (if the two movements are properly adjusted) will then travel down the tube without striking the inside at any part. When the observer arrives at B he will see the ball as if it had come from Q, whereas it has come from P. If the ball be taken to represent a ray of light coming from a

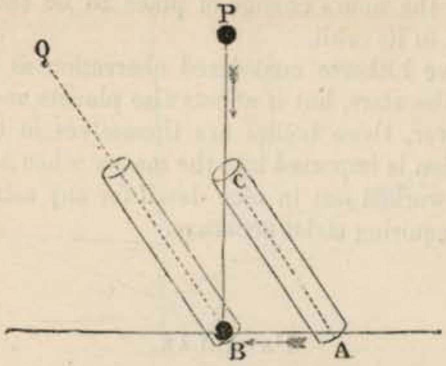

FIG. 24.—DIAGRAM ILLUSTRATING ABERRATION.

star, and A B a part of the Earth's orbit through which the Earth has passed in a given interval, the nature of the displacement of the star due to the aberration of light will be understood. Another illustration of this, often met with, is the striking of rain-drops against the face of a man walking quickly through a shower, notwithstanding that the drops are falling perpendicularly, and therefore ought to strike the top of his hat only, and not his face. In this case the rain-drops may be taken to be rays of light, and the man's change of place to be the Earth's movement in its orbit.

We have hitherto considered aberration as a matter affecting the stars, but it affects also planets and comets. As, however, those bodies are themselves in motion, a complication is imported into the matter when aberration has to be worked out in nice detail for any astronomical purpose requiring strict accuracy.

Parallax.

Parallax is another astronomical effect which depends upon the fact that we are placed on the Earth's surface, and not at its centre. It is necessary to take account of this, because in various astronomical calculations it is indispensable that the positions of the Sun, Moon, and planets must be referred to the Earth's centre.

The nature of parallax will be understood more clearly by referring to Fig. 25, where A represents an observer at some point on the surface of the Earth, and E the Earth's centre. A planet, S, will appear to a spectator at A to lie in the direction A C, while if it could be viewed

from the Earth's centre it would appear to lie in the direction E B; it is therefore seen from A, at a point in the heavens which lies *below* its position regarded in reference to E. The inclination of the lines A S and E S, that is, the angle A S E, which measures the displacement, is called the parallax of the planet. The effect of parallax is in all cases to depress the heavenly bodies below the positions which they would appear to have could they be observed from the Earth's centre; that is, it brings them nearer to the observer's horizon.

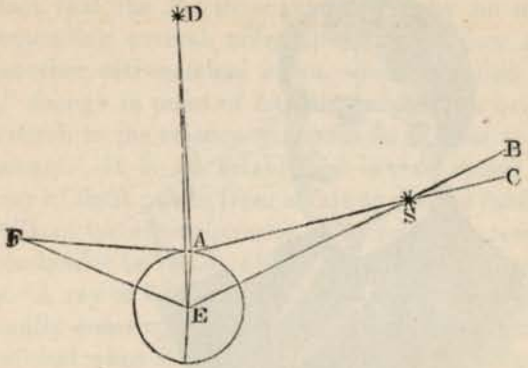

FIG. 25.—DIAGRAM ILLUSTRATING PARALLAX.

The nearer a body is to the Earth the greater its parallax, because the greater the angle, A S E, contained between the lines A S and E S; whilst the farther off the body is the less its parallax, because the less the angle contained between the lines A S and E S. For this reason the more distant planets are affected less by parallax than the nearer ones, whilst the fixed stars have either no parallax at all, or else a very small parallax, facts which indicate their extreme remoteness.

The nature and effect of parallax may be further illustrated by an experiment such as is suggested in Fig. 26. Let the reader place his finger as in the picture, and keeping both his head and finger motionless, let him close the left eye, and use the right eye by noting where the finger appears projected on the opposite wall of the room. If he will then close the right eye, and use the left, he will see that the finger appears projected on a considerably different part of the wall, though neither head nor finger has shifted. The apparent displacement of the finger is due to the different direction in which it is seen from the two different points of observation—that is, the two eyes: the amount of the angular displacement is the parallax of the finger.

FIG. 26.—EXPERIMENT TO ILLUSTRATE PARALLAX.

The term "parallax" has also some other applications in astronomy, with which, however, we need not concern ourselves here.

REFRACTION.

The fact that the Earth is surrounded by an atmosphere extending several miles above its surface gives rise to another astronomical effect, which is called "refraction," though in point of fact this expression belongs quite as much to the science of optics as it does to that of astronomy. It is an established law of optics that when a ray of light passes from a rare to a dense medium, it is bent from its original course more and more towards the perpendicular as the density of the medium traversed increases. A ray of light approaching the Earth's surface is continually entering denser strata of the Earth's atmosphere, so that when it reaches a spectator at the Earth's surface it will appear to be coming from a different direction than the true one. In Fig. 27 E represents the Earth, assumed to be surrounded by two different strata of atmosphere of different densities, though of course in fact no definite number of strata can be inferred, and they are not separated from one another by defined lines of demarcation. Remembering this, the reader will not be misled in considering the assumptions which follow. Let him imagine himself in a balloon at D, on the inner circle, one mile above the Earth's surface; the density of the atmosphere there is far greater than at C, a point on the outer circle, say two miles above the Earth's surface. Suppose A to be the true place in the heavens of a star; then a ray of light from it entering the higher regions of the Earth's atmosphere at C will be bent from its original course, and as it approaches the observer at O it will be more and more bent, until at O the star's place will appear to be not A but B, though its real place is A. Consequently the star is raised towards the zenith, Z, by the angular distance which is represented by A B, and which is the amount of the refraction. It is

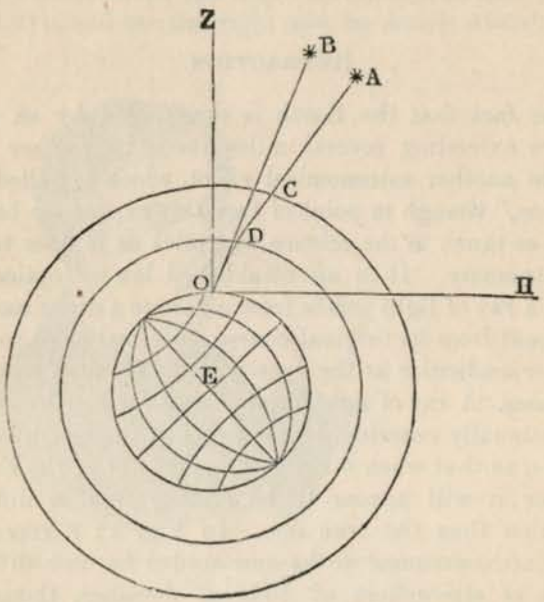

FIG. 27.—THE REFRACTION OF THE EARTH'S ATMOSPHERE.

therefore obvious that we do not in general see the heavenly bodies in the positions which they really occupy on the celestial vault, and that when it becomes necessary to compare strictly the place of one body with that of another, some allowance or correction must be applied to the apparent altitudes of each above the horizon as measured. This correction at the horizon amounts to fully half a degree, and thence diminishes, step by step (but not by regular gradations), to the zenith, where it is *nil.*

The correction needing to be applied for refraction at the horizon is actually greater than the angular diameter of both the Sun and Moon; consequently when we see either of these bodies apparently on the horizon it is really below it, and would be invisible but for its being displaced upwards by the influence of the Earth's atmosphere. Thus it comes about that refraction causes the Sun to rise sooner and set later than it would do had the Earth no atmosphere; and the result is that the length of the day, reckoning from apparent sunrise to apparent sunset, exceeds, owing to refraction, its theoretical length by several minutes.

It is also in consequence of refraction that the shapes of the Sun and Moon when near the horizon are distorted as they are, the refraction not being of the same amount at the upper part of the disc of each body as it is at the lower part. Each object thus appears nearly oval, with its vertical diameter less than the horizontal one. This distortion of shape in the case of the Sun and Moon when in the horizon is a phenomenon altogether independent of the apparently much enlarged size of both bodies under such circumstances. This latter is thought to be due to some imperfectly understood physiological cause or optical illusion, whilst the former is a measurable matter of fact.

TWILIGHT.

Twilight is another phenomenon which depends upon the atmosphere with which the Earth is surrounded. It is due jointly to the refraction and reflection of the rays of sunlight which reach the Earth's surface. Immediately after sunset, though the Sun has become invisible to an observer on the surface of the Earth, yet it continues to illuminate the upper strata of the air, especially the clouds floating there, when there are any. The atmospheric strata (or clouds) thus illuminated reflect to the surface beneath them part of the light which they receive, and thus produce after sunset and before sunrise that half-tone of light called "twilight," which is stronger or weaker according as the Sun is much or but little depressed below the horizon. Immediately after the Sun has disappeared, all the clouds in its vicinity are so highly illuminated that they reflect an amount of light scarcely inferior to the direct light of the Sun. According, however, as the Sun sinks lower and lower, less and less of its light reaches the upper strata of the atmosphere, and, consequently, less and less of it comes to the Earth's surface by reflection, until at length all reflection is at an end, and the darkness of night supervenes. What happens before and at sunrise is simply the precise converse of this, except that it has been suggested that twilight is less effective in the morning than in the evening, because there is more vapour in the lower portions of the atmosphere (to aid in distributing the Sun's rays) after sunset than before sunrise.

It is generally assumed that twilight lasts until the Sun has gone down 18° below the horizon, or that it begins when the Sun before sunrise has approached to within 18° of the horizon; but this limit must not be regarded as in all cases absolutely correct. The figures may vary between 16° and 21°, being dependent upon the latitude, the season of the year, and the meteorological condition of the atmosphere.

In certain latitudes, and for a certain number of weeks, it will happen, as a consequence of what has been stated above, that during the whole night, so called, it will be all twilight, and that there will be no true night whatever. This will be due to the fact that at no period of the night will the Sun be as much as 18° below the horizon. This is the state of things in the centre of England from about May 20 to July 20.

CHAPTER VI.

THE MOON.

THE Moon, as the Earth's satellite, is naturally to us an interesting and important object. It revolves round the Earth in 27 days 7 hours, at a mean distance of 237,000 miles. The eccentricity of its orbit causes this distance to vary between 221,000 miles and 253,000 miles. Its apparent diameter varies between $29\frac{1}{4}''$ and $33\frac{1}{2}''$; call it ½°, and think of it as the same as the Sun's diameter. The real diameter is close upon 2160 miles. No compression of the poles has been detected.

The motions of the Moon are of a very complex character, and have through all ages greatly exercised the skill of mathematicians and astronomers. It may be said, however, that owing to the researches of Airy, Hansen, and Delaunay, they have been now quite mastered.

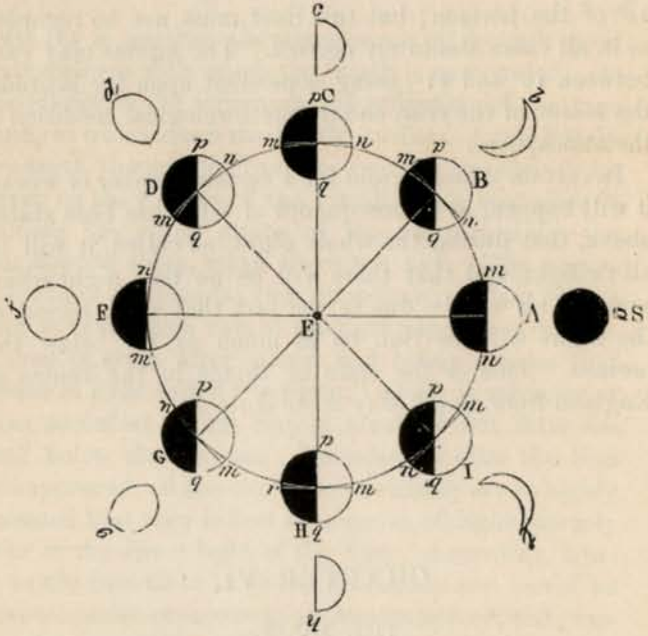

FIG. 28.—THE PHASES OF THE MOON.

The Moon's phases are so well known that it seems

scarcely worth while to devote space to them; nevertheless, something must be said on the subject. By the expression "phases of the Moon," we understand the various shapes which its illuminated portion exhibits in the course of its monthly journey round the Earth.

In Fig. 28 let A C F H represent the orbit of the Moon round E, the Earth, the Sun, whence the Moon derives its light, being in the direction indicated by S. It is easy to understand that only one-half of the Moon's surface can receive light from the Sun at any given moment. The line *m n*, which is perpendicular to one joining the centres of the Earth and Moon in each position of the latter at A B C, etc., defines the hemisphere which is visible to us who are on the Earth. If the Moon is at A between the Sun and us, the whole of its illuminated hemisphere is turned away from us; its limit corresponds with the boundary suggested by the line *m n*, and the Moon is invisible because it is more or less in front of the Sun, and lost in the Sun's rays (except on certain special occasions when it crosses in front of the Sun, and the phenomenon known as a total eclipse arises).[1] The Moon is now in conjunction with the Sun, and the phase is that known as "New Moon."

Now suppose the Moon to have advanced to B, corresponding to its position in the evening sky soon after sunset, and not far from our western horizon, the Moon's apparent motion in the heavens being from west to east. Here the line *p q* divides the illuminated half of the Moon from the unilluminated half, *m n* remaining as before the limit of her visible surface. In this position

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[1] See Chap. VIII., *post*.

so much of the illuminated hemisphere as lies between *q n* is visible from the Earth, with the result that the Moon as a whole exhibits such a crescent as *b* represents.

Continuing its progress round the Earth the Moon reaches C, where *p q* and *m n* meet one another at right angles. The Moon is now exactly half illuminated and half dark; the visible form is therefore that of a half Moon, such as *c*. The Moon has now accomplished one-fourth of her circuit, or 90° of angular measurement, and it is said in scientific parlance to be in "Quadrature," or, popularly, at its "first quarter."

The remainder of its journey round the Earth, during which it increases up to full Moon and then diminishes to a thin crescent again, will be as well understood by an examination of the diagram as by a verbal description.

Although it is true as a general statement that the Moon always exhibits the same hemisphere to us, yet attentive observation of marks on its surface, which are situated near the edge of its disc, will serve to prove that there exists a periodic oscillation on either side of the mean position. This oscillation is an optical effect which must be described and explained.

The Moon's motion of rotation on its axis is, of course, uniform, but its orbit being elliptical and not circular, its motion in its orbit is not uniform. Accordingly small tracts of surface near its eastern and western edges alternately come into view and disappear. This periodical change is known as the "Libration[1] in Longitude." The Moon's axis is not perpendicular to the plane of her orbit, but makes an angle with it of 83½°. The effect of this is,

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[1] *Librans*, swinging.

that the northern and southern poles lean alternately to and from the Earth by the amount of the difference between 83½° and 90°, that is to say, 6½°. To this extent, then, when the north pole of the Moon leans towards the Earth we look over beyond that pole, and similarly when it leans the contrary way we look over beyond the other, or south pole. This periodical phenomenon is called the "Libration in Latitude." By the diurnal motion of the Earth we are carried with it round its axis, and as the Moon continually presents the same hemisphere towards

FIG. 29.—TELESCOPIC APPEARANCE OF THE FULL MOON.

the Earth's centre, whilst we regard it not from the centre, but from the surface of the Earth, the hemisphere visible to us with the Moon near our eastern horizon is different from that visible when the Moon is near our western horizon. Hence another variation in the visible edges of the Moon, and which is called the "Diurnal Libration"; but the amount is small, only 1°. The general effect of these librations taken together is to enable us to see at one time or another four-sevenths of the actual surface of the moon, leaving three-sevenths which we never see.

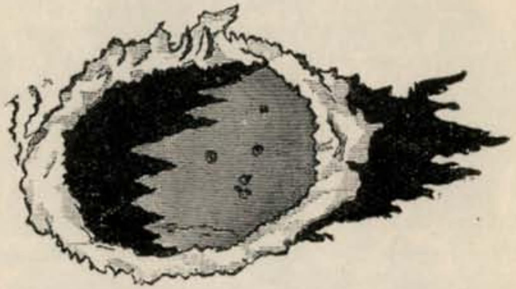

FIG. 30.—THE LUNAR MOUNTAIN PLATO OBLIQUELY ILLUMINATED BY THE SUN.

A naked eye view of the Moon enables us to see that it exhibits an irregular, that is, partly bright and partly shaded, appearance, but some optical assistance reveals the fact that the surface is covered with illuminated points intermixed with patches of shade, the position and shape of which vary with the different phases of the Moon. No one can doubt that the bright points are the summits of mountains, and that the shaded parts are either the direct shadows cast by these mountains, or are deep valleys into which the rays of the Sun do not penetrate. An attentive

consideration of these shadows will make it abundantly clear that they depend upon the ever-varying angles at which the rays of the Sun strike the Moon. At the epoch of Opposition, or full Moon, when the Sun is perpendicular, the shadows almost wholly disappear; but comparing the time when the Moon is approaching her full phase with the time when it is waning, it will be found that the shadows diminish in length day by day, then disappear, and then again increase in length, but on the reverse side. Moreover, when the Sun is exactly opposite the Moon,

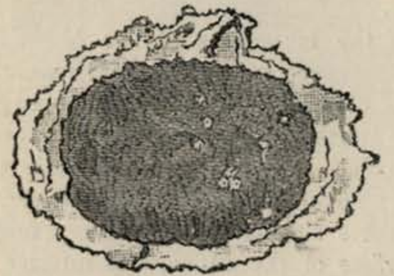

FIG. 31.—THE LUNAR MOUNTAIN PLATO AT FULL MOON.

the outline of the Moon is circular and its surface seemingly almost smooth, whilst at other periods of the lunation (as the Moon's monthly career is termed) its limb exhibits an irregular outline made up of elevations and depressions. It is easy to see the reason of these diversities. That the line which separates the illuminated from the unilluminated part should be broken and irregular is a clear proof that the surface itself is there broken and irregular; otherwise, if the moon's surface were smooth, the line of demarcation between the illuminated and unilluminated part (which line is called the "Terminator") would be a clean, well-defined curve.

The lunar mountains here alluded to have received the names of men eminent in science, and the heights of upwards of 1000 of them have been measured. The highest exceeds 20,000 feet.

Besides the mountains, there may be seen a number of grey plains in the nature of steppes or prairies. These are spoken of as "seas," an antiquated name which has never been discarded, though it is now well understood that there is no water on the Moon, and therefore no atmosphere.

Many of the mountains ot the Moon have a very striking appearance for this special reason. As a rule, they are not chains of mountains like those generally met with on the Earth, but are mostly circular areas, the outer edge of which is a rocky annulus, while the centre is occupied by an elevated peak. Moreover, the bottoms of some of these circular areas lie very much below the general surface of the Moon, the interior depth being often twice or three times that of the exterior height. From these and other circumstances we conclude that the lunar mountains are extinct volcanoes. The propriety of this theory will come very forcibly home to the reader if he will compare a mountain on the Moon, or a picture of one, with a good drawing or photograph of some such terrestrial volcano as Teneriffe or Vesuvius.

Sir John Herschel's remarks on this point are noteworthy. "Decisive marks of volcanic stratification, arising from successive deposits of ejected matter, and evident indications of lava currents streaming outwards in all directions, may be clearly traced with powerful telescopes. In Lord Rosse's magnificent reflector the flat bottom of the crater called Albategnius is seen to be strewed with blocks, not visible in inferior telescopes, while the exterior ridge of another (Aristillus) is all

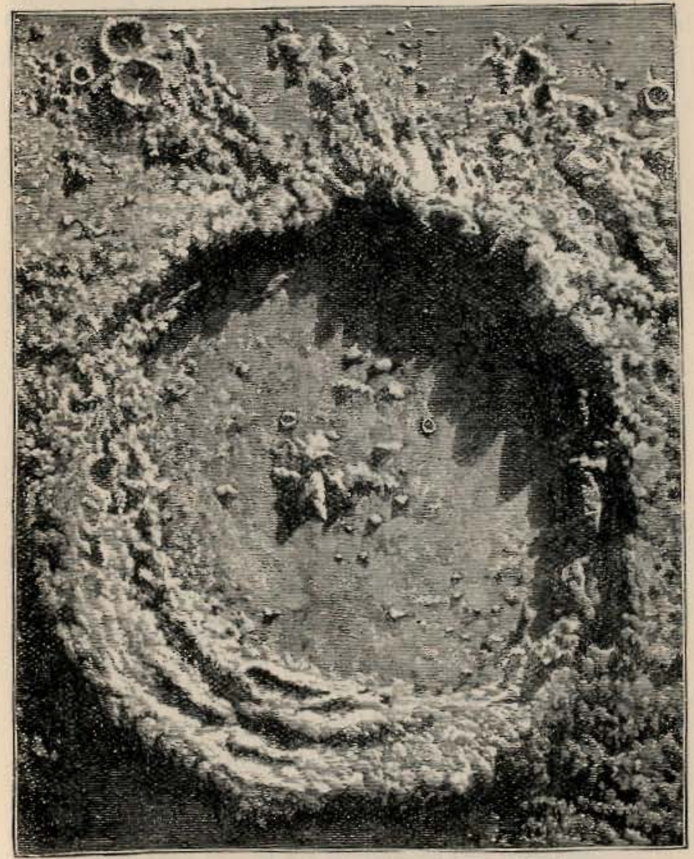

FIG. 32.—THE LUNAR MOUNTAIN COPERNICUS.

hatched over with deep gullies radiating towards its centre."

A phenomenon of much popular interest in connection with the Moon is what has long been called in England "the old Moon in the new Moon's arms." This is seen for two or three days before and after new Moon, and consists in the fact, that whilst only a narrow crescent is brightly illuminated by the direct sunlight, the whole of the remainder of the disc is rendered faintly visible by the light reflected on to it from the Earth. The light so reflected is indeed, literally, Earth-shine; but the term "ashy-light" is the expression made use of in French and other foreign languages. This light is stronger when seen just before new Moon in the early morning than it is just after new Moon in the evening. It has been suggested that this difference is due to the western part of the Moon's visible disc being better adapted for reflecting the Sun's light than the eastern part, but why this should be the case (if such is the true explanation) is unknown. It seems doubtful whether this explanation is a sound one.


FIG. 33.—SUNRISE ON PLATO, TYCHO, ETC.

The full Moon which falls nearest to the autumnal equinox is called the "Harvest Moon." The average eastward movement of the Moon being about 12° a day, its average time of rising will be about 50 minutes later each succeeding night. This interval, however, is unequal at different periods of the lunation; it may be as much as 1 hour 16 minutes, or as little as 17 minutes. When it is as little as 17 minutes, and the Moon is also near its full, the smallness of the retardation will naturally attract most attention, and this occurs with the Moon in Aries, and the Sun in Libra, corresponding to about the time of the autumnal equinox.

The brilliancy of the Moon has been very differently estimated by different physicists. Zöllner made it $\frac{1}{618000}$ of the Sun. This may be taken as something like equivalent to the statement that the whole sky covered with full Moons would scarcely make daylight. Investigations have been carried out to determine the question whether any warmth emanates from the Moon, and there appears to be evidence in favour of the supposition, but the difficulties attendant on, and the risk of error in such experiments, makes one distrust the results arrived at.

No question has been more often mooted or more hotly discussed than this: "Does the Moon affect the weather?" On the whole the general answer must be in the negative. It is true that the tides of the ocean are largely dependent on the Moon; it is also true that the fall of rain seems sometimes to be coincident with the time of high-water; it is also true that clouds and mist frequently disperse as a full Moon rises and comes to the meridian; but it seems impossible to carry beyond this point the contention that the Moon influences the weather.

CHAPTER VII.

THE SUPERIOR PLANETS.

HAVING already stated in a previous chapter that the planets are classed into inferior planets and superior planets, and having dealt with the former, it now remains to deal with the latter—those which circulate round the Sun in orbits exterior to the orbit of the Earth.

These planets are Mars, Jupiter, Saturn, Uranus and Neptune, together with a nondescript group of small bodies variously termed asteroids, planetoids, or ultra-zodiacal planets, but best described as the "Minor Planets," which lie between Mars and Jupiter, and now numbering about 300.

But before describing these planets in detail it will be necessary to explain their apparent movements, reverting for this purpose to one of the diagrams already given, but reproduced here on a larger scale (Fig. 34).

The superior planets differ from the inferior planets in one very important particular. Whilst the latter are never very far removed from the Sun's rays, that is to say, must always be studied more or less in twilight, the former at times travel so completely away from the Sun that they may be seen exactly opposite to the Sun, that is, on the meridian at midnight. In Fig. 34 a superior planet moving in the orbit K L M N is in Opposition to the Sun when at L, the Earth being at E. This is, of all positions, the most favourable one for the planet to be studied by an observer on the Earth. Not only are the Earth and the planet at their minimum distance (some-

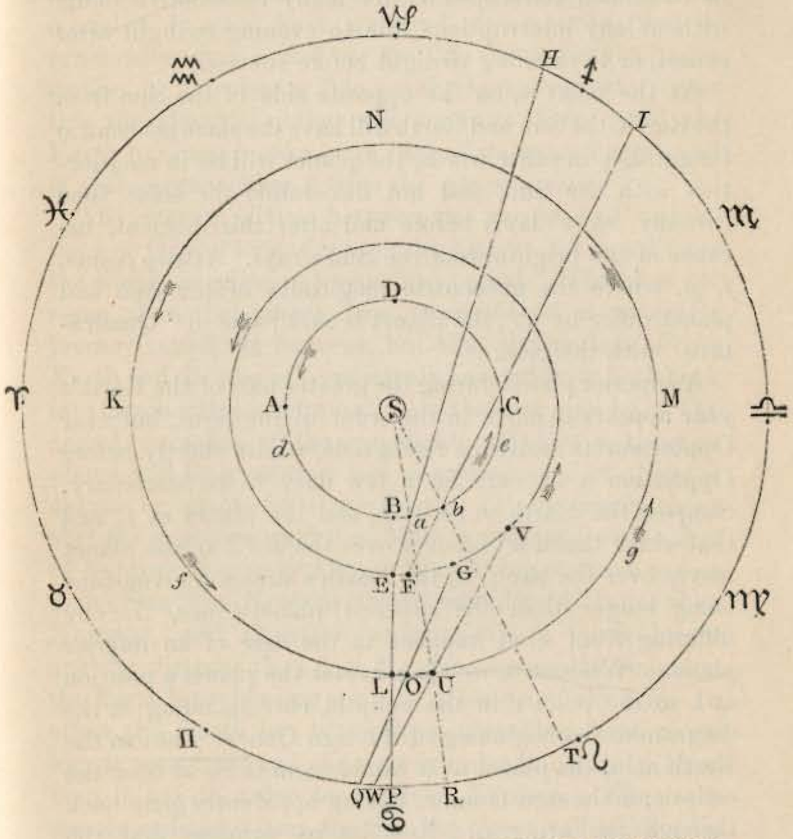

FIG. 34.—DIAGRAM FOR EXPLAINING THE MOVEMENTS OF THE PLANETS.

times expressed by saying that the planet is "in perigee"), but the planet being on the meridian at midnight, it can be examined telescopically for many consecutive hours without any interruptions due to evening twilight after sunset, or to morning twilight before sunrise.

At the point N, on the opposite side of the Sun from the Earth, the Sun and Earth will have the same geocentric longitude; in other words, the planet will be in conjunction with the Sun, and not discernible for some time (usually many days) before and after this moment, because of the brightness of the Sun's rays. At two points, *f*, *g*, where the geocentric longitudes of the Sun and planet differ by 90°, the planet is said to be in "Quadrature" with the Sun.

A superior planet during the greater part of the Earth's year appears to move in the order of the signs, but near Opposition its motion is retrograde, whilst shortly before Opposition it appears for a few days to be stationary. Suppose the Earth to be at E, and the planet at L, and that whilst the Earth moves over the arc E G the planet moves over the arc L O, the Earth's arc in a given time being longer than the superior planet's arc, thereby differing from what happens in the case of an inferior planet. When at E we should refer the planet's position at L to the point P in the ecliptic, corresponding in the diagram to the beginning of the sign Cancer; but to the Earth at G, the planet at O would seem to be at Q on the ecliptic, in the sign Gemini, having apparently gone back through the arc P Q. Now let us suppose that the Earth, continuing its advance, has got to V, while the planet has advanced from O to U, we should see it on the ecliptic at W, which is between Q and P; consequently since we were at G the planet's apparent course will have ceased to be backwards or retrograde. and will have become forwards or direct, so that at some point between Q and W it must have appeared momentarily (that is, practically, for a day or two) to have been without motion, or "stationary," to use the technical term. After this the planet's motion will continue direct until the Earth has completed a large part of its annual orbit, and is again approaching E from the opposite side.

The interval of time between two successive Conjunctions or Oppositions of a superior planet, as viewed from the Earth, is called its "synodical period." This does not mean that the planet has accomplished a complete journey round the heavens, but that the motions of the Earth and the planet respectively have brought both back into Conjunction or Opposition, as the case may be. The actual duration of the synodical period of a superior planet will be greater or less according as that planet is near to or remote from the Earth. Thus it comes about that the synodical period of Mars is 779 days, whilst that of Neptune is only 367 days. Mars, being so much nearer to the Sun than Neptune, moves considerably faster than Neptune, and therefore accomplishes a much larger angular distance than does Neptune during the time that the Earth is performing one revolution round the Sun. In effect the Earth has to continue travelling for a much longer period beyond one year in order to overtake Mars than it has in order to overtake Neptune. The more remote a planet is from the Sun the closer will its synodic period approach the length of the Earth's absolute or sidereal period (365 days, 5 hours, 48 minutes), though it must always somewhat exceed the latter.

Mars.

Mars is the planet nearest to the Earth but outside it, and, except in the matter of size, it seems to bear a closer analogy to the Earth than does any other planet. It revolves round the Sun in about 687 days, at a mean distance of 141 millions of miles, which the eccentricity of its orbit may increase to 154 millions, or diminish to 128 millions. The apparent diameter varies between 4″ in Conjunction and 30″ in Opposition, but the great eccentricity of Mars's orbit makes its apparent size as seen from the Earth to vary very much at different oppositions. The real diameter is nearly 5000 miles. The polar compression of Mars appears to be about $\frac{1}{50}$, but the measurements obtained by different astronomers are remarkably conflicting.

FIG. 35.—MARS NEAR ITS OPPOSITION.

Mars exhibits from time to time a slight change of

figure in the nature of a phase. When in Opposition its disc is round, but between Conjunction and Opposition the disc is gibbous, and most so at Quadrature; but even then the illuminated part of the disc is always considerably greater than a semi-circle or half Moon. It corresponds, in fact, to the Moon when about 11 days old. The restricted extent of Mars's phases is a proof that its orbit is without that of the Earth, but within that of Jupiter, whose maximum defalcation of light is considerably less than Mars's.

FIG. 36.—MARS IN QUADRATURE AND GIBBOUS.

Mars's synodic period is 780 days; it therefore only comes into Opposition to the Sun at intervals of rather more than 2 years, but owing to the eccentricity of its orbit every Opposition is not equally favourable. The most favourable occasions for seeing Mars are when it is in Opposition, and very near perihelion and perigee at the same time; this occurs only about every 15 years.

Fig. 37 will serve to indicate why there should often be substantial differences at different times in the apparent brilliancy of Mars as seen from the Earth. With the Earth at E_1 and Mars at M_1, Mars is in Opposition with the two bodies at their least distance from one another; but at E_3 and M_3 Mars is in Opposition at a time when it is at its greatest distance from the Earth.

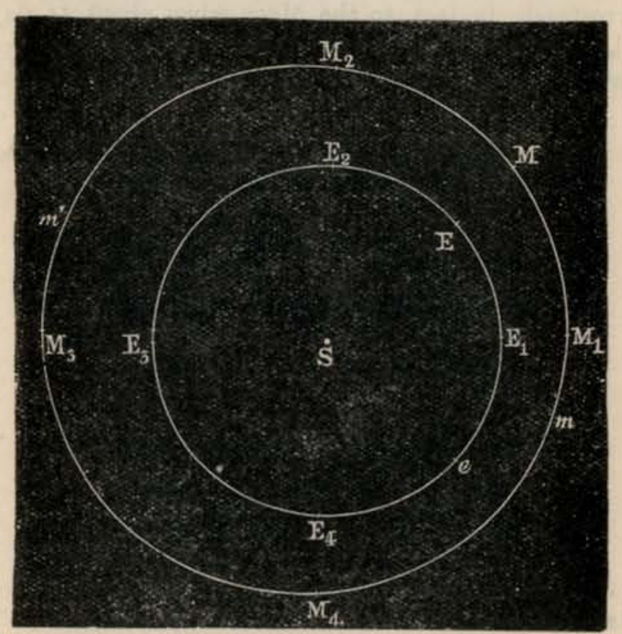

FIG. 37.—PLAN OF THE ORBITS OF THE EARTH AND MARS.

Mars always shines with a fiery red light, a fact which has given rise to the distinctive name which it bears in many languages. The telescope reveals numerous features of interest on it, especially diversities of surface, due, it is supposed, to the presence of land and water. Two tones of colour are almost always traceable, one reddish, and the other greenish. The reddish hue was set down by Sir John Herschel 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." Though the markings on Mars will seem to vary a little from time to time (after making due allowance for the effect of the planet's axial rotation), yet it is abundantly clear that they are practically permanent, drawings made by different observers and at widely separated epochs exhibiting the same general features. Schiaparelli of Milan claims to have discovered, in addition to the generally received main features, numerous minute streaks, which he has called "canals," but astronomers are not yet satisfied unreservedly to accept Schiaparelli's details, which seem to owe their origin to that observer's inability to reproduce accurately in a drawing those features which his eye has seen.

Near each of the poles of Mars white patches are occasionally visible. As these patches decrease and increase according as the rays of the Sun fall more directly or less directly on the planet, it seems reasonable to ascribe them to the existence of vast fields of polar ice and snow.

Spots are occasionally seen on Mars, and some of these have enabled astronomers to determine that the planet rotates on its axis in about 24½ hours. Mars has an atmosphere, but seemingly it is of no great density.

Two satellites, respectively named Deimos and Phobos, accompany Mars; they are extremely minute, and were only discovered as recently as 1877. Even now there are not many telescopes in existence which will show them.

THE MINOR PLANETS.

In 1766 a German named Titius, at Wittenberg, discovered a singular law respecting the relative distances of the older planets. A Berlin astronomer named Bode got hold of it, and published it in 1772 as his own.

Take the numbers—

0, 3, 6, 12, 24, 48, 96, 192, 384,

each of which (except the second) is double the preceding; adding 4 to each of these numbers we obtain—

4, 7, 10, 16, 28, 52, 100, 196, 388.

Certain of these new numbers approximately represent the distance of Mercury, Venus, the Earth, Mars, Jupiter, and Saturn, the radius of the Earth's orbit being taken at 10. Bode, studying these figures, and noticing that there was no planet corresponding to 28 and 196, predicted that new planets would sooner or later be found, and, true enough, the discovery of Uranus in 1781, at a distance of 191, and of Ceres in 1801, at a distance of 27, responded to Bode's expectations.[1]

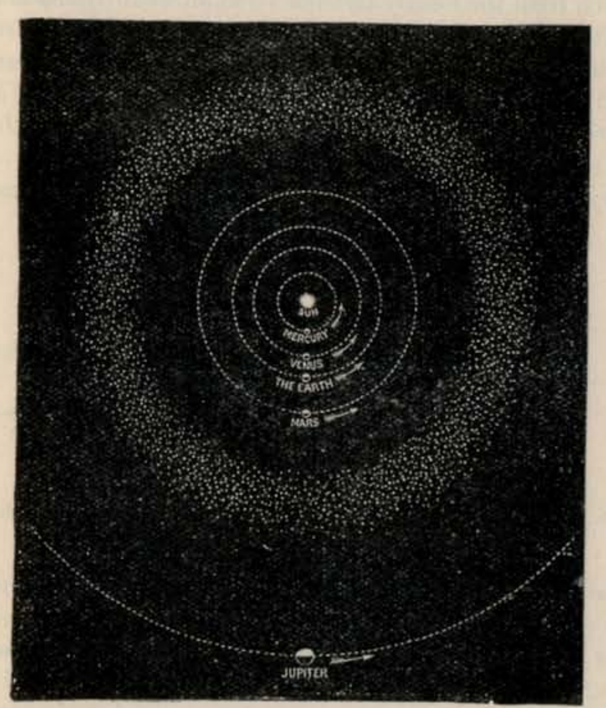

FIG. 38.—ZONE OF MINOR PLANETS BETWEEN MARS AND JUPITER.

These planets are planets in all essential respects, according to the usual technical definition of the term, but they differ from all the other planets in regard to their size, and the inclinations and eccentricities of their orbits. The largest of them is probably not more than 200 miles in diameter, whilst the smaller of them possess diameters of probably no more than two or three dozen miles. Whereas the orbits of all the major planets lie

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[1] It seems not improbable that the publication of Bode's Law may have inspired the astronomers of the period to have contemplated a search for new planets, but it does not seem possible to assert this as a fact.

within the limits of the ecliptic, several of the minor planets wander far beyond those limits. Moreover, some of the orbits are very eccentric; that is, depart very much from the nearly circular form affected by the major planets. The brightest of these little planets is *Vesta*, which is sometimes as bright as a 6th magnitude star, and just perceptible to the naked eye. *Pallas* and *Ceres* are, at their best, like 7th magnitude stars; *Juno* resembles an 8th magnitude, whilst all the rest are very much smaller. It would, indeed, seem that no more planets as bright as 12th magnitude stars remain to be discovered. It was for a while thought, when only a few of these objects had been found, that those few were fragments of some one large planet which had been broken in pieces by some great catastrophe of nature; but this theory, plausible once, is now no longer tenable. It need hardly be added, after what has just been said, that these planets are not of the slightest intrinsic interest to the telescopist, and the search for more of them is much to be deprecated.

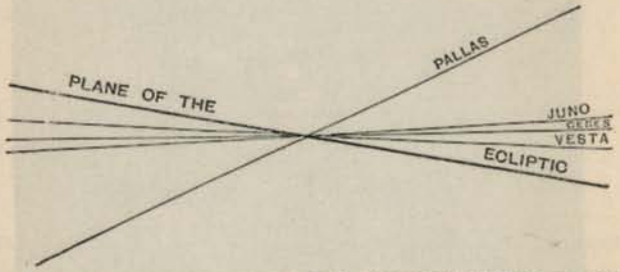

FIG. 39.—DIAGRAM ILLUSTRATING THE INCLINATIONS OF THE ORBITS OF THE FIRST 4 MINOR PLANETS.

JUPITER.

Jupiter is the largest of the planets, and, with the exception of Venus, is the brightest. Under certain circumstances it falls very little short indeed of Venus in point of brilliancy. It revolves round the Sun in 11¾ years, at a mean distance of 483 millions of miles. The eccentricity of its orbit causes this distance to vary between 506 and and 460 millions of miles. The apparent diameter of the planet varies between 50″ in Opposition and 30″ in Conjunction. The real diameter is about 88,000 miles.

FIG. 40.—JUPITER, MARCH 7, 1873.

The polar compression of Jupiter is very marked, and amounts to $\frac{1}{16}$. Jupiter is subject to a slight phase, but even when the defalcation of light is at its maximum, namely, when the planet is in either Quadrature, it is only just perceptible in the form of a slight shading off of the limb farthest from the Sun. The principal telescopic feature of Jupiter is its "belts." These are dusky or shaded streaks of varying breadth and number, and lying more or less parallel to the planet's equator. Sometimes two or three broad belts are seen, with or without some narrower ones; sometimes all the belts may properly be described as narrow. They seldom remain long absolutely unchanged, yet the changes are not always very rapid. Whilst no belt is visible as a rule immediately under the equator, well-marked belts are often to be found on either side of the equator. Perhaps it may be said that generally towards the poles the belts are much narrower, whilst at the poles the shading becomes more solid and less streaky, and otherwise more pronounced than it is anywhere else. Sometimes belts are seen lying across the planet in an oblique direction, but these are rare.

Dark spots are occasionally visible on the planet, and from some of these it has been inferred that Jupiter rotates on its axis in about 9 hours 55 minutes. More rare than dark spots are bright spots. But the most celebrated of Jupiter's spots is that known as the "Great Red Spot," which was especially visible as such between 1878 and 1882. In the autumn of the latter year it began to fade, and little more than, if as much as, its colourless outline can now be detected.

The physical nature both of the dark spots and of the bright spots on Jupiter cannot be with any real certainty explained. It is, however, generally thought that whilst the belts represent portions of the solid body of the planet rendered visible by rifts in an atmosphere, the spots, dark ones and bright ones alike, are masses of matter projecting above the general surface of the planet's atmosphere. Both kinds of spots exhibit more or less a circular outline.

It seems not unlikely that Jupiter must be regarded as occupying an exceptional position amongst the major planets. Besides shining, as do the other planets, by light reflected from the Sun, it has been thought that this planet possesses some inherent luminosity of its own. Moreover, it has been averred that an identity in point of time exists between the prevalence of spots on the Sun and of spots on Jupiter, and that both depend upon some extraneous cosmical influence. Some evidence appears to exist to support this theory, but it awaits future and more decisive proof.

Jupiter possesses five satellites, four of them discovered by Galileo in 1610, the fifth, which is the nearest of all, in America in 1892. This last-named is so minute that there are few telescopes powerful enough to show it. Galileo's satellites shine as stars of the 6th or 7th magnitudes, but, except under very rare circumstances, are not distinguishable by the naked eye. The four old satellites, which are designated by Roman numerals according to their distance from their primary, as I., II., III., IV., need, however, very little optical assistance, and their various configurations around, and in front of, and behind the planet, furnish an endless variety of interesting phenomena for small telescopes. In Fig. 41 these satellites are represented as two on each side of their primary, but sometimes all four are on one side. Sometimes only three, or only two, are visible ; more rarely only one, and on very rare occasions indeed none at all. This condition of things contemplates not so much a literal invisibility of the satellites as their absence from the field of the telescope ; for when no satellites are visible in the field it will be because some of them are passing across in front of the planet, while the others are, perhaps, occulted behind the planet, or are suffering eclipse in the planet's shadow. These several phenomena are all constantly taking place, and greatly intensify the interest

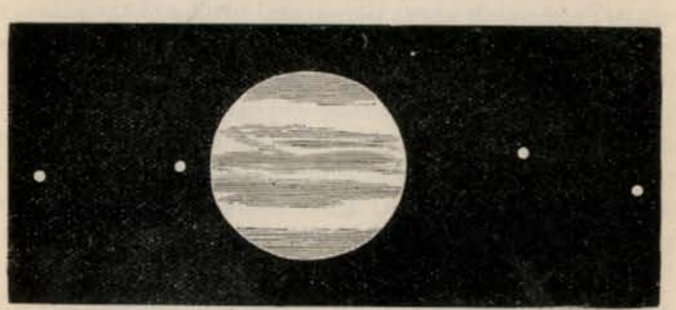

FIG. 41.—JUPITER AND ITS SATELLITES.

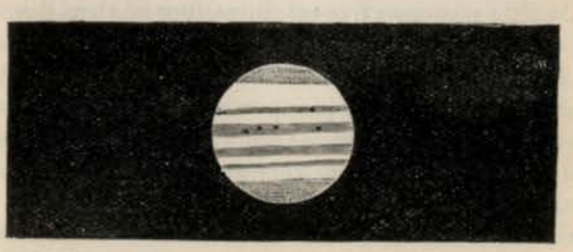

FIG. 42.—JUPITER APPARENTLY WITHOUT SATELLITES, AUG. 21, 1867.

which the possessor of a small telescope will derive from giving his attention to the planet Jupiter.

Under these circumstances, perhaps, these phenomena deserve a little more description in detail. Jupiter, being an opaque body, casts a shadow into space, and, therefore, obviously its satellites will frequently pass into this shadow in travelling round their primary. Fig. 43 will assist in making the movements of Jupiter's satellites more intelligible. Let S represent the Sun ; E F G a portion of the Earth's orbit ; J Jupiter casting a black shadow into space ; and *i r b* the orbit of one of its satellites. An observer on the Earth at E will see the satellite moving in the direction of the arrows, and enter the shadow at *i* ; it will be invisible, because eclipsed,

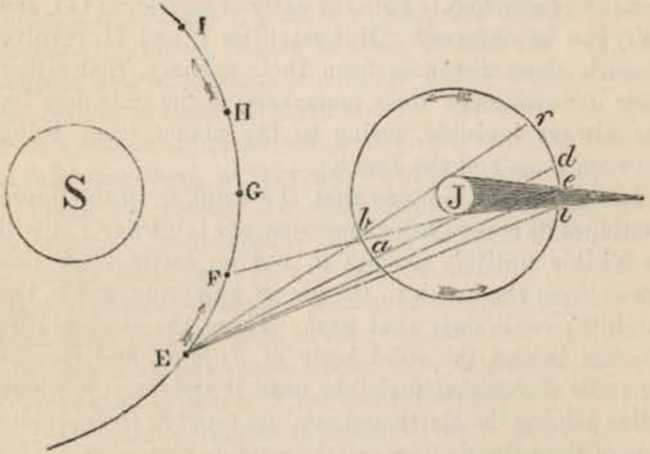

FIG. 43.—THE MOVEMENTS OF JUPITER'S SATELLITES.

during its passage from *i* to *e*, at which point, emerging from the shadow, it will again become visible to the observer at E. The point *i* is called the point of "immersion," and the point *e* that of "emersion," with respect to the shadow. When the Earth is at E, that is, before Jupiter comes into Opposition with the Sun, both the points named lie some distance away from the planet on its western side. Under such circumstances the immersions and emersions of both the exterior satellites (III. and IV.) can be observed. But satellites I. and II. revolve at such short distances from their primary, that either their immersions or their emersions, as the case may be, are always invisible, owing to the planet itself being between them and the Earth.

Let us further suppose that the satellite in the figure continues its course, after emersion, at *e* towards *r*; it will be visible until it reaches *d*, but no farther. A line drawn from the Earth to the planet, and prolonged to the satellite's orbit, cuts that at *d*. There the satellite disappears behind the solid body of Jupiter, and thenceforwards it remains invisible until it arrives at *r*, where a line joining the Earth and satellite touches the opposite side of the planet's disc, and the satellite reappears. This phenomenon taken as a whole constitutes what is called an "Occultation."

As the Earth advances from E towards Opposition at G, the point of emersion, *e*, after an eclipse, will fall nearer and nearer to the disc of Jupiter. When the Earth arrives at F, the edge of the shadow where it is crossed by the satellite's orbit will coincide with the limb of the planet, and for some time after this only immersions can be observed. At Opposition, the Earth being at G in the line of the shadow (which will be a prolongation of the straight line S G J), all eclipses will occur while the satellites are behind the planet, and, therefore, occultations only will be visible to an observer on the Earth.

The above explanation applies only from the time that Jupiter comes into view before sunrise after Conjunction with the Sun until it reaches Opposition, or while the Earth is moving from E towards G, to the west of the line joining S and J. But after this, as the Earth advances through H towards I, that is to say, as Jupiter, having passed Opposition, begins to close in with the Sun, the eclipses and occultation will occur under circumstances the reverse of those set forth above. Moreover, as seen from I, the occultations will *precede* the eclipses instead of following them, as they did when seen from E.

There yet remain for consideration two other phenomena of considerable interest in connection with Jupiter's satellites. It will not be difficult to understand that since these bodies sometimes pass exactly behind their primary, and suffer occultation or eclipse, so also they may be expected from time to time to pass in front of their primary. Thus doing, they perform what are called "transits" across the planet's disc. Moreover the satellites being solid bodies, they themselves cast shadows into space, which reach to a distance greater than the distance which separates such satellite from the actual surface of Jupiter. Hence, then, we have a transit of the *shadow* of a satellite as a fourth phenomenon.

When a satellite is thus crossing the disc, sometimes it appears brighter and sometimes darker than the planet's background behind it. This is often merely an effect of contrast, yet there are grounds for thinking that the satellites themselves sometimes exhibit shadings and changes of shadings which are real and are not optical illusions. The shadow of a satellite may be said to be always black, or blackish. On a few occasions, and under circumstances not hitherto explained, a secondary or duplicate shadow has been noticed.

FIG. 44.—THE THIRD SATELLITE OF JUPITER, AUG. 26, 1855.

FIG. 45.—THE THIRD SATELLITE OF JUPITER, AUG. 27, 1855.

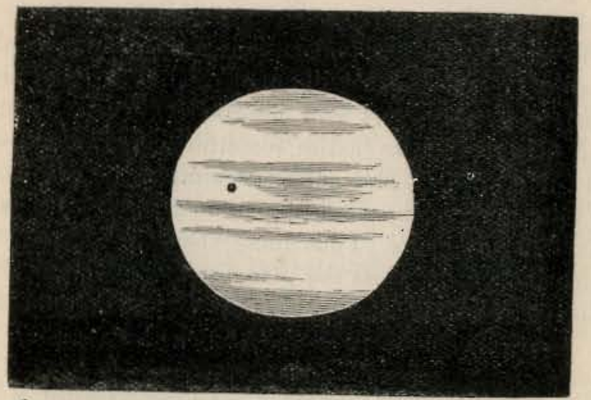

FIG. 46.—JUPITER WITH THE SHADOW OF A SATELLITE TRANSITING ITS DISC.

To the entrance of a satellite, and also of a shadow on to the disc, the term "ingress" is applied, the departure of both off the opposite side of the disc being called an "egress."

For observations of transit phenomena a telescope of greater power is required than for observations of eclipses and occultations.

Observations of eclipses of Jupiter's satellites can be used for the approximate determination of terrestrial longitudes. Such an eclipse may be said to occur at absolutely the same moment of time to every place on the Earth's surface which has Jupiter in sight. If then calculations in an almanack published beforehand should state when an eclipse will take place under the meridian of Greenwich, the time at which such an eclipse is observed to take place under a different meridian (expressed in local time) is a measure of the difference of the longitude of the two meridians. Unfortunately, however, the existing tables of Jupiter's satellites are not good enough to enable the eclipses to be predicted with that precise accuracy which is desirable. Likewise the light of a satellite does not disappear in the shadow and reappear out of it instantaneously. Hence the observed times of a disappearance and reappearance will vary with the power of the telescope employed. Thus it comes about that this method of determining terrestrial longitudes is less valuable in practice than in theory.

In the year 1675 a Danish astronomer named Römer, at that time resident in France, computed a table of the eclipses of Jupiter's satellites for a year in advance. He then proceeded to test his calculations by observations of the eclipses as they occurred. At the commencement of his observations the Earth was, we will say, at G (Fig. 43), that is, with the planet in Opposition, which was also of course perigee. As the Earth moved towards H and I, and so on round to the opposite side of the Sun, thereby bringing Jupiter into Conjunction, Römer found that the eclipses occurred later and later, until the discrepancy reached 16 minutes. After this, with the Earth proceeding round its orbit so as to arrive at the place where another Opposition occurred, the discrepancy gradually became less and less, until the observed times again agreed exactly with the computed times. Römer eventually came to the conclusion that the discrepancies which he observed were due simply to the fact that light from Jupiter's satellites did not travel instantaneously through space, but required a measurable time to traverse the additional distance (namely, the whole diameter of the Earth's orbit) which it had to pass over, according as the Earth was near Jupiter when the latter was in Opposition, or remote from Jupiter when the latter was in Conjunction. Römer's calculations resulted in an estimate of the velocity of light from which modern calculations differ by an amount which is very unimportant. The newest determination of this velocity is about 187,000 miles per second.

SATURN.

Saturn, though inferior to Jupiter in size, is by far the most beautiful of the planets. It revolves round the Sun in 29½ years, at a mean distance of 886 millions of miles, which the eccentricity of its orbit may increase to 931 millions, or diminish to 841 millions. Its apparent diameter varies between 15" in Conjunction, and 20" in Opposition. Its real (equatorial) diameter may be taken at 75,000 miles. Its polar compression is larger than that of any other planet, Jupiter not even excepted; but it is usually not so noticeable as Jupiter's, because

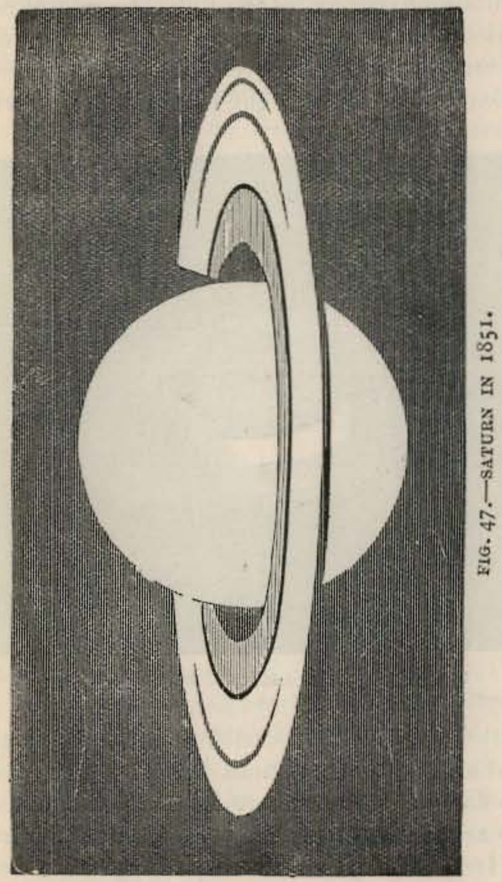

FIG. 47.—SATURN IN 1851.

the ring distracts the eye, and so spoils the judgment. The greater distance of Saturn compared with Jupiter results in its having no perceptible phase. A curious idea was once advanced by Sir W. Herschel, that the visible form of Saturn was neither that of a sphere nor of an oblate spheroid, but that it resembled a parallelogram with the corners rounded off, leaving both the equatorial and the polar regions flatter than they would be in the case of a true spheroid. Modern measures of Saturn, executed with extreme care, have shown that Sir W. Herschel's eye or telescope must have been at fault, strange though it may sound to say so.

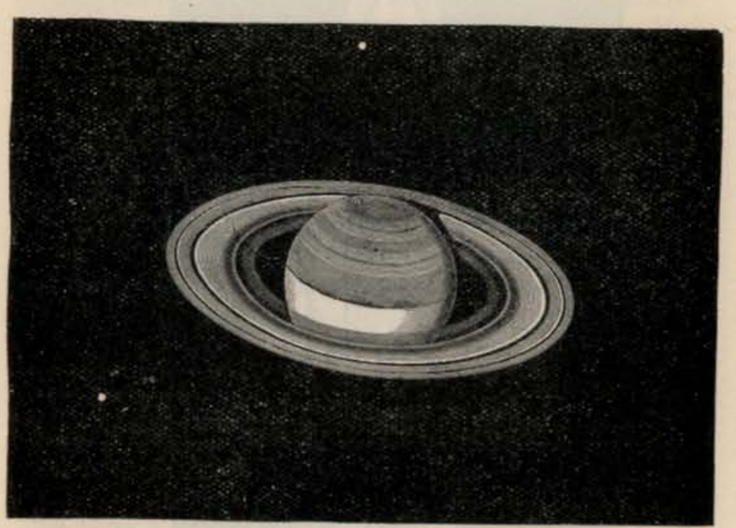

FIG. 48.—SATURN IN 1856 (DE LA RUE).

Saturn has belts, probably analogous in character to

those of Jupiter, but much fainter. They exhibit at times a sensible curvature, whilst those of Jupiter are fairly straight. Hence the conclusion that if Saturn's belts are parallel to its equator, which is no doubt the case, then that equator must be inclined at a rather considerable angle to the ecliptic. Sometimes, but very rarely, spots are seen on Saturn. By observations of these, and of changes in the belts, it has been inferred that Saturn rotates on its axis in about 10¼ hours. It is uncertain whether Saturn has any atmosphere.

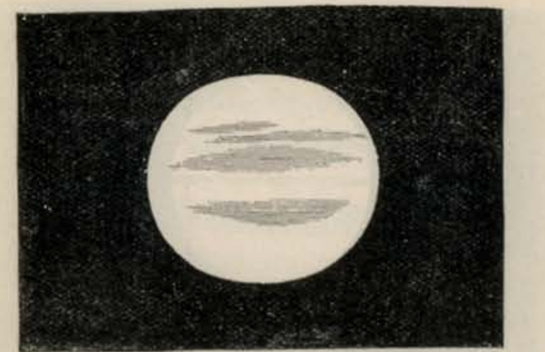

FIG. 49.—SATURN WITH ITS RING INVISIBLE.

The history of the progress of our knowledge of this planet, since the day when Galileo brought his first telescope to bear on it, is extremely interesting. The tale deserves to be told at length, but space for that is wanting here. Galileo's first examination disclosed the planet as having an oval outline, which he assumed to be due to the joint effect of one central disc, having a smaller one on either side. After a while the two supposed companions seemed steadily to diminish in size and then to disappear. Subsequently they reappeared, and came to be regarded as the handles (*ansæ*) of the principal globe, though why they should be visible at one time and not at another could not be divined. It was not till about 50 years after Galileo's first observations that another astronomer, a Dutchman named Huygens, discovered and announced that Saturn was surrounded by a slender flat ring, which nowhere touched the planet. Having got this idea fixed in his head, he predicted that in 1661 the rings would disappear, and the planet again present a circular outline. Next followed further discoveries as to the ring. In 1675 Cassini ascertained that Huygens's single ring was in reality made up of a pair of rings, and we now know that there are indeed several rings.

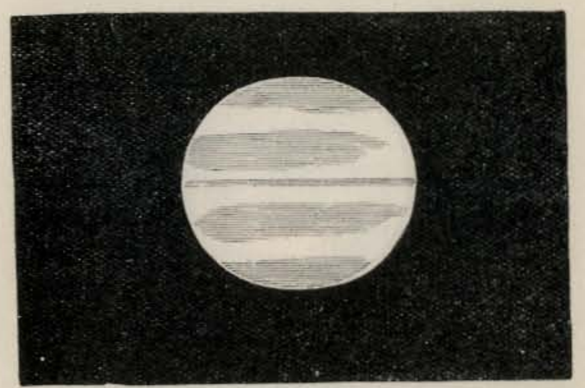

FIG. 50.—SATURN WITH ITS RING INVISIBLE, BUT THE SHADOW THEREOF VISIBLE.

At this point it seems worth while to remark that some evidence exists in two entirely different quarters which tends to show that the ancients possessed some clue to the existence of a ring round Saturn. The Assyrian deity, which corresponds to the Chronos of the Greeks, or the Saturn of the Romans, is represented in some of the Assyrian monuments encircled by a perfect ring. And again, Sani, supposed to be the Saturn of the Hindoos, has been found represented with a circle around him, formed by the intertwining of two serpents. As regards the possibility of the Assyrians having any knowledge of Saturn's ring, it is to be remembered that Sir A. H. Layard thought he had found proofs that that people knew of the properties of lenses, and therefore, perhaps, might have possessed crude telescopes.

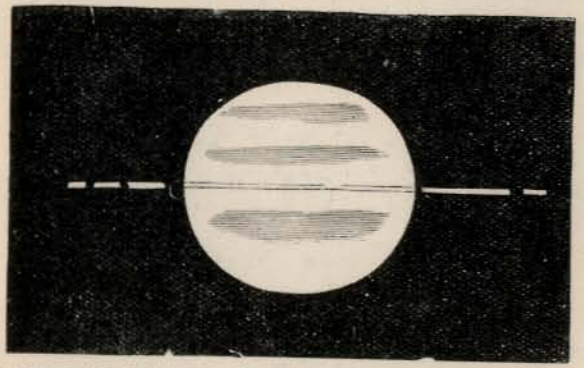

FIG. 51.—SATURN WITH THE EDGE OF THE RING VISIBLE AS A BROKEN LINE.

Besides the bright rings, which are the well-recognized characteristic of Saturn, there exists inside the innermost of these a shaded or dusky ring, which is semi-transparent, and is sometimes spoken of as the crape ring.

The phases of Saturn's rings will be best understood by some diagrams. Their actual form is, no doubt, circular, but we on the Earth always see them foreshortened more or less. Saturn, of course, revolves round the Sun in the ecliptic, and in an orbit inclined thereto at an angle of 2½°, but the plane of the rings is inclined 28°, and these divergences will affect the appearance of the rings as seen from the Earth at different periods during the 29½ years which constitute the sidereal period of Saturn.

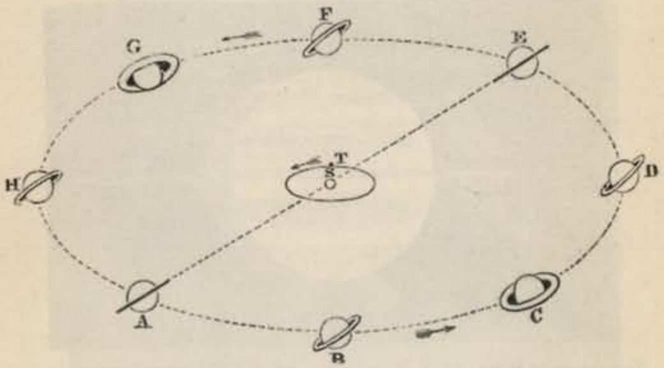

FIG. 52.—PHASES OF SATURN'S RING.

In the annexed diagram S represents the Sun, T the Earth and its orbit, and A B C various positions of Saturn in its orbit. When Saturn is at A, the 18th degree of Virgo, and the place of the ascending node, (so called because the Earth there ascends from beneath the plane of the rings to their northern side), the Sun is in the plane of the ring, and therefore only shines on its edge, which becomes nearly or quite invisible, according to circumstances.

As Saturn advances in its orbit round the Sun, more and more of the northern side of the ring comes into view; it widens out until the planet arrives at C, which point is distant 90°, or one-fourth of the circumference of the orbit from A. Here the ring is seen opened out to the widest extent that is possible, so far as the Earth is concerned. After passing C the planet descends upon the ecliptic towards E, the place of the descending node. As this is approached we see less and less of the northern surface, until the whole of it is lost at E, corresponding to the 18th degree of Pisces. The Sun is now again in the plain of the ring, which is first seen edgeways, and then not seen at all. As Saturn continues to move forwards the southern side of the ring comes into view; more and more of this side becomes visible until at G the ring becomes opened out to its widest extent as regards the Earth, because the Earth is then depressed 28° below the plane of the ring. From this point the ring begins to close in, until, reaching A, 29½ years after it was

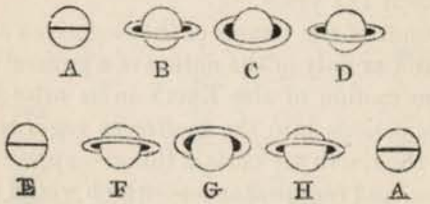

FIG. 53.—SUCCESSIVE APPEARANCES OF SATURN DURING 29½ YEARS.

previously there, the planet completes a whole revolution round the Sun.

The several successive appearances of the ring during those 29½ years, as seen in a telescope, are represented in the annexed series of skeleton diagrams [see Fig. 53], the letters of which correspond with the letters in Fig. 52.

It may here be added that the ring is most open, and therefore best seen, when the planet is in Gemini and Sagittarius, and invisible when the planet is in Virgo and Pisces. When passing from Virgo to Pisces the northern side is turned towards the Earth, and when passing from Pisces to Virgo the southern side. Each side remains in view for about 14¾ years.

The account of the phases of the ring given above must be considered as only in the nature of a general statement, because the motion of the Earth in its orbit introduces some complications into the matter as regards the ring; and we on the Earth see certain things—appearances, disappearances, and reappearances—which would not be seen by an observer on the Sun.

When speaking of the Saturnian system as a whole, it is not unusual to speak of the rings collectively as "the ring"; but in order to distinguish one ring from another, astronomers, accepting a suggestion of O. Struve's, designate the outer bright ring as A, the inner bright ring as B, the dusky ring being C. The interesting features which present themselves in connection with these rings are far too numerous to be dealt with at length in such a work as the present. Suffice it then to say, that the rings are not concentric with the ball; they are sensibly brighter than the planet; and B is brighter than A. Sir J. Herschel estimated the thickness of the rings

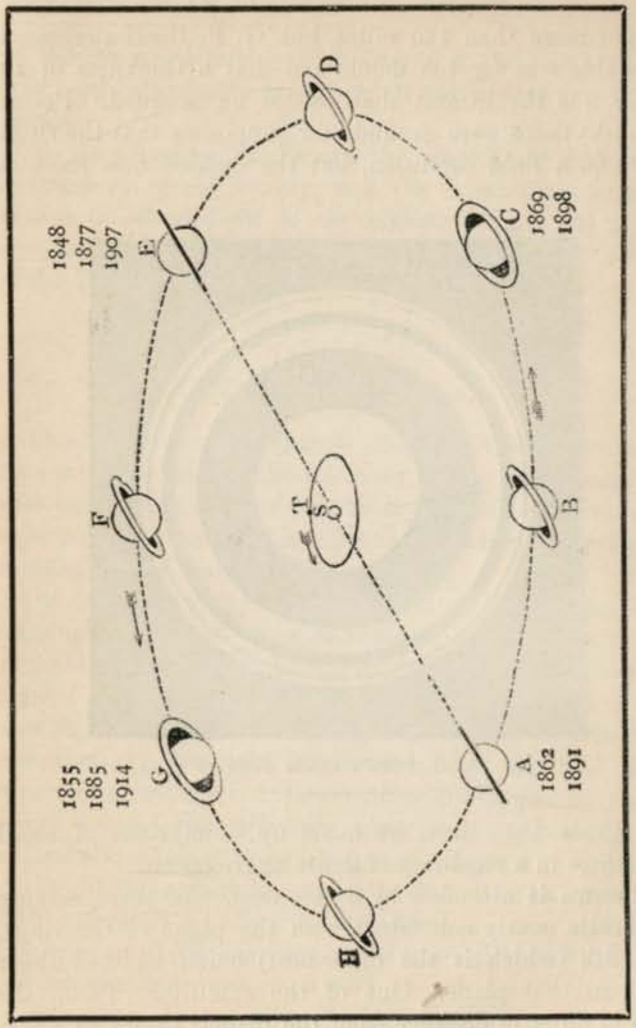

FIG. 54.—PHASES OF SATURN'S RING AT SPECIFIED DATES.

at not more than 250 miles, but G. P. Bond suggested that this was far too much, and that a thickness of 40 miles was the utmost that should be assigned. Peirce thought there were grounds for supposing that the rings were in a fluid condition, but the opinion now most in favour is that they are made up of myriads of small satellites in a condition of dense aggregation.

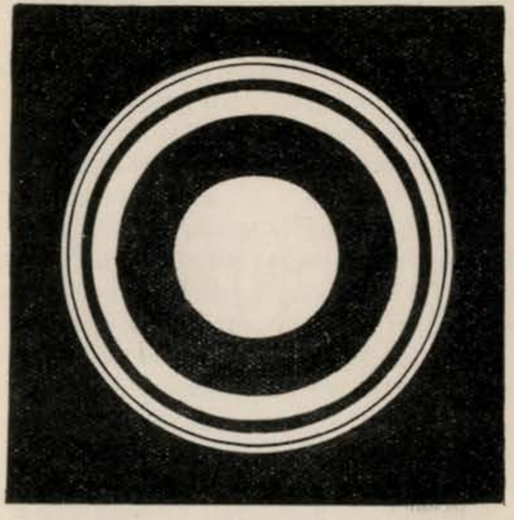

FIG. 55.—SATURN'S RINGS SEEN IN PLAN.

Saturn is attended by 8 satellites, 7 of them moving in orbits nearly coincident with the plane of the rings, the 8th (which is the outermost) being inclined about 12° to that plane. One of the satellites (Titan, the 6th in order of distance from the planet) shines as a star

of the 8th magnitude. The outermost (Iapetus) resembles a 9th magnitude star, but all the others are much smaller.

To an observer on Saturn the rings must furnish a spectacle of great beauty, and the 8 satellites help of course to afford light to the planet, though the space occupied by them is no more than about six times the area of the Moon.

URANUS AND NEPTUNE.

These two modern planets may be taken together, because the history of the discovery of one has a considerable bearing on that of the other; whilst as telescopic objects neither has any interest for the ordinary amateur working with a small telescope.

On March 13, 1781, Sir W. Herschel, whilst examining some small stars in Gemini, noticed something unusual about one of them, which he quickly assured himself was an object not of a stellar character; he soon found that it was moving, and having ascertained this fact, he publicly announced that he had discovered a new comet. Observations prolonged for some weeks showed that the new body was not moving in a parabolic orbit, or in an elongated ellipse, as did practically all the comets known up to that time, but that its orbit was nearly circular, and in truth that it was a planet. Inquiries as to old observations of stars showed that the new planet had been seen and recorded as a star on no less than 20 occasions before the date of Sir W. Herschel's first observation, but none of those who had previously seen it had been fortunate enough to detect its motion, and therefore its planetary character.

Uranus revolves round the Sun in 84 of our years, at a mean distance of nearly 1800 millions of miles. Its apparent diameter, as seen from the Earth, varies but little, being on an average about 3½″. The real diameter is about 31,000 miles. A compression of the poles has been noticed by some observers, but not by others. The discrepancies which exist as to this may perhaps be explained by the fact that, owing to the peculiar inclination of the planet's axis, we do not always see its equator exactly in profile.

The disc of Uranus is thought to have generally a bluish tinge, and belts have been more than suspected. Uranus is attended by 4 extremely minute satellites, revolving round their primary in a retrograde direction, in orbits lying nearly perpendicular to the planet's ecliptic.

Observations of the movements of Uranus during the 50 years subsequent to its discovery, revealed systematic discordances in those movements, which entirely baffled astronomers in their endeavours to determine exactly the planet's orbit. The conclusion was eventually arrived at that there existed some unknown planet exterior to Uranus, which attracted it, and disturbed the regularity of its orbit. In 1843 a Cambridge student of the name of Adams resolved to investigate the orbit of Uranus with the view of ascertaining whether he could do anything which might lead to the discovery of the suspected planet. He came to the conclusion that there really was such a planet, and in October, 1845, he transmitted to Sir G. B. Airy, then Astronomer Royal, a statement

respecting the probable elements of the suspected planet, and the quarter of the heavens in which it would be likely to be found. Unknown to Adams, a Frenchman named Le Verrier took up the same matter in very much the same way, and arrived at the same conclusion. Le Verrier's printed statement reached Airy in June, 1846, and, finding how closely its conclusions agreed with those of Adams, he took steps for causing a large telescope at Cambridge to be employed in searching for the unknown planet.

It was seen on August 4 and on August 12, but its planetary nature was not suspected until September 29. While matters were thus advancing at Cambridge, Le Verrier was pushing on with his researches, still in ignorance of Adams's labours. On September 23, 1846, a letter was received by Encke at Berlin, requesting that the telescope of the Berlin Observatory might be directed to a certain part of the heavens which Le Verrier indicated as the probable position of the planet. This was at once done, and the planet was seen that self-same evening, though its planetary nature was not established until the following evening.

It will not be wondered at that an international controversy of great bitterness sprung out of these events. A fair summing up of the facts will result in the honours of the discovery as a whole being equally divided between Adams and Le Verrier. It is, however, abundantly clear upon the facts, that absolute priority would have been secured for Adams if Airy had acted with promptitude, and had turned to proper account the information as to the probable elements of the suspected planet which Adams had placed at his disposal as far back as October,

1845. It must be confessed, however, that Airy seems not to have had confidence in Adams, or otherwise he would not have been so unfair as to have ignored his suggestions for so long a time. The planet being found, the next question of controversy was the name to be given to it. Many names were suggested, but after a while that of Neptune met with general acceptance.

Neptune revolves round the Sun in 164 years, at a mean distance of 2791 millions of miles. Its average apparent diameter is no more than 2¾". Its true diameter is about 37,000 miles, or rather more than that of Uranus. No polar compression is perceptible, nor are any spots or belts visible. There seems, however, some reason to suppose that Neptune revolves on its axis in about 8 hours.

Neptune has one very minute satellite, but a second has been suspected. The one revolves round its primary in a retrograde direction, just as the satellites of Uranus do.

The question has often been mooted, "Does there exist any planet revolving round the Sun outside the orbit of Neptune?" There are some slight grounds for answering this question in the affirmative, but whether astronomers will ever succeed in finding a Trans-Neptunian planet is another matter.

Sir Henry Holland, the celebrated physician, and a devoted student of astronomy, has left on record an incident in his life connected with the planet Neptune of singular interest. I give it here, and in his own words, because it is scarcely likely otherwise to fall under the notice of astronomical readers. After stating that his interest in astronomy had led him to take advantage of all opportunities of visiting foreign observatories, he says:—

"Some of these opportunities indeed, arising out of my visits to observatories both in Europe and America, have been remarkable enough to warrant a more particular mention of them. That which most strongly clings to my memory is an evening I passed with Encke and Galle in the Observatory at Berlin, some 10 or 12 days after the discovery of the planet Neptune on this very spot; and when every night's observations of its motions had still an especial value in denoting the elements of its orbit. I had casually heard of the discovery at Bremen, and lost no time in hurrying on to Berlin. The night in question was one of floating clouds, grauually growing into cumuli; and hour after hour passed away without sight of the planet which had just come to our knowledge by so wonderful a method of predictive research. Frustrated in this main point, it was some compensation to stay and converse with Encke in his own observatory, one signalized by so many discoveries, the stillness and darkness of the place broken only by the solemn ticking of the astronomical clock, which, as the unfailing interpreter of the celestial times and motions, has a sort of living existence to the astronomer. Among other things discussed while thus sitting together in a sort of tremulous impatience, was the name to be given to the new planet. Encke told me he had thought of 'Vulcan, but deemed it right to remit the choice to Le Verrier, then supposed the sole indicator of the planet and its place in the heavens; adding that he expected Le Verrier's answer by the first post. Not an hour had elapsed before a knock at the door of the observatory announced the letter expected. Encke read it aloud; and, coming to the passage where Le Verrier proposed the name of 'Neptune,' exclaimed, '*So lass den Namen Neptun sein.*' It was a midnight scene not easily to be forgotten. A royal baptism, with its long array of titles, would ill compare with this simple naming of the remote and solitary planet thus wonderfully discovered. There is no place, indeed, where the grandeur and wild ambitions of the world are so thoroughly rebuked and dwarfed into littleness, as in the astronomical observatory. As a practical illustration of this remark, I would add that my own knowledge of astronomers—those who have worked themselves with the telescope—has shown them to be generally men of tranquil temperament, and less disturbed than others by worldly affairs, or by the quarrels incident even to scientific research. I may mention as instances occurring to me at the moment, the two Herschels, Encke, Bessel, Piazzi, and Bond. Other examples might readily be supplied."[1]

CHAPTER VIII.

ECLIPSES, TRANSITS, AND OCCULTATIONS.

WE are now going to consider certain astronomical phenomena of considerable intrinsic interest to the general public, which, bearing various names, and depending in all cases on causes in some degree slightly different, yet bear to one another such a family likeness that it is convenient to link them together in one chapter.

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[1] *Recollections of Past Life*, 2nd ed., p. 298.

In order clearly to grasp the general principles involved in these phenomena, certain facts must be stated and accepted by the reader which cannot be conveniently dwelt upon in this particular place.

The Moon, in its monthly journey round the Earth, travels through the signs of the zodiac, pursuing an orbit which does not lie precisely in the same plane as the Earth's orbit, but is inclined thereto at an angle of about 5°. Hence it results that there are two points where the Moon's path cuts the ecliptic when it crosses from one side to the other. These are called the "Nodes," and an imaginary line joining these points is termed the "Line of Nodes." When the Moon is crossing the ecliptic from south to north it is crossing through the "Ascending Node," the point on the opposite side of its orbit where the Moon passes from the north to the south side of the ecliptic being the "Descending Node." When the Moon is in Conjunction, or "New," it is in that part of the heavens which will put it nearly or quite in a straight line between the centre of the Earth and the centre of the Sun. When it is only in a nearly straight line nothing, as a rule, happens (so far as our present purpose is concerned), but when by reason of the Moon being at or near one of its nodes some part, however small, of the Moon's body passes through the straight line joining the centre of the Earth and the centre of the Sun, that portion of the Moon's body, be it small or great, will to an observer at the centre of the Earth be projected on some part of the Sun's body. Thus will arise an *eclipse of the Sun*, so far as the principle of an eclipse is concerned. Inasmuch, however, as nobody lives in the centre of the Earth, but all observations of such phenomena have to be made from some or other point on the surface of the Earth, things are not practically quite so simple as suggested above.

The Moon when in a line with the Earth and the Sun so far as its *longitude* is concerned, may (its orbit being inclined) have a *latitude* several degrees north or south of the Sun's place, and the Sun may thus escape being covered by any part of the Moon. And this indeed is what happens most months in the year. Once in every month the Moon's longitude is 0° because once in every month the Moon passes through its position of Conjunction with the Sun; but it is only at intervals of several or many months (dependent upon conditions rather too complex to be explained here) that the Moon passes through Conjunction *and* either through a node with no latitude at all, or near a node with so small a latitude, as to impinge upon the Sun's disc.

Now we will consider the complementary phenomenon of an eclipse of the Moon. The Earth being an opaque body, it necessarily casts a shadow into space. When the Moon is in Opposition or "Full," it will be in that part of the heavens which will put it nearly or quite in a straight line between the centre of the Sun and the centre of the Earth, and so running through the axis, as it were, of the Earth's shadow outwards into space. When the Moon is only in nearly a straight line nothing, as a rule, happens (so far as our present purpose is concerned), but when by reason of the Moon being at or near one of its nodes some part, however small, of the Moon's body passes through the Earth's shadow, that portion of the Moon's body, be it great or small, will to an observer at the centre of the Earth be robbed of its sunlight by the concealment caused by the Earth's shadow. Thus will arise an *eclipse of the Moon*, so far as the principle of such an eclipse is concerned. But just as in the case of an eclipse of the Sun, we view it from the surface and not from the centre of the Earth, so the circumstances of the eclipse will in practice be somewhat different.

The fact that the Moon's orbit is inclined, as already stated, introduces into the question just the same element of uncertainty that it does in the case of eclipses of the Sun; otherwise there would be an eclipse of the Moon at every full Moon.

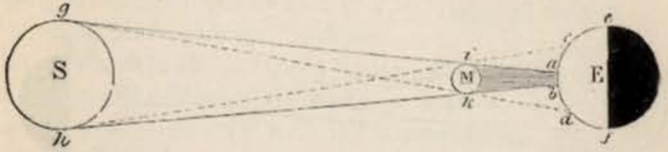


FIG. 56.—THEORY OF A TOTAL ECLIPSE OF THE SUN.

Eclipses of the Sun are of three kinds,—Total, Annular, or Partial. In Fig. 56 S represents the Sun, M the Moon in Conjunction, and E the Earth. In this particular diagram the Moon is exactly between the Earth and the Sun, and at its *least* distance from the Earth. When such a state of things subsists, the Moon's dark shadow falls upon the Earth's surface at *a b*, and within that area the Sun will be entirely hid by the Moon. The breadth of the zone *a b* on the Earth's surface will usually not be more than 150 miles. The point *a*, which is a prolongation of the line *g i* joining the northern limbs of the Sun and Moon, is the northern limit on the Earth of the total phase. The zone comprised between *a* and *c* will represent on the northern side of the Earth the zone within which the eclipse will be partial, *c* being the point struck by the prolongation of the line *h i*, which is the line joining the southern limb of the Sun and the northern limb of the Moon. Northwards of *c* in the direction of *e* the inhabitants will see no sort of eclipse at all, because no part of the Moon touches any part of the Sun; whilst the inhabitants of the opposite hemisphere of the Earth, looking away as they do from the Sun altogether, have night, and therefore see nothing of what is happening to the Sun. The converse of what has been stated above applies to the inhabitants of the Earth living towards the south pole, between *b d* and *d f* respectively, as the reader will be able to think out for himself by aid of the diagram.

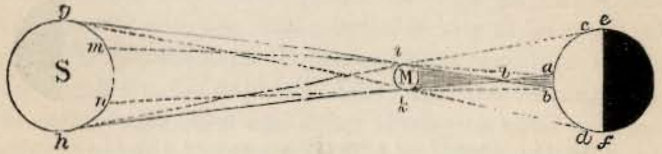


FIG. 57.—THEORY OF AN ANNULAR ECLIPSE OF THE SUN.

We must now consider the conditions of an annular eclipse of the Sun. In Fig. 57 S represents the Sun, M the Moon in Conjunction, and E the Earth. As before, the Moon is exactly between the Earth and the Sun, but at its *greatest* distance from the Earth. When such a state of things subsists, the Moon's dark shadow falls of course, as before, towards the Earth, but does not reach it. It reaches no farther than *l*, and under these circumstances no total obscuration of the Sun can occur. The edges of the shadow, prolonged to the Earth, will touch the Earth at *a* and *b*. An observer exactly midway between *a* and *b* will see a portion of the Sun's disc, such as *m g* and *n h*, unobscured; while the central portion of the Sun from *m* to *n* will be covered by the Moon. The visible part of the Sun will then exhibit a ring of light, and the phenomenon will be that of a "central and annular" eclipse. At *a*, which is the northern limit of the annular phase as seen from the Earth, the southern limb of the Moon, *k*, will appear in contact with the southern limb of the Sun at *h*, and the form of the eclipse will be that represented in Fig. 59. On the other hand, at *b*, the southern limit of the annular phase as seen on the Earth, the northern limb of the Moon, *i*, will be in contact with the northern limb of the Sun, *g*, and the form of the eclipse will be that represented in Fig. 60. On the surface of the Earth, from *a* to *c* in the northern hemisphere, and from *b* to *d* in the southern hemisphere, a partial eclipse will be visible, the magnitude of which will be less and less the nearer we approach *c* and *d* respectively. At *c* the

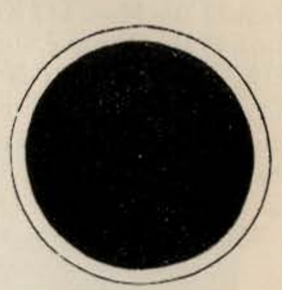


FIG. 58.—CENTRAL AND ANNULAR ECLIPSE.

FIG. 59.—ANNULAR ECLIPSE: NORTHERN LIMIT.

northern limb of the Moon at *i* will be in contact with the southern limb of the Sun at *h*; whilst at *d* the southern limb of the Moon at *k* will be in contact with the northern limb of the Sun at *g*, so that beyond *c* and *d* in the direction of the Earth's poles no sort of eclipse will be visible at all. Of course the inhabitants of the hemisphere of the Earth which looks away from the Sun, being in darkness, because it is their night, see nothing of what is going on in front of the Sun.

The zone on the Earth's surface which is covered by the Moon's shadow being so limited, as stated above, it follows that, however often total or annular eclipses occur considering the Earth as a whole, they are extremely rare at any one particular place on the Earth, total eclipses, indeed, peculiarly so. Thus no total eclipse will be visible in England until August 11, 1999, whilst the last occurred on April 22, 1715 (O.S). The difficulty of observing total eclipses satisfactorily when they do occur is aggravated by the fact that under the best of circumstances the total phase only lasts 7 minutes, and is commonly no more than 3 or 4 minutes. Annular eclipses may last slightly longer.

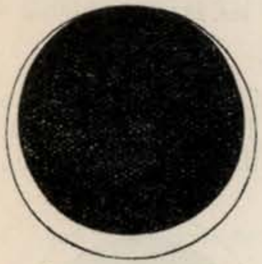
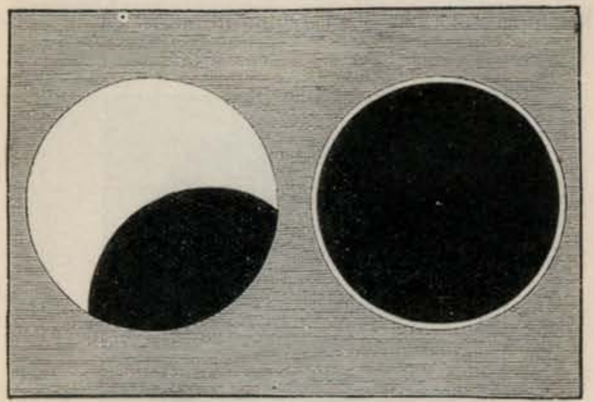


FIG. 60.—ANNULAR ECLIPSE: SOUTHERN LIMIT.

Eclipses of the Sun, when they are total, are phenomena of very great grandeur and interest. The sudden turning of day into night itself involves a spectacular effect which is impressive in no ordinary degree; and we can easily realize how that, in the early ages of mankind, a celestial effect of this character was naturally deemed to be an indication of Divine displeasure, or the presage of some impending calamity. It must, however, be stated that such sentiments did not characterize bygone times only, because eclipses as recent as those of 1878 and 1880 exercised remarkable influences of terror amongst certain uncivilized tribes in Asia and North America respectively.



A partial eclipse. *An annular eclipse.*

FIG 61.—ECLIPSES OF THE SUN.

The total obscuration of the Sun brings with it a darkness over the landscape which is strictly nocturnal in its character; so much so, that frequently it is impossible to read the dial of a watch or of a chronometer without the assistance of artificial light. Nevertheless, comparing one eclipse with another, the darkness varies very much, and depends in some degree on whether the observer is or is not deeply immersed in the Moon's shadow. Atmospheric conditions also seem to affect the matter.

When the disc of the Moon advancing over that of the Sun has reduced the Sun's disc to a very thin crescent, either immediately before the beginning of, or immediately after the end of complete obscuration, it is usually noticed that the thin crescent appears to be broken up into a series of brilliant points of light separated by dark spaces, which give the whole the appearance of a string of beads, which seem to move and to merge into one another. These phenomena are generally known as "Baily's Beads," after the name of the English observer who first described them in detail. The philosophy of their appearance and disappearance cannot be said to be altogether satisfactorily understood, but they are generally regarded as an exemplification of the optical phenomenon known as "Irradiation."

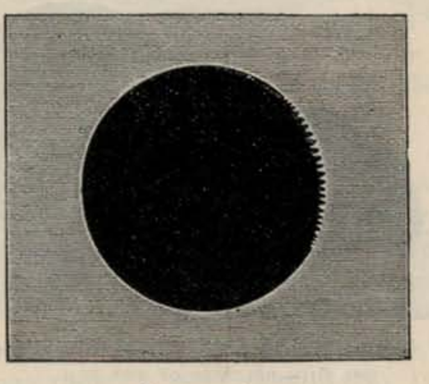


FIG. 62.—BAILY'S BEADS.

It is, however, when the stage of actual totality is reached that the most striking and characteristic features of a total Solar eclipse manifest themselves. Two of these must be singled out for special mention—the "Red Flames," or "Prominences," and the "Corona." Fig. 63 will, in a general way, afford an idea of what these two features are. At various points, few or many in number, as the case may be, around the black limb of the Moon there will be noticed irregular and ever-changing patches of matter, more or less pink or crimson in colour. These were formerly spoken of as the "Red Flames," a name perfectly appropriate, albeit the less satisfactory term

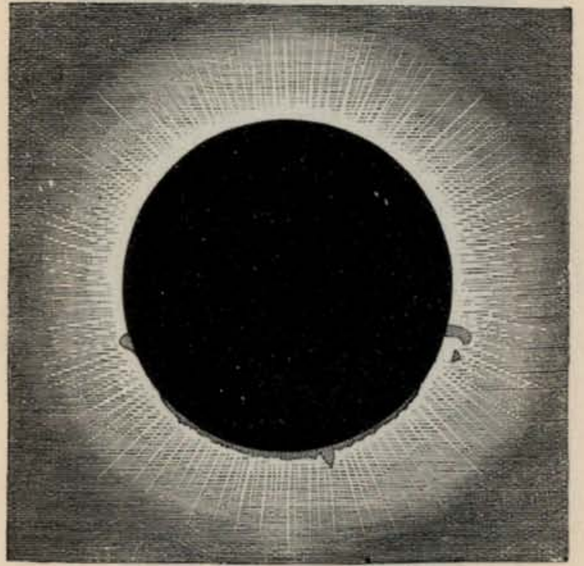


FIG. 63.—THE SUN TOTALLY ECLIPSED, JULY 18, 1851.

"Prominence" is now generally applied to them. Astronomers were long unable to determine the nature of these rose-coloured emanations, but it is now accepted that they belong to the Sun; and the spectroscope has disclosed the fact that they consist of gaseous matter (chiefly hydrogen) in an incandescent state, rushing violently upwards, that is, away from the Sun's body outwards into space.

FIG. 64.—EXPLOSION OF A SOLAR PROMINENCE. SEPT. 7, 1871, AT 12.55 P.M. (YOUNG).

Figs. 64—7 represent various views of prominences, and will serve to convey an idea of the rapid and remarkable

changes of shape which they frequently—one might almost say habitually—undergo.

On September 7, 1871, the well-known American observer, Professor Young, was watching the large prominence shown in Fig. 64. At 12.30 p.m. it was about 100,000 miles long, and 54,000 miles high. He was called away for nearly half an hour, and when he returned he found, to use his own graphic words, that "the whole thing had been literally blown to shreds by

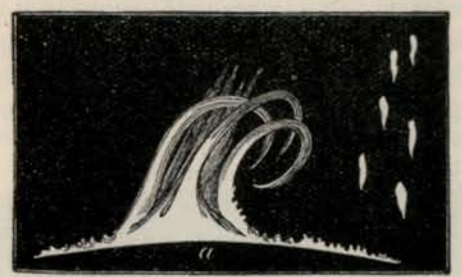


FIG. 65.—THE SAME AT 1.40 P.M.

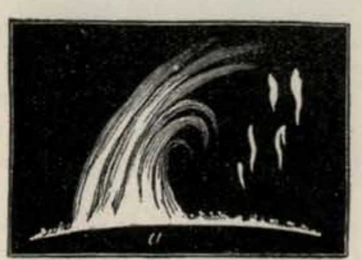


FIG. 66.—THE SAME AT 1.55 P.M.

some inconceivable uprush from below." The transformation thus accomplished is portrayed in Fig. 65. He traced the fragments, which he had termed shreds, moving upwards, until they reached a height of at least 200,000 miles, at which immense elevation most of them disappeared. During the next succeeding hour the force of the uprush seems to have spent itself, for it is evident that it gradually subsided, and no doubt eventually ceased altogether.

It may be taken that prominences are to be found from time to time more or less all the way round the Sun's disc, nevertheless there is an evident difference in the character of the prominences found over the zones frequented by spots and those found in other parts of the Sun's circumference. Whilst these latter are usually cloud-like masses of a somewhat stable or stagnant character, the prominences which may be assumed to have some relationship with the spots are often of a violently eruptive character.

It has also been suggested that a direct relationship subsists between the prominences and the periodicity of the spots, so far that when spots are numerous large prominences are also numerous, and conversely, when spots are scarce, or altogether wanting, large prominences are likewise scarce, and conspicuous eruptive prominences are altogether wanting. It would seem, regarding the foregoing suppositions to be absolute facts, that changes of some kind are periodically taking place in the condition of the Sun as a whole, which, whilst resulting in the periodic changes so well recognized in the number and size of the spots, also cause, or at any rate are coincident with, systematic changes in the red flames, which involve their rising up higher above the Sun's surface, or clinging closer to that surface, respectively, as time goes by.

Still more striking and more interesting than the Red Flames is the Corona. Its general effect may be realized by an inspection of Fig. 63, but it does not exhibit the symmetrical form there portrayed; that is to say, though it is in general concentric with the Sun, yet its exterior limits are by no means regular. On the contrary, there are frequently visible rifts running through the corona on both sides, dividing it more or less into two halves. Moreover, streamers or rays of light of no defined shape, length, or breadth, are also frequently to be seen. Speaking broadly, it may be said that the corona is something in the nature of an atmosphere round the Sun, shining, however, not by its own intrinsic, but by reflected light. A theory has been started, that inasmuch as the form of the corona varies from time to time, and that different

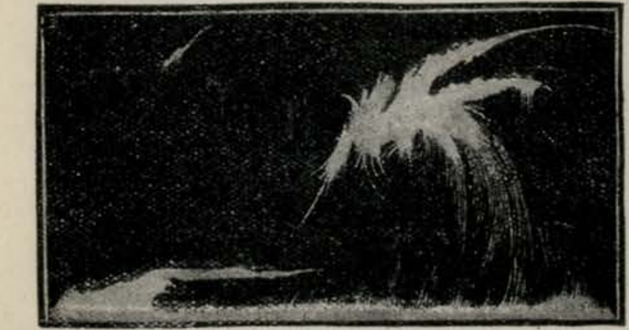


FIG. 67.—A SOLAR PROMINENCE. (TACCHINI).

eclipses yield coronas capable of being grouped under certain typical forms, that the prevalence, or the contrary, of Sun-spots has some effect upon the form exhibited by the corona at any given eclipse. More information, however, is needed before we shall be in a position to make any confident assertions on this point.

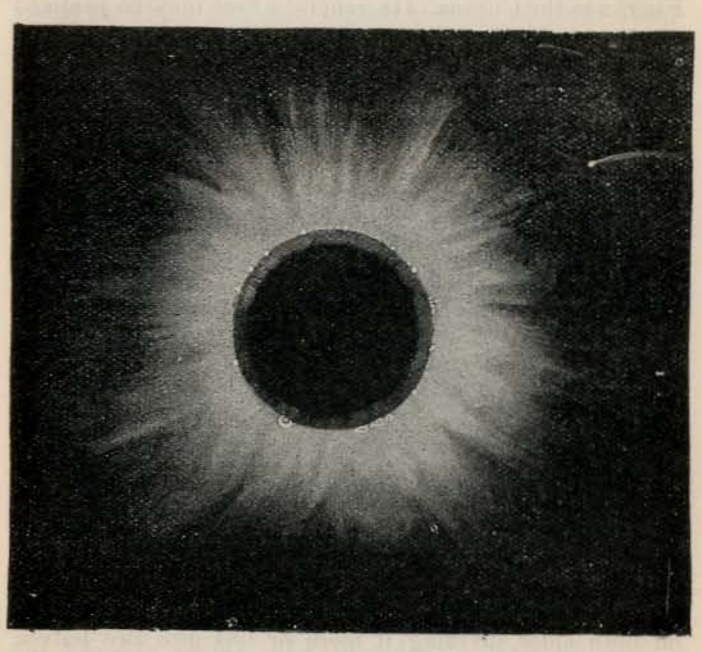


FIG. 68.—THE SUN TOTALLY ECLIPSED, MAY 17, 1882; SHOWING ALSO AN UNKNOWN COMET.

Turn we now to eclipses of the Moon. The difference in principle between an eclipse of the Sun and an eclipse

of the Moon, which has already been pointed out, naturally carries with it differences in the effects observed. Foremost among the facts resulting from the essential principle of an eclipse of the Moon being what it is, is the fact, that whereas an eclipse of the Sun is visible only within a very narrow strip of country on the Earth's surface, an eclipse of the Moon is visible over an entire hemisphere.

The circumstances of an eclipse of the Moon will be understood from Fig. 69, where S represents the Sun, E the Earth (the shading representing its shadow), and *a b c d* different positions of the Moon before, during, and after it is Full. The Earth being between the Sun and the Moon, the Earth's shadow falls towards the direction where the Moon is. This shadow is defined by lines drawn through the upper and lower edges of both Sun and Earth, which lines will meet at *k*. The form of the shadow thus indicated is evidently that of a cone.

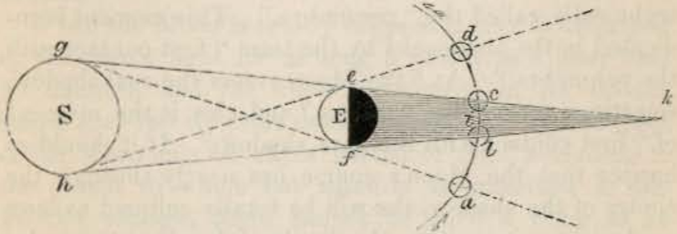


FIG. 69.—THEORY OF AN ECLIPSE OF THE MOON.

If we draw lines from the upper edge of the Sun to touch the lower edge of the Earth, and from the lower edge of the Sun to touch the upper edge of the Moon, such lines will be *g f* and *h e*. These produced as far as the Moon's orbit, will cut that orbit at *a* and *d*; and so doing will inclose triangular spaces *b f a* and *d e c*, within which the Moon only loses a portion of the Sun's rays when passing those parts of its orbit lying between *a* and *b*, and *c* and *d*, respectively. The result of the Moon losing only some, but not all of the Sun's rays, is that she begins by experiencing a partial obscuration which does not become absolute until a later stage. The eclipse commences when the Moon reaches *a*, and enters the semi-shadow technically called the "penumbra." This moment is indicated in the almanacks by the term "first contact with the penumbra." At *b* the Moon enters the real shadow, sometimes termed the "umbra," and this is the moment of "first contact with the dark shadow." If it should so happen that the Moon's course lies nearly through the centre of the shadow, she will be totally eclipsed as long as she is moving within the limits of *b c*, because under those circumstances the intervention of the solid body of the Earth will entirely cut off all Sunlight. If, however, it should happen that on the occasion of an eclipse the Moon should be some little distance from her node, north or south of the ecliptic, it may well be that a part only of the Moon will travel through the dark shadow whilst she is journeying from *b* to *c*. In this case there will be what is called only a "partial eclipse" of the Moon, and only a slice of her disc on the northern or on the southern side will, as it were, be blackened. Be the eclipse, however, total or partial, the Moon's arrival at *i* constitutes the "middle of the eclipse." When the Moon reaches *c*, that is the moment of "last contact with the dark shadow"; whilst *d* indicates the place of "last contact with the penumbra."

It has just been stated that the eclipse will only be a partial one if the Moon attains its phase of Full (otherwise called its Opposition) whilst no more than a little north or south of the ecliptic. That this should be so will be readily understood when it is stated that the breadth of the Earth's shadow at the Moon's distance from the Earth is no more than about 1½ diameters of the Moon above and below the actual plane of the ecliptic.

When the Moon is totally eclipsed it may be deprived of the Sun's light for as long a period as 1 hour and 50 minutes, and the whole phenomena in its various stages may last for more than 5 hours. Though eclipses of the Moon may be either partial or total, according to the extent to which our satellite is immersed in the Earth's shadow, there cannot be such a thing as an annular eclipse of the Moon, because the diameter of the Earth's shadow at the greatest possible distance of the Moon from the Earth is always in excess of the diameter of the Moon's disc. Whereas eclipses of the Sun always begin on the western side of the Sun and finish on the eastern side, lunar eclipses always commence on the eastern side of the Moon and finish on the western side. Even when most deeply immersed in the Earth's shadow the Moon does not as a rule disappear, for it may generally be detected with a telescope, and frequently also with the naked eye, exhibiting a dull coppery red hue. Sometimes, however, the Moon does really become absolutely invisible. The fluctuations recorded in the visibility of the Moon at different eclipses is to be ascribed to differences in the condition of the Earth's atmosphere at the different times.

Thus far we have been considering eclipses of the Sun and Moon simply from the standpoint of a modern observer armed with instruments capable of revealing information respecting physical facts; but a good deal might be said about eclipses in their relation to history and chronology. It is obvious that it is only since the invention of the telescope that observations of precision on the movements of the heavenly bodies have been possible; and as it was not until a long time after the invention of the telescope that graduated circles of proper accuracy for purposes of measurement were fitted to the telescope-stands in use, it follows that it is only during the past 150 years that astronomical observations of real value in regard to measurements have been accumulating. But in cases where we can find such a phenomenon as an eclipse of the Sun observed on a definite day at a definite place many centuries ago, such a record of the Moon's place in the heavens becomes at once an astronomical record available as a starting-point for investigations as to the Moon's motions. Accordingly a number of ancient eclipses mentioned by ordinary historians have been turned to account by astronomers in their investigations of the Moon's motions. Amongst the historical eclipses thus subjected to special astronomical investigation may be mentioned the celebrated eclipse of 585 B.C., predicted by Thales, and recorded by Herodotus; that of 557 B.C., mentioned by Xenophon as having led to the capture by the Persians of the Median city Larissa; and that of 431 B.C., which occurred on the eve of an Athenian expedition against the Lacedemonians. This last-named eclipse furnished the Athenian commander Pericles with an opportunity of delivering a very effective address on the philosophy of eclipses. We are told by Plutarch that:—"The whole fleet was in readiness, and Pericles on board his own galley, when there happened an eclipse of the sun. The sudden darkness was looked upon as an unfavourable omen, and threw the sailors into the greatest consternation. Pericles, observing that the pilot was much astonished and perplexed, took his cloak, and having covered his eyes with it, asked him if he found anything terrible in that, or considered it as a bad presage. Upon the pilot answering in the negative, Pericles said: 'Where is the difference, then, between this and the other, except that something bigger than my cloak causes the eclipse?'"

Passing over many centuries, we come to March 1, 1504, where we find that there happened an eclipse of the Moon which proved of much service to Columbus. Being on the Island of Jamaica, and short of provisions, which the islanders refused to supply, he threatened to punish them by depriving them of the Moon's light. Not unnaturally his threat was at first treated with indifference, but when the eclipse actually commenced, the natives, terror-struck with the apparently supernatural powers of the great Spanish commander, immediately commenced to collect provisions for the fleet, and thenceforward treated their visitors with profound respect.

TRANSITS.

The term "transit," as applied to a planet, has a special meaning. It is used with reference to the passage of an inferior planet, *e.g.*, Mercury or Venus, across the Sun's disc. In principle the phenomenon is strictly identical with an eclipse of the Sun by the Moon, that being no more than a transit of the Moon across the Sun. Both the known inferior planets are, however, too small to obscure any appreciable amount of the Sun's light; they cross the Sun's disc simply as small black spots.

Transits of Mercury occur at irregular intervals, varying from 3 to 13 years, or about 4 times in 33 years. The first observed transit of Mercury occurred on November 7, 1631, and was observed by Gassendi at Paris, after having been predicted by Kepler. The next transit of Mercury will occur on November 10, 1894.

The transits of Venus are much more rare; they only occur at intervals of more than a century, and then of 8 years; after which there will again be an interval of more than a century.

The first observed transit of Venus took place on November 24, 1639 (O.S.), and was observed in Lancashire by two young Englishmen, named Horrox and Crabtree, who have left behind them a very graphic account of their difficulties and successes. The transits which have occurred since have been in 1761, 1769, 1874, and 1882, all of which were observed with very special care and attention, for a reason which will be referred to presently.

Regarded merely as a sight, a transit of an inferior

planet is by no means devoid of interest. When the planet has just completely entered upon the Sun it does not exhibit immediately a strictly circular black disc, but the disc seems to hang on to the disc of the Sun by means of a black streak or ligament. When this has eventually disappeared, and the planet has well advanced on to the disc of the Sun, it generally happens that a ring is seen to encompass the planet. This ring is sometimes dusky and sometimes luminous; that is, it is apparently sometimes darker and sometimes brighter than the luminous background of the Sun. It does not yet clearly appear to what causes these varying effects must be ascribed. Moreover there is often seen on the black disc of Mercury and Venus a white or grayish spot of light, for which also no satisfactory explanation has yet been found.

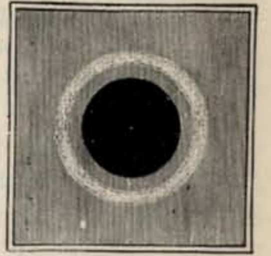


FIG. 70.—RING ROUND AN INFERIOR PLANET IN TRANSIT.

Transits of Venus are made use of for ascertaining the distance of the Earth from the Sun.

Fig. 71 will illustrate the principle which underlies this method of determining the Sun's distance, though it must be understood that there are other methods in use. E represents the Earth, V the planet Venus moving round the Sun in the direction of the arrows, and the large circle F C D G the Sun's disc. When Venus at inferior Conjunction comes between the Earth and the Sun at V, an observer stationed on the Earth at *a* would see the planet projected upon the Sun's disc at B; and an observer stationed at *b* on the opposite side of the Earth would see the planet as if at A. The distance A B represents the difference in the two apparent positions of Venus on the Sun's disc due to the difference between the two stations *a* and *b* on the Earth's surface at which the planet is observed ; and the wider these stations are apart on the Earth, the greater will be the angular displacement of the planet on the Sun.

The angles formed at V by the intersection of the lines *a* B and *b* A are equal (that is to say, the angle *a* V *b* is equal to the angle A V B), and the distance *a b* will therefore bear the same proportion to A B that the distance of Venus from the Earth (V *a*) does to its distance from the Sun (V B) ; this proportion is ascertainable by aid of Kepler's Third Law.

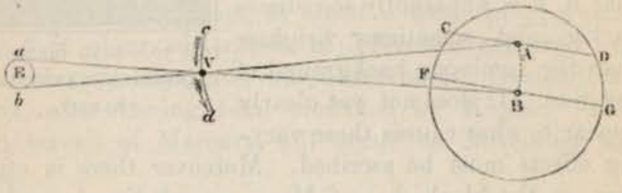


FIG. 71.—OBSERVATIONS OF TRANSITS OF VENUS.

To find the distance A B is a matter involving telescopic observation ; it is only necessary to observe the times when the planet, moving in its orbit from *c* to *d*, enters and leaves the Sun's disc, as we can then determine the intervals which the planet occupies in describing the chords C D and F G to the observers stationed at *b* and *a* respectively ; thus we can arrive at the exact apparent course of the planet as viewed from each station, and so find the distance A B.

Knowing A B, and likewise the distance between the two stations on the Earth's surface, it is not difficult to ascertain what angle the Earth's semi-diameter (or half the distance *a b*) would subtend, as seen from the Sun. This information is arrived at by reducing its measure upon the Sun's disc in the proportion of the distance between Venus and the Sun and Venus and the Earth. This angle is known as the "Sun's horizontal parallax," being, in fact, equal to the displacement in the Sun's position due to parallax, according as the Sun is viewed from the Earth's pole or the Earth's equator. Having thus found the apparent breadth of the Earth's semi-diameter at the Sun, its proportion to the whole distance between the two bodies can be calculated by trigonometry.

The observations of the transit of Venus in 1769 yielded results which, though at first regarded as very trustworthy, were thought, as time passed away and practical astronomy made progress under the influence of enlarged experience and better instruments, to be open to doubts ; accordingly astronomers looked forward with great eagerness to the transits of 1874 and 1882. By means of the results of these transits, confirmed as they are by results furnished by other methods, it is now agreed that the equatorial horizontal parallax of the Sun, by which is implied the apparent equatorial diameter of the Earth as seen from the Sun at mean distance, is as nearly as may be 8·8″. Hence we learn by trigonometry that the Sun's distance from the Earth is 23,464 times the radius of the Earth ; and as this radius measures

3963 miles, it follows that the interval which separates the centre of the Earth from the centre of the Sun, taken at its mean value, amounts to 92,890,000 miles.

Fig. 72 will be useful to illustrate certain technical expressions used in connection with transits of inferior planets, some of which have been mentioned on a previous page without having been very fully explained. The moment at which Mercury or Venus visibly enters upon the Sun's disc is called the "ingress," and that of their departure off the disc the "egress." As each planet possesses a measurable breadth, that is to say, exhibits a measurable disc, when projected upon the Sun's disc, it is necessary to take steps to refer all the observations to the Sun's centre. This is done by taking the observations in duplicate, as it were, first at one edge and then at the other edge, and so obtaining a mean value. The simple process of noting the times when the planet first touches the limb of the Sun on the outside, as at A, and then when the planet is just exactly within the disc, as at B, accomplishes this. A is called the "external contact at ingress," and B the "internal contact at ingress." Similarly on the planet leaving the Sun the corresponding moments are noted, as at D and E, D being the "internal contact at egress," and E the "external contact at egress."

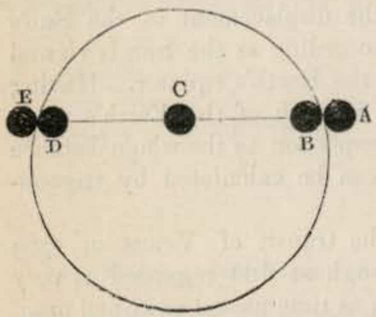


FIG. 72.—TRANSIT OBSERVATIONS OF AN INFERIOR PLANET.

When the planet arrives at C the "least distance of centres" is said to take place, because this is the moment of the nearest approach of the centres of the planet and Sun respectively.

OCCULTATIONS.

The term "occultation" is used, in general, astronomically, to describe the concealment of one object by another, but it is more especially applied to the concealment of planets and stars by the Moon in the course of its monthly journey through the heavens. Inasmuch as the Moon's apparent diameter is about $\frac{1}{2}^{\circ}$, it follows that all objects, whether planets, stars, or clusters of stars, situated in a zone extending $\frac{1}{4}^{\circ}$ on each side of her path, will necessarily be occulted in succession. The brilliancy of the Moon overpowers the smaller stars, but the disappearances of the planets and of the larger stars can be observed with a telescope, and a table of them is published every year in the almanacks. The disappearances always take place at the limb of the Moon which is presented in the direction of its motion. From New to Full the Moon moves with its dark edge foremost, and from Full to New with its illuminated edge foremost. During the former interval the objects occulted

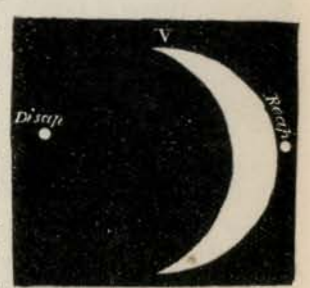


FIG. 73.—OCCULTATION OF A STAR BY THE MOON THREE DAYS OLD.

disappear at the dark edge and reappear at the illuminated edge; whilst during the second part of every lunation the contrary takes place. If an occultation be watched when a star disappears at the dark edge of the Moon, that is to say, during the first half of a lunation, and preferably when the Moon is not more than 2 or 3 days old, the disappearance is an extremely striking phenomenon, for the object occulted seems suddenly extinguished at a point of the sky where there is nothing to interfere with it. Occultations of stars by the Moon can be made use of for ascertaining the longitude of places on the Earth's surface.

CHAPTER IX.

COMETS.

THE celestial objects which will be considered in the present chapter may be regarded as on the whole of more general popular interest than any others which the astronomer has to observe and describe. They are so because of their erratic courses, because of the suddenness with which they come and go, and because of the strange differences of size and appearance which they exhibit, differences which not only serve to distinguish one comet from another, but the same comet at intervals of time which may be as short as only a few weeks. Historians of all ages and countries have recorded with admiration or alarm, or both, the great comets which have come under their notice, the reason being in many

cases that such objects were generally considered to be "ominous of the wrath of heaven, and as harbingers of wars and famines, of the dethronement of monarchs, and the dissolution of empires." Thus it has come about that

FIG. 74.—A COMET PANIC IN OLDEN TIMES.

the ordinary historians rarely dealing with common astronomical facts have yet preserved for us, during upwards of 2000 years, accounts, more or less full, of probably every comet conspicuously visible to the naked eye which has come within sight of the Earth.

FIG. 75.—COMMON FORM OF NAKED-EYE COMET.

Shakespeare's allusions to comets are numerous and interesting. They are as follows:—

"Comets, importing change of times and states,
Brandish your crystal tresses in the sky,
And with them scourge the bad revolting stars
That have consented unto Henry's death."
Henry VI., First Part, Act I. Scene 1.

"Now shine it like a Comet of revenge,
A prophet to the fall of all our foes."
Henry VI., Act III. Scene 3.

"Some Comet or unusual prodigy."
Taming the Shrew, Act III. Scene 2.

"When beggars die, there are no Comets seen;
The heavens themselves blaze forth the death of princes."
Julius Cæsar, Act II. Scene 2.

"As stars with trains of fire, and dews of blood,
Disasters in the Sun."
Hamlet, Act I. Scene 1.

It must be explained at the outset that a considerable difference exists between the popular and the scientific idea of a comet. It may be safely said that in the popular mind no object of this class is really a comet unless it has a distinct tail. But the comet of the astronomer in two cases out of three falls altogether short of this standard. To an astronomer the tail is a mere accident; that is to say, two-thirds or more of the comets discovered and watched by astronomers have no tails at all. The average comet may be said to be in the first instance merely a faint nebulous patch, not always possessed of a head, and still more rarely possessed of a tail. If the comet should happen to be approaching the Earth, or the Sun, or both, probably it will be found that its size

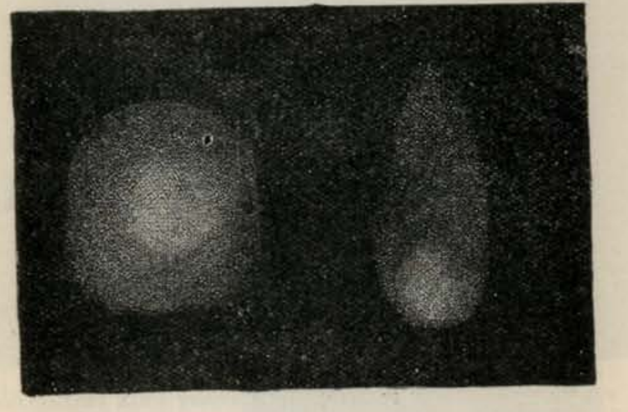


FIG. 76.—COMMON FORMS OF TELESCOPIC COMETS.

increases; and that after a while it begins to exhibit a central condensation of light of a stellar character, and technically termed a "nucleus." Around this nucleus there is often developed a cloud-like mass of luminous matter (known as a "coma"), which sometimes grows into a tail, properly so called; though frequently that which at one time promised to become a tail, does not get beyond an oval, or it may be a sort of pear-shaped, expansion of the head. Nucleus and coma taken together constitute the "head" of a comet.

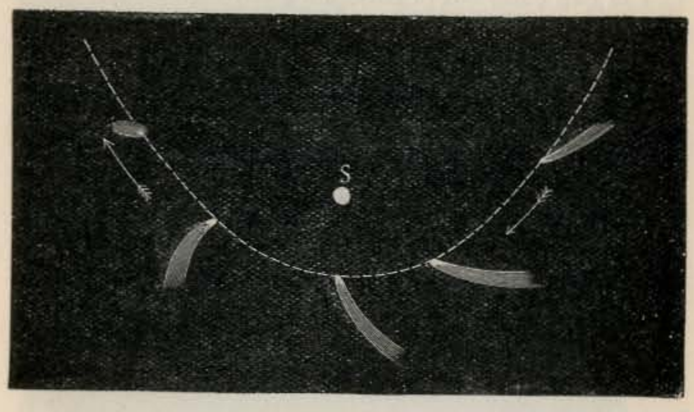


FIG. 77.—SUCCESSIVE POSITIONS OF A COMET NEAR PERIHELION.

In size and brightness comets exhibit great diversity. When and whilst they are comparable with stars they are usually spoken of as being of the brightness of a star of such-and-such a magnitude. But size is no index of brightness. A comet may have a diameter of 5′ of arc, and be much fainter than one $\frac{1}{2}'$ in diameter. Comets of this size would generally be "telescopic" comets, that is, comets invisible to the naked eye. Telescopic comets are usually more or less circular in shape; but comets visible to the naked eye are rarely so. Comets of this latter class almost always have tails.

FIG. 78.—COMET WITH 2 TAILS (1861, II.).

The tails of comets offer an endless variety of form and dimensions. On the one hand, they may be entirely telescopic, and not only so, but so small and faint as only to be visible in telescopes of great power; or, on the other hand, they may be conspicuously visible to the naked eye, and sometimes so long as to reach from the horizon to the zenith, or through 90° or more of arc. It is something like a general rule that the tail of a comet is a prolongation of an imaginary line joining the Sun and the comet; that is to say, that such a line carried forwards from the comet into space will run through the whole or the greater part of the tail. Occasionally a comet has 2 tails; but in such a case the second is often a branch or off-shoot of the principal tail, rather than an independent second tail.

Sometimes the second tail is directed more or less *towards* the Sun, in which case it used to be called by the old English writers a "beard."

The great comet of 1825 is recorded by one observer to have had 5 tails, and that of 1744 as many as 6. Many tails are curved so as to resemble in some degree a sabre. The comet of 1769 had a double-curved tail, something like a thin elongated capital S (∽). The great comet of 1882 exhibited a very remarkable form of tail—rather, a tail inside a tail, the ordinary tail which first would catch the eye having been enveloped in a semi-transparent cylindrical sort of casing, seemingly independent of the inside tail. Sometimes vibrations or pulsations are to be noticed in a comet's tail; but it would seem, according to the best authorities, that these are due to atmospheric causes, and are not connected with the comet itself.

The question, "What is a comet?" is one which is not capable of a very direct answer. All we know is that they are bodies of density so small that stars can be seen through them, and of mass so slight that when they pass near planets they in no discoverable way affect the motions of such planets. On the contrary, it has been plainly proved in the case of the planet Jupiter that the orbits of comets which have come within the sphere of its influence have often been materially deranged by it. Whatever may be the character of the matter of which comets are composed, it seems clear that all parts of a comet—head and tail alike—are formed of the same kind of material. The disposition of the matter constituting the tail seems to be in most cases either that of a hollow cone or of a hollow cylinder. This supposition harmonizes with the fact that towards their edges most tails

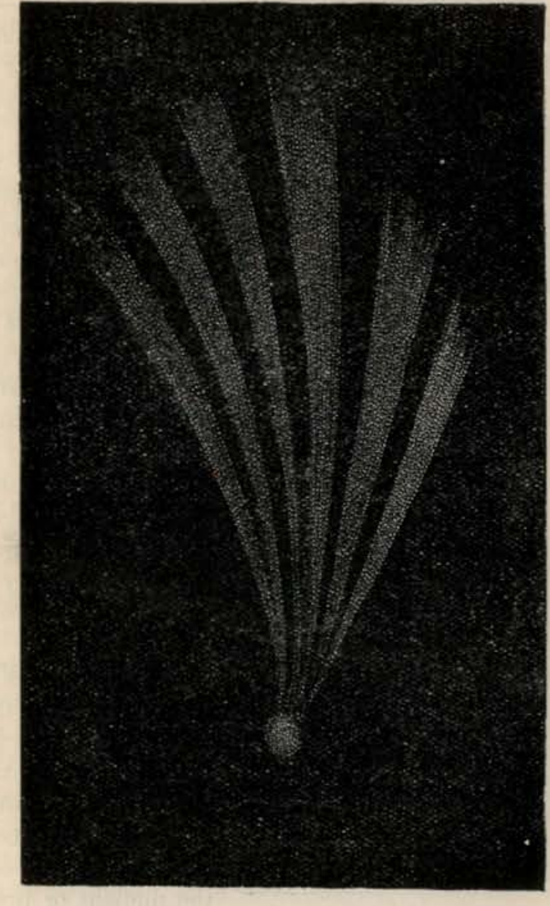


FIG. 79.—COMET WITH 6 TAILS (1744).

are brighter than in the centre; and it may be presumed that they are brighter in those parts because we are looking there through a greater thickness of luminous matter.

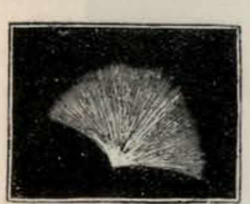


FIG. 80.—JET OF LIGHT SEEN IN THE HEAD OF THE GREAT COMET OF 1861 (JULY 3).

It may here be remarked that the expression "luminous matter," just made use of, seems a proper one. There appears little reason to doubt that comets are self-luminous. If they are not so, but receive their light from the Sun, they would under some circumstances exhibit phases. Now, though some older observers do make mention of phases, there do not seem to exist sufficient grounds for accepting the accuracy of their testimony, and the evidence to the contrary may be deemed overwhelming.

FIG. 81.—HEAD OF THE GREAT COMET OF 1861 (JULY 2).

Careful study of the head of a comet from day to day will often disclose many striking and interesting changes. The occasions are numerous of the nucleus or bright centre of a comet ceasing to be a symmetrical bright point of light, and throwing off, especially on the side away from the Sun, a jet or jets of luminous

matter. Fig. 80 represents a simple jet such as was seen in the case of the great comet of 1861, on July 3 of that year. That jet had, indeed, been noticed on the previous evening, when it was of smaller size; and the fact that the head of the comet, regarded as a whole, had been developed by a process resembling that of the uprush of water from a fountain, is well brought out by the engraving which is dated July 2.

A matter connected with the physical constitution of comets, which has attracted much notice of late years, has been the discovery in the case of some of them of a disposition to break up into fragments. An instance of this, said to have occurred as far back as 371 B.C., is on record; and something of the same sort was noted by two observers of the comet of 1618, but neither of these cases seem to have commended themselves to astronomers. The first well-authenticated case of a comet breaking up into 2 portions occurred in the winter of 1845-6. A comet known as Biela's, which then became visible as a single comet, separated into 2 parts about a month after its discovery, and the 2 parts travelled together as 2 separate comets for a period of 3 months. This comet returned again to the Sun in 1852, and its 2 parts still remained visible as such, but separated by a wider interval than before. This comet has never been seen since 1852, and it is now supposed to have become broken up into fragments so small that there is no chance of us ever seeing it again as a comet. In a later chapter I shall have something else to say respecting this body, by way of carrying forwards its history to a later epoch.

It is now time to say something about the movements of comets. The astronomers of antiquity were much puzzled by the motions of comets. They were thought to be so erratic as to be altogether beyond the reach of any laws. Later on, however, in the world's history, Tycho Brahe thought that they moved in circular orbits, whilst Kepler suggested straight lines. Step by step, however, observers found out that the paths of comets conformed to some one of three out of the 4 possible sections of a cone; conclusions which were reduced to a final definite shape by Sir I. Newton. The consideration of this matter in detail is beyond the scope of these pages. It must suffice, then, to say, that 4 different sections can be obtained by cutting through a cone. A cut such as A A, at right angles to the axis, yields a circle; a cut made obliquely, such as A D, yields an ellipse; a cut such as B A B yields a hyperbola; and a cut such as C A C yields a parabola. No comets move in a circle; a great many in elliptic orbits; a still larger number in parabolic orbits; but only a few (about a dozen) in hyperbolic orbits.

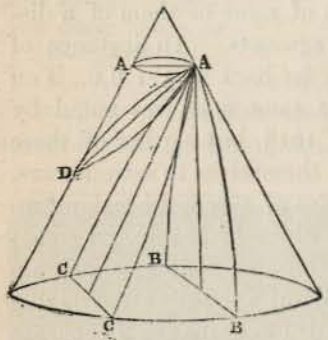


FIG. 82.—DIFFERENT SECTIONS OF A CONE.

When a new comet is found astronomers try to obtain as quickly as they can 3 observations of its place in the heavens, at intervals of time as nearly equal as possible. This done, they can calculate its orbit, and determine whether it is approaching the Sun or receding from the Sun, and what its future course through the heavens will be during the next succeeding weeks or months of its visibility.

Comets which are found to be following parabolic or hyperbolic orbits are to be regarded as stray objects which are wandering about the universe, and which, having paid one visit to us, that is, to the Sun, have gone off again, no one knows whither. But comets which have been found to follow elliptic orbits may be regarded as permanent members of the Solar system, that is to say, they come, and though they go away, yet they come again. It may be said that about 2 dozen comets are known to be regular members of the Solar system. Of these about 12 revolve round the Sun at intervals varying from 3 to 8 years. Some of these have returned so often

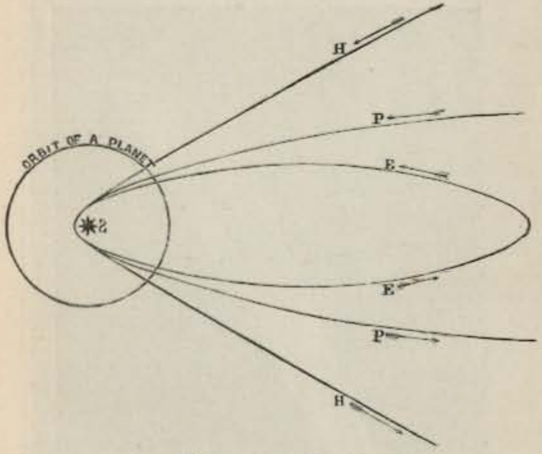


FIG. 83.—COMETARY ORBITS.

E Ellipse. **P** Parabola. **H** Hyperbola.

that their physical appearance and movements are thoroughly familiar to astronomers. Of these the best known are the following:—Encke's, Faye's, Brorsen's, Winnecke's, and D'Arrest's.

Besides these short-period comets there is one tolerably well-known comet revolving in 13½ years (Tuttle's), and a group of 6, whose periods average 70—80 years, of which the most important and best known by far is Halley's, revolving in 76¾ years, and due to return in 1910.

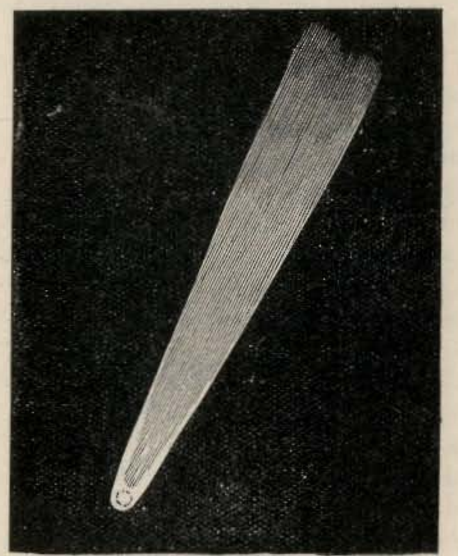


FIG. 84.—HALLEY'S COMET IN 1835.

Over and above these, there are a number of large comets known to us, and believed to revolve in elliptic orbits of great eccentricity, and with long periods,

amounting in some cases to thousands of years. The great comets of 1811, 1843, 1858, 1861, and 1882, are some of the most important of those which may be included in this category.

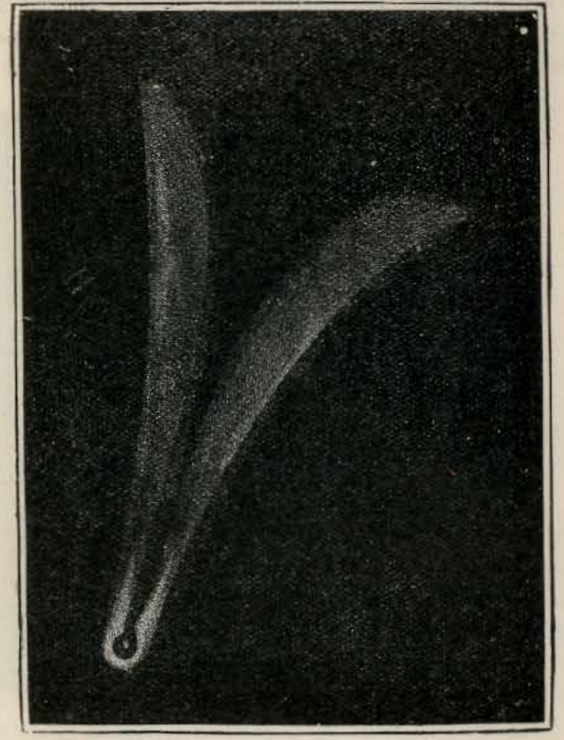


FIG. 85.—THE GREAT COMET OF 1811.

A few miscellaneous remarks will complete this account of comets. The German astronomer, Encke, in the course of his prolonged study of the comet which bears his name, found that, notwithstanding every allowance which he could make for planetary influences, the comet always returned to perihelion 2½ hours sooner than it should have done. To explain this he conjectured the existence of some thin ethereal "Resisting Medium," sufficiently dense to produce an effect on a body of such extreme tenuity as his comet, but incapable of exercising any sensible influence on the planets. The propriety of this theory seems still open to some doubt, no clear confirmation of its existence having yet been obtained in the case of any other comet.

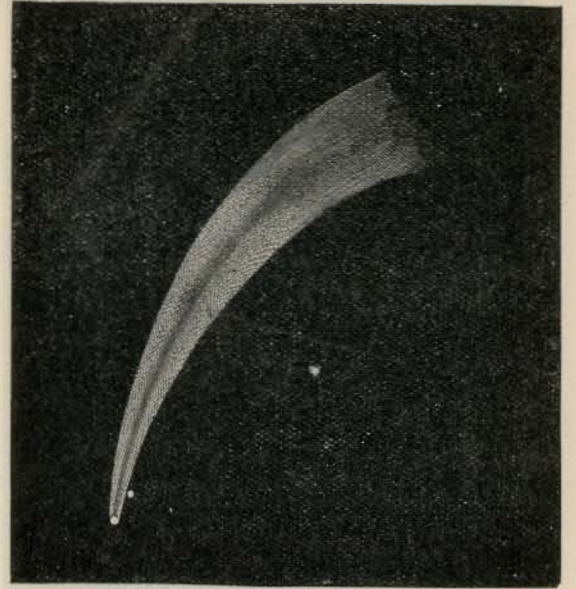


FIG. 86.—THE GREAT COMET OF 1858 (DONATI'S).

The total number of comets on record up to the present time is rather more than 900, and of these about 400 have been the subject of calculation as regards their orbits. These numbers include, in both cases, apparitions of comets known to be periodical.

CHAPTER X.

METEORS.

UNDER this title will be included the bodies which go by the name of Aërolites (or meteoric stones), Fire-balls, and Shooting Stars, it being now recognized that all these are closely related to one another, and also that they fall within the legitimate province of the astronomer.

Meteoric stones may be described as large and irregular mineral masses, which have been seen to fall on to the Earth, or to have been found after falling unnoticed by human eye. These stones are composed of various elements, all of which occur amongst the minerals found on the Earth. We know not whence these bodies come, but it is clearly established that from time to time masses of stone, often of considerable weight, do pass through space, and are precipitated upon the Earth, either singly or in showers. Moreover, instances are on record of showers of dust having occurred on the Earth, which dust is supposed to have been of cosmical, in other words of meteoric, origin. Fig. 87 represents a magnified view of some of this dust examined by Silvestri of Catania, who found it to contain metallic iron, nickel, and various other substances probably of non-terrestrial origin.

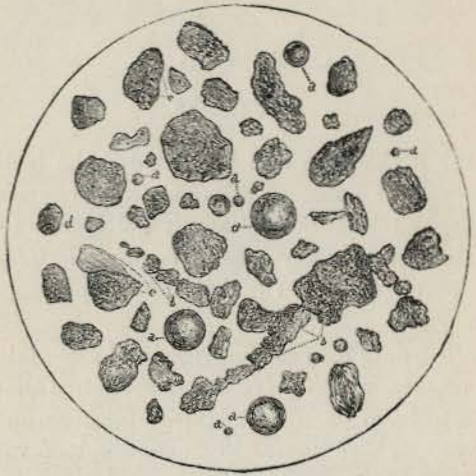


FIG. 87.—METEORIC DUST (MAGNIFIED).

When meteoric stones fall in numbers, the curious and unexplained fact has been noticed that the area over which they fall is generally an oval from 6 to 10 miles in length by 2 or 3 miles in breadth, and that the largest stones may be looked for at one extremity of this oval. Meteoric stones seem to fall more often in March, May, July, and November, than in any other months, and comparing the first 6 months of the year with the last 6, they are more numerous in the latter period.

Fire-balls may be regarded as intermediate in character between the meteoric stones just alluded to and the shooting stars to be described presently. They appear

in the sky suddenly, and very often affect a pear-shaped form. Usually they are noiseless, but sometimes an explosion accompanies their appearance, and in this latter case, if the whole truth could be known, very likely a fall of meteoric stones is the result. Slow moving fire-balls usually evolve trains of sparks, but the swifter ones often yield phosphorescent streaks, which sometimes linger for many minutes, assume irregular shapes, and drift slowly away, presumably under the influence of currents of air in the higher regions of the atmosphere. Regarded according to the months of the year, it is found that fire-balls are more numerous in the last 6 months of the year than in the first 6 months, and somewhat in the proportion of 2 to 1. The following appear to be dates when fire-balls may especially be expected :—

Jan. 2.
Feb. 7.
April 11-12, 19-20.
June 6.
July 25-30.
Aug. 7-13.
Sept. 1-2, 6-7.
Nov. 1-2, 6-9, 11-15, 19, 27.
Dec. 8, 11-12, 21.

It occasionally occurs that the same fire-ball is observed by two different persons at places separated by perhaps 50 or 100 miles. When this is the case, and the observers happen to be experienced in work of this sort, it is possible to calculate the height above the Earth at which the fire-ball appears, its absolute diameter, and the velocity of its movement through space. It would seem, from some of the calculations that have been thus made, that the height of a fire-ball may be anything between 5 miles and 500 miles; its diameter anything between a few hundred feet and a mile ; whilst its velocity may vary between

2 miles and 50 miles a second. Of the figures just stated, those which refer to the maximum diameter of fire-balls are most open to suspicion; and in spite of there being several calculations to that effect, it seems extremely improbable that any fire-ball would be at all likely to have so great a diameter as that it could be measured by miles, like the fire-ball of August 18, 1841, to which a diameter of 2½ miles was attributed.

Shooting stars are in all probability nothing more than minute fire-balls, or objects of kindred character. It was long thought that they were merely incandescent objects of atmospheric origin, but this theory is quite exploded, and it is now agreed that they are of celestial origin, pursuing objects similar, certainly in some cases, to the orbits of comets, and grouped into streams containing myriads upon myriads of detached particles. They are rendered visible to us by being inflamed by the friction resulting from contact with our atmosphere, into which they rush with immense velocity, becoming thereupon consumed instantly, and reduced to imperceptible dust. It may be taken as an established fact that an attentive observer will be able to see at least a few shooting stars on every clear night throughout the year. On a fine starlight night, with the Moon absent, half-a-dozen or more may be noticed every hour, but it seems that the hourly average is greater during the hours after midnight of the last 6 months of the year. Under such circumstances the hourly average may be put at 20 or more.

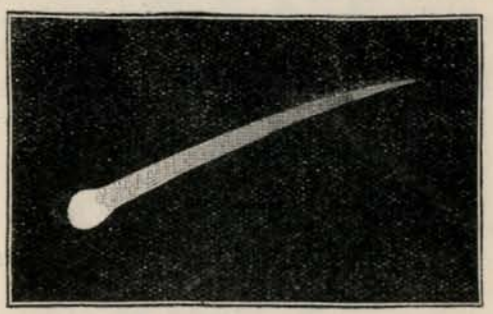


FIG. 88.—FIRE-BALL OF OCT. 7, 1867.

The statement just made merely applies to the casual shooting stars which present themselves here and there, and nowhere in particular; but besides these, at certain definite points in certain constellations, and at certain definite epochs, great numbers—to be counted by thousands—of shooting stars are visible.

The most important of these definite points from which shooting stars radiate (hence called "Radiant Points") are:—

Date.	Constellation and Place.
Jan. 2	Quadrans, 12° N.N.E. of β Boötis.
April 20	Lyra, 8½° S.W. of α.
July 23	Lacerta, 8° S. of δ Cephei.
July 28	Aquarius, 5° N.N.W. of δ.
Aug. 10	Perseus, 4° N.E. of η.
Oct. 18	Orion, 2° E. of ν.
Nov. 13	Leo, 5° W.N.W. of γ.
Nov. 20	Taurus, 5° N.N.W. of ε.
Nov. 27	Andromeda, 4° N.W. of γ.
Dec. 10	Gemini, 3° W.N.W. of α.

Though shooting stars had been mentioned by various old writers as curious phenomena of unknown nature, yet it would seem that the first shower which was carefully observed and described by a competent scientific writer was that of November 13, 1799, seen by Humboldt, then travelling in South America. Fine displays took place in 1831 and 1832, in both cases on November 13. But the grandest display of all, and one which has not yet been surpassed, was that of November 13, 1833, which served to bring home to scientific men the periodicity of the phenomenon. It was visible over nearly the whole of the North American continent, and was magnificent to an extent which no words can describe. In many parts the population were terror-stricken in a remarkable manner. A South Carolina planter thus describes his experience:—

"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 600 or 800. While earnestly listening for the cause I heard a faint voice near the door calling my name. I rose, 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 most,—the awfulness of the scene, or the distressed cries of the negroes. Upwards of 100 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 than the meteors fell towards the earth; east, west, north, and south, it was the same."

This November shower fell off after that year, but re-

FIG. 89.—SHOOTING STARS SEEN AT SEA.

curred with considerable brilliancy in 1866, and to a less extent in subsequent years.

Another meteor shower of great importance occurs with much regularity on August 10, the Radiant Point being in Perseus, near the star η Persei. Though that is the principal date and place of the Perseus shower, yet it really extends over a number of days before and after August 10, during which time the principal centre shifts slightly from night to night. This shower does not exhibit any great variations from year to year. On the morning of August 11 it usually yields from 60 to 80 meteors per hour to one observer.

Another meteor shower which of late years has become very prominent is that of November 27, and known as the Andromeda shower. This varies from year to year, and recurs as a special display every 13 years. The next great display should be in 1898. On December 10, as a mean date, there occurs annually a rather prominent shower of swift, short meteors in the constellation Gemini.

As in the case of aërolites and fire-balls so also is it with the shooting stars. The showers are more numerous and more important by far in the last 6 months of the year than they are in the first 6 months. The ratio may be taken at 3 to 1.

The periodicity of some of the showers of shooting stars was recognized a long time before the significance of the circumstance was at all realized. Thus far I have described shooting stars merely as regards the appearance they present to our eyes when we see them; but no account of them would be complete without a few words to point out their connection with comets, or the connection of comets with them (for at present it is not clear what is the proper and best way of putting it).

It was long ago noticed that the November meteors seemed to recur at intervals of about 33 years. Starting with the supposition that this was not a mere accident, an American observer named Newton set himself the task of calculating directly the possible orbit of these meteors regarded as bodies circulating round the Sun. After various calculations he arrived at the conclusion that these so-called meteors were planetary bodies revolving round the Sun in a definite orbit, the size, position, and character of which he had no difficulty in approximately stating. His calculations were repeated at a later period in a different form by Professor Adams, of Cambridge, who arrived at a result substantially identical with Newton's.

At about the same time that Adams was giving his mind in this way to the November meteors, Schiaparelli, of Milan, was studying his own observations of the Perseus meteors of August, 1866. He tried to compute a parabolic orbit for them, regarded as a swarm of planets travelling round the Sun. After he had accomplished this he noticed that the meteors were pursuing an orbit substantially identical in every particular with that which had been found to be the orbit of the 3rd comet of 1862. The agreement was so close as to make it clear beyond a doubt that the comet and the meteors were intimately related.

Subsequent investigations enabled astronomers to identify by the similarity of their orbits several other showers of shooting stars with particular comets which had recently been observed. The most remarkable by far of these identifications is that of the Andromeda shower of November 27 with the lost comet of Biela. Without dogmatizing too much, it seems safe to assert that the meteors of November 27 are fragments of Biela's comet, the disintegration of which, whilst it may have been going on for several centuries, was actually brought under our eyes as a fact in 1845. It will be remembered that in that year (as mentioned on a previous page) the actual separation of the comet into 2 parts was noticed, which separation was found to have been maintained when the comet returned to the Sun and the Earth in 1852. The theory of the connection between comets and meteors will, perhaps, be best understood in a popular way by the following statement, put forth by a well-known American observer, Professor Kirkwood: "Meteors and meteoric rings are the *débris* of ancient but now disintegrated comets whose matter has become distributed around their orbits."

CHAPTER XI.

THE STARS.

LET us suppose an observer stationed on a fine cloudless evening, soon after sunset, in a position open in all directions, and if possible raised a little above the level of the ground; a magnificent and varied spectacle will present itself to him. The stars rendered invisible during the daytime, because their light was overpowered by that of the Sun, will successively become visible; their number will increase every minute, and likewise their individual brilliancy, until very soon the whole sky—east, west, north, and south—will be spangled over with glittering points of light of various apparent sizes.

It is usual to divide the stars, as regards their brilliancy, into about 15 classes, or "magnitudes," of which it is commonly said that the first 6 magnitudes are visible to the naked eye as separate points of light; but it would probably be more correct to say that average eyes can distinguish no stars smaller than those of about magnitude 5 or 5½ at the most. It should be clearly understood that this division of the stars into reputed classes is entirely arbitrary. Comparatively few naked eye stars, especially amongst the larger ones, are absolutely of identical brightness.

Begin where you will, whilst it is not difficult perhaps to enumerate the larger stars in a progressive series of diminishing brilliancy, yet there exists in no case even an approximate dividing line between class and class, so that even observers of skill and experience will be at issue with one another—say, as to whether a particular star should be placed at the bottom of the 3rd magnitudes, or at the top of the 4th magnitudes. It will be necessary to return to this question of star magnitudes later on; but meanwhile let us proceed with our consideration of those general principles which concern the changes which take place in the nocturnal aspect of the sky.

Having taken a first general view of the heavens, the spectator will soon discover that, though he has been taught, probably, to speak of the "fixed stars," yet the statement is evidently not true, and the expression must possess some secondary meaning. He will notice, look where he may, that though the stars preserve almost precisely their relative positions, comparing one with another, yet they are not fixed in the sense of being motionless, but possess a motion of translation across the heavens in some degree similar to that of the Sun as between sunrise and sunset. Let us suppose the spectator to turn his back towards that part of the sky where the Sun is seen at midday. If he looks to the right he will see at each moment, or at any rate, say, every 5 or 10 minutes, new stars rising above the horizon. If he follows any one star in particular he will notice it gradually rise higher in the heavens, advancing somewhat towards the south; after a while, having reached a certain elevation, it will begin to descend on his left, proceeding somewhat in a northerly direction, whilst in time it will gradually sink below the western horizon.

What has just been stated is not absolutely true of all the stars. There exists for all latitudes, exclusive of the equator, a certain portion of the heavens (which differs for every latitude northwards or southwards from the equator), the stars of which neither rise nor set—that is to say, they are always above the horizon. Among these there are some which seem to describe a circle, the circumference of which towards the north scrapes, as it were, the visible surface of the Earth; whilst others describe circles which become smaller and smaller as the stars are nearer to a certain motionless point called the Pole. This polar point in the northern hemisphere is the north pole, and is nearly, but not quite, indicated by a star which we call the pole-star, otherwise known as α Ursæ Minoris. Persons living in the southern hemisphere of the Earth have always within their view a certain point which is correspondingly called the south pole; but unfortunately for them it is not indicated by any conspicuous star, the nearest one being a small star of the 5th magnitude, known as σ Octantis.

From this general statement of things it results that the heavens seem to turn, all in one piece as it were, around an imaginary axis, called the axis of the world, which passes through the place of observation, and through a fixed point near our pole-stars. If certain stars rise and set, it is because they traverse below the horizon the complement of the arc which they have traversed above the horizon. In fact, such a star already set at London will be visible on the horizon at Dublin, but will not yet have risen to the view of an observer at New York. Notwithstanding their apparent movement around the axis of the world, the stars preserve continually the same positions relatively to one another. In other words, the angle formed by the rays of light from any 2 stars whatever to an observer on the Earth is an invariable angle. This angle is said to express the "angular distance" of the 2 stars.

The truth of the foregoing statement may be verified in a general way by fastening together 2 straight rods in such a manner that, when fixed, they may form just the proper angle for their ends to point to any 2 particular stars when the observer, placing his eye at the point of their junction, looks along each rod. If these rods, thus fastened, are brought to bear on the same 2 stars after any interval of time, be it 2 hours or 4 hours, or what not, it will be found that the rods used in the same way as at first still point precisely to the 2 stars.

The movement which we are now talking about is commonly spoken of as the "diurnal movement" of the heavens. Its nature will, perhaps, be rendered more clear to our minds if we regard the stars as attached to the surface of an immense hollow sphere (this being in fact the view taken of the stars by Anaximenes and some other of the philosophers of antiquity). This idea of a sphere thus decorated with stars is so far recognized by astronomers that the term "celestial sphere" or "celestial vault" may be said to be in common use, though in strictness it should be added that "celestial vault" belongs rather to the particular hemisphere of stars which is above the horizon at a given moment.

We have seen that there are certain stars which are always above the horizon of the observer. Let us suppose, by way of fixing our ideas, that this observer is located on the Earth at some point whose latitude is something between 1° north and 70° north. The stars which he will always see are called "circumpolar" stars, and the line which bounds the area containing these stars is called the "circle of perpetual apparition." It separates the circumpolar stars from those which are subject to rising and setting. Similarly on the opposite side of the heavens there will be an area containing stars of the southern hemisphere which are perpetually hidden from every observer in the northern hemisphere, wheresoever he may be. The line which separates such stars from those which do rise and set to the northern spectator is called the "circle of perpetual occultation." It is evident that the places of these circles is not in any

sense fixed in the heavens, but that they change place as the spectator moves to the north or to the south. It may be added that these two expressions, "circle of perpetual apparition," and "circle of perpetual occultation," though logically correct and scientific, are not in very general use, it being more usual in English to speak of the stars within the circle of perpetual apparition as simply "circumpolar," whatever their distance from the Pole; and those within the circle of perpetual occultation simply as the stars "invisible in England," or as the case may be.

Allusion has already been made to the stars being classified into magnitudes. It is generally considered that the stars of the 1st magnitude are 20 in number. They are exhibited, as nearly as may be in the order of brightness, in the following table:—

α Canis Majoris. (Sirius.)
α Argûs. (Canopus.) Invisible in England.
α Centauri. Invisible in England.
α Boötis. (Arcturus.)
β Orionis. (Rigel.)
α Aurigæ. (Capella.)
α Lyræ. (Vega.)
α Canis Minoris. (Procyon.)
α Orionis. (Betelgueze.)
α Eridani. (Archernar.) Invisible in England.
α Tauri. (Aldebaran.)
β Centauri. Invisible in England.
α Crucis. Invisible in England.
α Scorpii. (Antares.)
α Aquilæ. (Altair.)
α Virginis. (Spica.)
α Piscis Australis. (Fomalhaut.)
β Crucis. Invisible in England.
β Geminorum. (Pollux.)
α Leonis. (Regulus.)

These 20 stars will be found to be nearly equally divided between the northern and southern hemispheres, 9 being northern and 11 southern stars.

It would occupy too much space to enumerate the stars of any lower magnitudes than the 1st, but it will be useful to exhibit here a table which has been framed by a very competent German observer named Seidel, for the purpose of suggesting suitable stars as standard stars for their respective magnitudes:—

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 (too faint).

THE CONSTELLATIONS.

Hitherto the stars have been spoken of merely as if they were isolated points of light scattered all over the heavens. They are this, but they are something more, because it has long been customary to treat the stars in groups which are called "Constellations." To these constellations thus formed in the imagination, names have been assigned borrowed from various sources, especially mythology, history, and science.

Finally, in order to distinguish one star from another, all the conspicuous stars of each constellation are designated first of all by letters of the Greek alphabet, and then by Arabic numbers in progressive order. Though the earlier letters of the Greek alphabet (such as α, β, γ, δ, etc.) will commonly be found to indicate the brighter stars, and the closing letters of that alphabet (such as φ, χ, ψ, ω,) the fainter stars visible to the naked eye, yet it is a mistake to suppose that the actual order of those letters in the alphabet is necessarily the order of the brilliancy of the stars to which those letters are applied. It may also perhaps be worth while to state that though particular groups of stars bear the specific names of familiar objects, yet it is only in a very few cases indeed that even a person of vivid imagination would be able to trace in a constellation any resemblance to the object, terrestrial or otherwise, whose name the constellation bears.

A person desirous of "getting up" the constellations, and of learning the names of the particular stars therein, should possess a star atlas of some kind; and a "planisphere" will also be found very useful.[1]

I recommend that in all cases in learning the constellations a start should be made from the Pole-star to the Great Bear, and so step by step, that all the circumpolar constellations should be thoroughly known before proceeding southwards towards the equator. It is somewhat difficult to recognize a constellation which is not circumpolar, because the disposition of its stars is at the first glance very different when such a constellation is setting in the west from what it was when it was rising in the east.

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[1] A planisphere (= plane—sphere) generally consists in its simplest form of a projection on paper of the stars belonging to one or other hemisphere, or the stars of a half or a quarter of a hemisphere, fitted with a movable ring of card-board or metal. This ring has certain graduations, so contrived, that by choosing a day of the month and an hour of the day, the observer will have brought centrally before him just exactly the stars then on his meridian or above his horizon, and none others.

A full account of all the constellations would be beyond the scope of the present volume. It must suffice then to indicate briefly the principal constellations visible in England.

Ursa Major. If the observer will face the north and find the Pole-star, he will soon, by the aid of his atlas, discover the whereabouts of the 7 principal stars of the Great Bear, a group which is known as "Charles's Wain." Its 7 stars comprise 6 (α, β, γ, ε, ζ, η) of the 2nd magnitude, more or less, whilst the 7th (δ) is of the 3rd magnitude. Four of these stars (α, β, γ, δ) form a trapezium; the three others (ε, ζ, η), which make the tail, are nearly a prolongation of the diagonal of the trapezium, formed by joining the stars β and δ; finally, α and β are known as "The Guards."

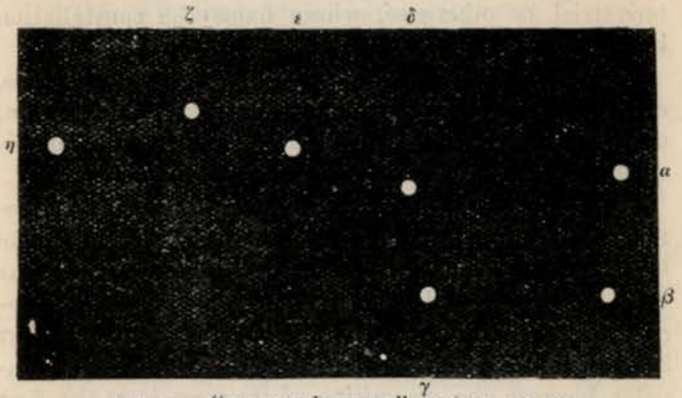


FIG. 90.—"CHARLES'S WAIN" IN URSA MAJOR.

Ursa Minor. The stars β and α just mentioned are also, and perhaps better, known as "The Pointers," because they point to α of the Little Bear, otherwise known as "Polaris," or the Pole-star. This constellation has as its principal feature a group of 7 stars resembling not a little "Charles's Wain"; but the stars are less bright, the dimensions of the figure are more contracted, and the stars occupy an inverse position. The stars here referred to are α, δ, ε, ζ, η, γ, and β.

Cassiopeia. An imaginary line carried from δ Ursæ Majoris, to the Pole-star, and prolonged to about the same extent, will touch one of the extremities of the W, formed by the 5 principal stars (ε, δ, γ, α, β) of the 3rd magnitude which constitute the chief feature of Cassiopeia.

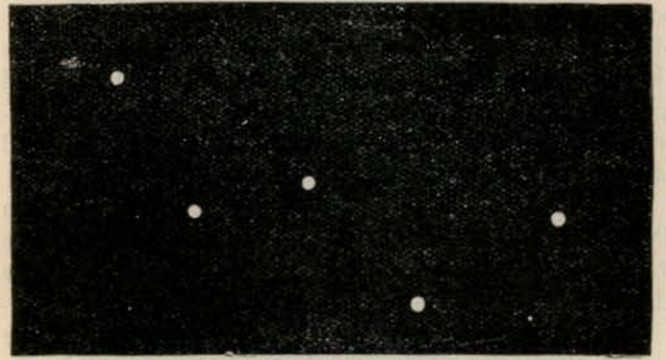


FIG. 91.—THE "W" IN CASSIOPEIA.

Cepheus. This constellation is marked by α of the 2nd magnitude, and 3 stars (γ, β, η), all of the 3rd magnitude. These latter make an arc, of which β at one extremity is almost in the middle of a straight line running from δ Ursæ Minoris, to β Cassiopeiæ.

Pegasus, Andromeda, and *Perseus.* The principal stars of these 3 constellations are of the 2nd magnitude, and 7 of them (α, β, γ Pegasi, α, β, γ Andromedæ, and α Persei) also form a group not unlike the 7 stars of the Great Bear. A line drawn through the Pointers and prolonged beyond Cassiopeia will pass through α and β Pegasi. γ Andromedæ, is near the circle of perpetual apparition for London.

Draco. This constellation, which always passes near the horizon of London at its lower meridian passage, comprises a large number of 2nd and 3rd magnitude stars, which, starting from the space comprised between the Great and Little Bears, encompasses the latter, and approaching Cepheus, and then receding from it, terminates in 5 stars (β, γ, ξ, ν, μ), which constitute the head of the Dragon.

Auriga. A line drawn from β Draconis, through Polaris, and prolonged as far beyond, will nearly strike 3 beautiful stars, α, β, δ Aurigæ; the brightest of these bears the name of "Capella," and is of the 1st magnitude.

Boötes. A straight line carried backwards from the tail of the Great Bear, and beyond the circle of perpetual apparition, will reach α Boötes, otherwise known as "Arcturus," a star of the 1st magnitude. This constellation also contains 7 stars, varying from magnitudes 2½ to 3¾.

Lyra. Not far from the head of the Dragon, and a little below the circle of perpetual apparition, will be found α Lyræ, otherwise called "Vega," of the 1st magnitude. Two 3rd magnitude stars, and 10 between the 4th and 5th magnitudes, help to distinguish this constellation. Vega makes with Polaris and Arcturus a large right-angled triangle.

Cygnus. Between Lyra and Pegasus, but nearer Lyra, will be found the constellation Cygnus, composed chiefly of 5 stars of the 2nd or 3rd magnitudes (α, γ, β, ε, δ), arranged somewhat in the form of a Latin cross.

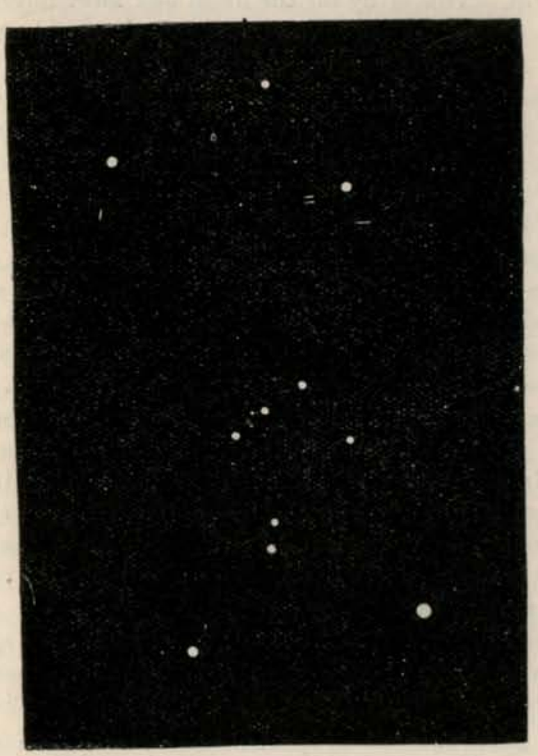


FIG. 92.—ORION.

Aquila. A straight line drawn from Polaris to δ Cygni, will just pass through Aquila, which consists of several 3rd magnitude stars (γ, ζ, θ, δ, λ, η), and one of the 1st magnitude, α, known as "Altair."

Orion. This is by far the finest and most interesting of all the constellations. Its principal stars (α, γ, β, κ) make a large trapezium, with a very striking group in its centre, comprising δ, ε, and ζ, which are in the "Belt" of the figure. One of the sides of the trapezium forms a prolongation of the straight line which joins Polaris and Capella. Of the stars on this side the most northerly is γ (Bellatrix), of magnitude 2, the most southerly being β (Rigel), of magnitude 1.

The corresponding stars on the opposite side of the trapezium are α (Betelgueze), of magnitude 1, and κ, of magnitude 2. The telescopist will find this constellation peculiarly rich in objects of every size and variety.

Canis Major. Almost at the intersection of the diagonal line running from β to δ of the Great Bear with the line of Orion's belt is situated α Canis Majoris, otherwise called Sirius, which is by a long way the brightest of all the stars in the heavens. This constellation also contains 4 stars of about the 2nd magnitude, and 5 of about the 3rd.

Canis Minor. The imaginary diagonal line just spoken of passes very near α of this constellation, known as Procyon, an extra bright 1st magnitude star. There is also a 3rd magnitude star (β) in this constellation.

Aries. The 12 zodiacal constellations, following one another as they do in immediate succession, are not difficult to trace when one has been dropped upon for use as a starting point. In the head of Aries are 3 stars, of which 2 (α and β) are of the 2nd magnitude, and the third (γ) is of the 4th magnitude. These serve to indicate the position of the constellation; but otherwise it offers to the naked eye nothing to attract notice. Aries lies immediately to the east of the "square of Pegasus," at about double the distance of one of the sides of that square.

Taurus follows Aries. The line of Orion's Belt prolonged in the direction opposite to that of Sirius will, at about the same distance, strike upon the beautiful star of the 1st magnitude known as Aldebaran. This found, there will be seen close to it the scattered cluster well-known as "The Hyades," whilst about 10° beyond, in a north-westerly direction, will be found the celebrated group of "The Pleiades," of classic renown. Taurus also contains a star of the 2nd magnitude (β). The principal Pleiad is η or Alcyone.

Gemini. About midway between Ursa Major and Canis Major lie the two well-known stars, Castor (α) of the 2nd magnitude, and Pollux (β) of the 1st magnitude. There are also in this constellation 9 stars, ranging from magnitude 2, to magnitude 3¾.

Cancer. This constellation has no more conspicuous star than (β), of magnitude 3¾, but the cluster "Præsepe," which is nearly in the centre of the constellation, will help the naked-eye observer to find it.

Leo. In Leo we have an important and interesting constellation, one prominent feature of which is the group of stars known as "The Sickle." A line carried through the Pointers, but *away* from Polaris, will nearly strike the centre of the Sickle. The stars which form the Sickle are α, γ, δ, θ, and β, of which the brightest is α or Regulus. γ, δ, and β are of magnitude 2; and θ is of magnitude 3½.

Virgo. Leo being known, Virgo will be readily found, by reason of the fact that it contains a very bright star of the 1st magnitude, known as Spica (α). This forms a nearly equilateral triangle with Arcturus and β Leonis. This constellation may also be found by carrying a line southwards from the diagonal line joining α and γ, Ursæ Majoris, and on the opposite side to Perseus. To the south of Virgo, but not visible in England, is the most beautiful constellation of the Southern Hemisphere, "The Southern Cross." It is a constellation small in size, but always spoken of with enthusiasm by those who have seen it. The two principal stars are of the 1st magnitude, and the next 2 are of the 2nd and 3rd magnitudes respectively.

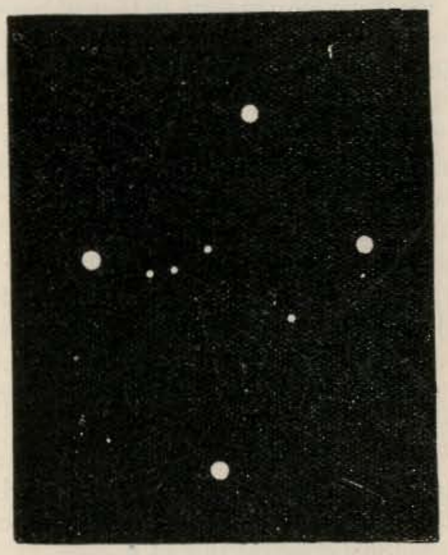


FIG. 93.—THE SOUTHERN CROSS.

Libra has only one conspicuous star, β, of the 3rd magnitude.

Scorpio, although lying near the southern horizon in England, can always be found by reason of its containing a very bright and beautiful star of the 1st magnitude, named Antares (α). This is a red star, a fact from which it derives its Greek name "Antares," which means "rivalling Mars." A line carried from Aldebaran to Polaris, and thence towards the horizon, will nearly strike Antares.

Sagittarius and *Capricornus* are 2 zodiacal constellations lying near the southern horizon in England. Sagittarius has one star as bright as the 2nd magnitude (ε), together with 7 others of about the 3rd magnitude (σ, δ, ζ, γ, η, λ, π). Capricornus has for its brightest star δ of magnitude 3. For the study of both these constellations an atlas is indispensable.

Aquarius and *Pisces*. When we have reached these constellations it will be found that the line of the ecliptic, which up to this point, from Gemini, has been running towards the south, now turns northward. The brightest star in Aquarius is β, of magnitude 3, and in Pisces is ε, of magnitude $3\frac{3}{4}$. Here again therefore the help of an atlas is indispensable.

The foregoing statement of the Northern Constellations does not by any means exhaust them: it is only intended to furnish a general outline of the Northern Heavens which the reader must fill in for himself by resort to his maps.

Having learnt to recognize the principal stars in the heavens, the next step should be to learn how to record on paper their positions; that is to say, how to take the measurements necessary for defining their positions. This undertaking will involve the study of the laws which regulate the diurnal movement of the heavens, and eventually, if the reader wishes to carry his researches to their fullest extent, it will be necessary for him to make use of certain instruments. Before, however, dealing with these laws and explaining these instruments, it will be better to complete our survey of the constellations, so far, that is to say, as is necessary to convey a general idea of some of the sights of the sidereal heavens which a telescope will disclose. To do this I must anticipate matters by presuming, for the moment, that the reader already knows where to look for, and how to find, what I am going to describe.

If we look through a telescope at a planet, say Jupiter, we see, not a point of light, but a distinct disc, more or less sharply defined, and more or less large, according to the power of the telescope we employ. But this is not the case with a star. A star yields no real defined disc, but only what is called a spurious disc, which is an optical effect due to the dispersion of light in passing through the Earth's atmosphere.

Every observer of the stars, especially if he is working in the open air, and in frosty weather, will be struck with their twinkling. The philosophy of twinkling is very little understood, and the phenomenon is one which has received very little attention from men of science. Twinkling differs very much on different nights. Bright stars twinkle much more than faint ones; and the smallest of those visible to the naked eye may be said not to twinkle at all.

A quiescent condition of the air is unfavourable to the

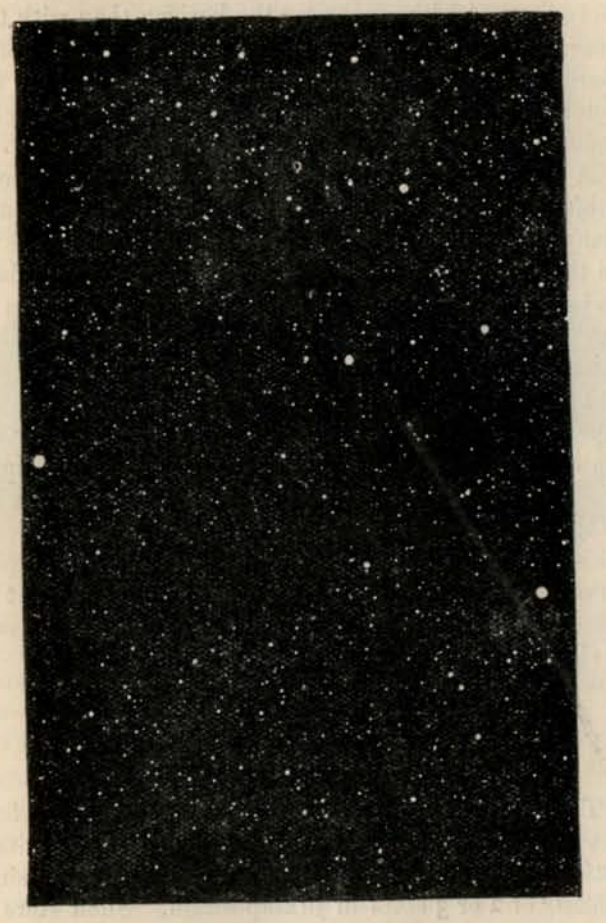


FIG. 94.—"THE STARRY HEAVENS."

manifestation of the phenomenon, which in general is more marked with stars near the horizon than with those near the zenith; and more marked at the surface of the Earth than in mountainous districts—all of which facts point out the atmosphere as probably an influential agent.

A Belgian observer, named Montigny, who made the subject of twinkling a matter of attentive study during many years, found that twinkling depended in some way on the approach of rainy weather; and also that it plainly and also systematically varied with differences in the character of the light yielded by different stars, as ascertained by the spectroscope.

The number of stars visible to the naked eye is very much less than most people imagine. Argelander estimated that the total number of stars visible belonging to the first 6 magnitudes was just about 5000, of which 3200 was the number visible for the latitude of Berlin. This would make the total number visible at one place on one night to be no more than about 2000; but the stars visible with a telescope are, in the most literal sense of the word, innumerable—simply millions.

DOUBLE STARS, ETC.

To the naked eye every star is a single point of light, but in numerous instances the application of suitable optical assistance shows that a star apparently single consists of 2 or 3 stars in juxtaposition. Such stars are termed double or triple stars. These stars are again divisible into 2 well-defined classes:—(1) those which are

"optical" doubles or triples, that is, stars casually looking as if they were near one another and motionless; and (2) those which are termed "binary" or "ternary" stars, because they not only seem near one another, but are linked to and revolve round one another under the influence of some attractive force, probably identical with that force of gravitation which links together the Sun and planets of our solar system. The discovery of binary stars was one of the many results of Sir W. Herschel's labours in the investigation of the starry heavens.

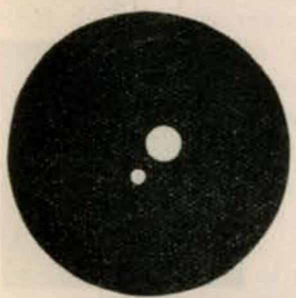


FIG. 95.—THE BINARY STAR ζ HERCULIS.

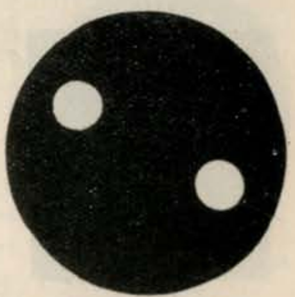
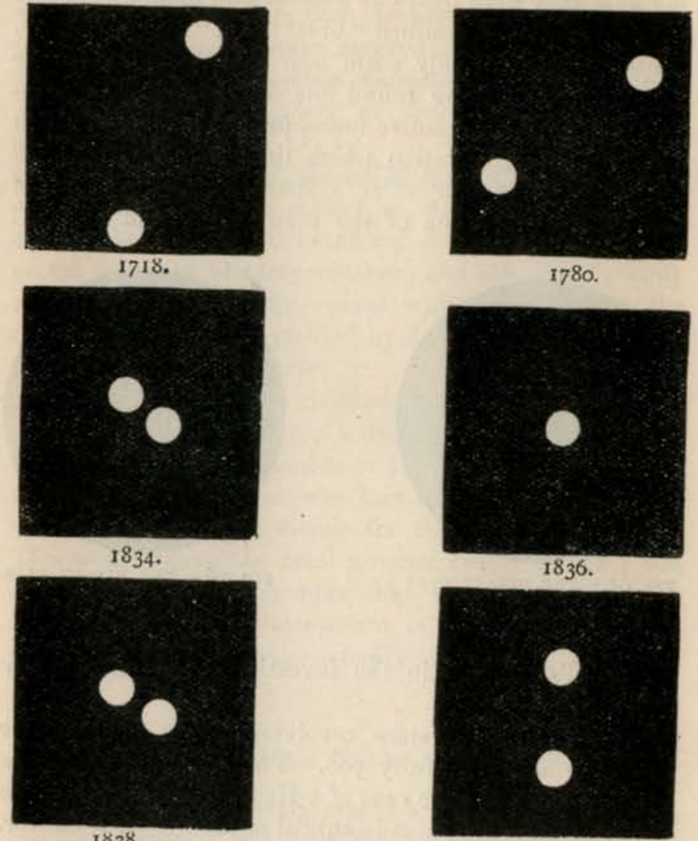


FIG. 96.—THE BINARY STAR α GEMINORUM.

The number of stars revolving round one another may now be put at fully 500. Their periods vary from about 30 years in the case of ζ Herculis to 1000 years or more. One of the most beautiful of these stars is Castor, or α Geminorum. This object is well within the reach of small telescopes, for the two components are both of them large stars (magnitudes 3 and 3½ respectively) and their distance is 5″. It has been calculated that Castor completes a revolution in about 990 years. It was first measured as a double star by Bradley and Pound in 1718.



1718. 1780.

1834. 1836.

1838. 1852.

FIG. 97.—THE BINARY STAR γ VIRGINIS AT DIFFERENT EPOCHS.

Another very remarkable binary star is γ Virginis, the components of which are both of the 4th magnitude and about 6″ apart. This star was first measured in 1718, and the changes which it underwent between 1718 and 1852 will be best understood by an inspection of the annexed diagrams. The stars gradually approached one another between 1718 and 1836, when they were so close as to be apparently one. Since then they have parted company, and their distance is now the same as it was in 1780, but the stars are reversed; that which was then the uppermost being now the lowermost. The period is evidently about 180 years.

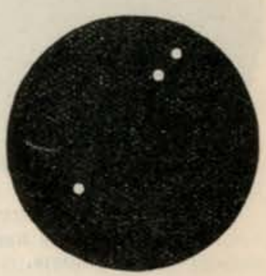


FIG. 98.—THE TRIPLE STAR ζ CANCRI.

The triple stars are naturally not by any means so numerous as the double stars. Amongst the most interesting of them may be mentioned 11 Monocerotis, ζ Cancri, γ Andromedæ, and 51 Libræ. In the case of ζ Cancri, it appears certain that whilst the two larger stars (which are of magnitudes 6 and 7) revolve round each other in about 58 years, they both, with the 3rd, which is of magnitude 7½, revolve round their common centre of gravity in a much longer time; 500 or more years. Whilst 11 Monocerotis very much resembles ζ Cancri in the size and distance of its component stars, it differs therefrom in the fact that, notwithstanding the appearance which it suggests of connection between the stars, seemingly there is no connection, or at least no motion.

In ε Lyræ we have a striking instance of a double-double, which makes therefore a quadruple star. It would seem that the two stars in each pair revolve round one another, and the two pairs revolve round their common centre of gravity, forming therefore an exceedingly complex system. The 4 stars of ε Lyræ being all of good size (about magnitude 5) and wide apart, the group may easily be seen with a small telescope.

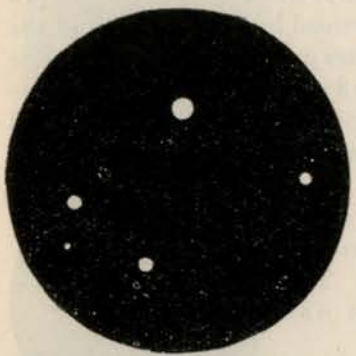


FIG. 99.—THE TRAPEZIUM IN ORION, OTHERWISE KNOWN AS θ ORIONIS.

In θ Orionis we have what is first of all visible as a quadruple star, but as a telescope of sufficient power discloses two other stars the group is really to be described as a sextuple one. It appears, however, to be fixed.

COLOURED STARS.

Many stars exhibit distinct tinges of colour. Isolated orange or red stars are very common, but isolated blue or green stars are very rare. In the case, however, of double stars a much greater variety is noticeable in the matter of colour. Combinations of yellow (or orange) and blue are frequent; and in many instances a greenish hue takes the place of the blue where the principal star is yellow or orange. Many stars exhibit, therefore, complementary colours. In such cases, if there is much disparity in the size of the components, very likely the fact that the colours are complementary is merely an effect of contrast. Yet it cannot be doubted that in many instances there are stars, double or otherwise, which actually emit light of definite colour. Supposing there should be planets revolving round these stars regarded as suns, the light imparted to such planets would have a very striking and beautiful effect, analogous to that which we sometimes see in drawing-rooms, where all the gas-jets or candles, as the case may be, are hid within globes of crimson or other hues.

The following are examples of isolated stars which are both large in size and of decided colour:—

White stars.—α Canis Majoris, α Leonis, β Leonis, 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 Lyræ, α Aquilæ, α Cygni.
Yellow star.—α Boötis.

VARIABLE STARS.

A consideration of the colours of stars leads us on to a subject of great interest and importance, and which has undergone much development of late years. I am referring to "Variable" stars. It has been found that a large number of stars which are orange or red in colour are also variable; although, of course, on the other hand, it must be admitted that there exist many stars which are variable, but which are neither red, nor, indeed, coloured at all. A variable star may be defined to be a star which looked at casually would be said to be of a certain magnitude. If, however, the observer recurs to the star after an interval of a few weeks, or a few months, he will find that it is brighter or fainter than before. Observations sufficiently prolonged, and made with sufficient care, will disclose the fact that this star is subject to periodical changes of brilliancy at stated intervals of time. The period may be either no more than 2 or 3 days, or as many months, or 2 or 3 years. No distinct clue has been obtained to the causes of the increase and decrease which thus takes place in the light of the stars which are catalogued as variable stars, and which now are fully 300 in number. Two theories have been put forth, either of which may be said to be possible; at least they would explain the observed facts:—(1) That around the stars which are found to be variable there revolve opaque bodies, which may be properly termed satellites, and which at certain times intercept a portion of the light transmitted by the star to the Earth; such a condition of things would virtually resemble what takes place when our Sun is eclipsed by the Moon. (2) The second theory is that a variable star is a body which rotates on its axis, and is more luminous at one part of its surface than at another. Hence the light yielded by the star would be greater at one time than at another time.

Fortunately for the general reader it happens that some of the most striking and remarkable of the variable stars are visible to the naked eye. The following is a selection of these:—

Name.	Period days.	Changes of magnitude.
β Persei . .	2·8 . .	2¼ to 3½
δ Cephei . .	5·3 . .	3½ to 4½
η Aquilæ . .	7·2 . .	3½ to 4½
β Lyræ . .	12·9 . .	3½ to 4½
α Herculis . .	88·5 . .	3 to 4
ο Ceti . .	330·0 . .	2 to 0

Algol or β Persei is one of the shortest period variable stars known, and its position in the heavens, coupled with the range of its variability, renders it one particularly worthy of the attention of the amateur astronomer resident in England. It is commonly of the 2nd magnitude: from that it descends to the 4th magnitude in about 3½ hours, where it remains for about 20 minutes; after another period of about 3½ hours it again reaches the 2nd magnitude, at which it remains for 2 days, 13 hours, when the changes recur as before. The variability of this star was discovered as far back as 1669 by Montanari.

δ Cephei occupies a position in the heavens which permits of it being frequently observed in England. The interval between maximum and minimum (3 days, 19 hours) is greater than that between minimum and maximum (1 day, 14 hours).

One of the most remarkable variables known is ο Ceti, often called "Mira," or the "wonderful" star, in Cetus. Its variability was first noticed by David Fabricius as far back as 1596. Mira appears about 12 times in 11 years; whence it follows that its period is about 331 days. It remains at its greatest brilliancy for about a fortnight, when it sometimes reaches the 2nd magnitude. It decreases during about 3 months till it becomes totally invisible; remains invisible for about 5 months, and then during the next following 3 months it gradually regains the stage of maximum brilliancy. The average duration of the naked eye visibility of Mira is about 18 weeks, but it has been known to remain visible for as long a time as 21 weeks, and for as short a time as 12 weeks.

Of late years much attention has been paid to variable stars, and a large body of new facts concerning them has been brought to light. One of the most noticeable of these facts is that variable stars are not scattered promiscuously over the heavens, but are much more abundant in certain regions than in others. It would also seem that a very large number of them, which are of large size, and white or red in colour, have periods less than 70 days; whilst another group which have periods of more than 135 days are chiefly red in colour and small in size.

Possibly somewhat similar in character to the variable stars are certain objects which have been from time to time seen, and which are commonly designated "temporary" stars. These are stars which suddenly blaze out, and after a time fade away. Pliny tells us that it was the appearance of a star of this kind which induced Hipparchus to construct his, the first, catalogue of stars. This statement was once regarded as a fiction, but within the last few years it has been found out that the Chinese Chronicles record a new star in Scorpio in 134 B.C., and there appears now no longer any reason for doubting Pliny's statement. One of the most celebrated temporary stars on record seems to have been that of 1572, a full account of which has been handed down to us by Tycho Brahe. It lasted from November, 1572, to March, 1574. It was brighter than Sirius, and rivalled Venus. Its colour was successively white, yellow, red, and white again. The subsequent history of this star is in one sense unknown. There were no telescopes in those days, and the star disappeared altogether so far as the naked eye was concerned; yet there exists at this very moment within 1′ of the place assigned by Argelander to Tycho's star a small star sensibly variable in its light.

Temporary stars of considerable brilliancy shone forth in 1604 in the constellation Ophiuchus; in 1670 in Cygnus; in 1848 in Ophiuchus; in 1866 in Corona Borealis; in 1876 in Cygnus; and in 1885 in Andromeda.

The temporary star of 1876, discovered on November 24 of that year by Schmidt, at Athens, was then of the 3rd magnitude; but between that date and the end of December it dwindled down to the 7th magnitude.

The temporary star which blazed forth in Corona Borealis, in May, 1866, was even more remarkable. It had been recorded by Argelander, in 1855, as being of magnitude 9½, yet on May 12, 1866, it was found by Birmingham at Tuam shining as a 2nd magnitude star. Putting together certain observations by Schmidt of Athens, and by Birmingham, it would seem that this star rose from the 4th to the 2nd magnitude in about 3 hours on the day in question. It soon began to fade away, and continued no brighter than the 9th magnitude all through the following summer. It rose, however, to magnitude 7½ in September, and has fluctuated apparently between that and magnitude 9½ ever since. It is now included amongst the recognized variables, though its period and the extent of the fluctuations of its light are unknown.

CHAPTER XII.

CLUSTERS AND NEBULÆ.

WE have successively advanced from the single stars to double stars, and from double stars to multiple stars. The next stage will bring us to further combinations of stars forming what are called "Clusters," and from these we shall get to "Nebulæ," some of which appear to be clusters of stars whilst others are something else.

Clusters must of course be regarded as essentially telescopic objects, but there are a few which are visible to the naked eye. It may be said in particular that in the northern hemisphere there are 3 such clusters, the "Pleiades" and the "Hyades" in Taurus, and "Præsepe" in Cancer. In the southern hemisphere we find 2 large objects of stellar character, respectively called the "Nubecula Major" and "Nubecula Minor," or sometimes the "Magellanic Clouds." In that hemisphere there is also the fine cluster surrounding the star ω Centauri. Besides these, there can also be seen with the naked eye the "great nebula in Andromeda" and the "great nebula in Orion," and perhaps a few others.

Of all the objects just enumerated probably the Pleiades is the most celebrated and best known. When looked at directly few persons can see more than 6 stars, but by turning the eye sideways more, perhaps a dozen, may be detected. An ordinary telescope will reveal 50 or more. Of course the number increases as a larger telescope is used, and photography has recorded as many as 1400 stars in the Pleiades. The most brilliant star in the group is "Alcyone" of the 3rd magnitude; next in order come "Electra" and "Atlas" of the 4th; "Maia" and "Taygeta" of the 5th; "Pleione" and "Celeno," which are between the 6th and 7th; and "Asterope," which is a small 7th magnitude star. The remainder are telescopic for all ordinary eyes.

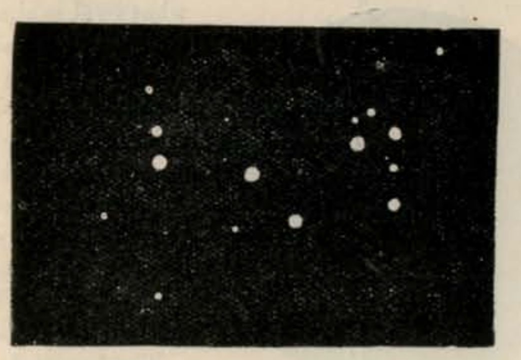


FIG. 100.—THE PLEIADES AS SEEN WITH SLIGHT OPTICAL ASSISTANCE.

The "Hyades" form a group altogether much less interesting, because the stars are too scattered to make a good telescopic field.

"Præsepe" used to be called the "Bee-hive," and is a particularly good object for a small telescope. It is an aggregation of small stars which had long borne the name of a nebula, because the component stars could not be separately seen with the naked eye.

The constellation Coma Berenicis comprises a group of somewhat large and scattered stars, which, if we could view them at a sufficient distance, would evidently appear to us as a nebula.

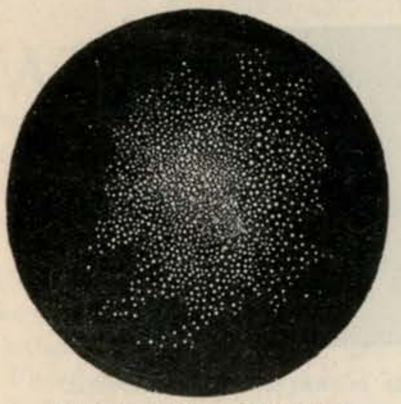


FIG. 101.—THE CLUSTER 13 M HERCULIS.

The "Nubecula Major" is in the constellation Dorado, and the "Nubecula Minor" in Toucan; both are somewhat oval in shape, and visible to the naked eye in the absence of the moon, but the smaller object disappears in strong moonlight. Sir J. Herschel described these objects as consisting of swarms of stars, clusters, and nebulæ of every description.

The line of demarcation between clusters and nebulæ is naturally not very sharply defined. The term "Cluster" may be said to be applied to coarse groups of stars, the individual members of which are easily recognized with ordinary telescopes. A nebula, on the other hand, is a densely compacted mass of small stars, which either cannot be separately distinguished at all, or only with extreme difficulty, and by the use of telescopes of great size. Moreover, the spectroscope suggests that some of the irresolvable nebulæ are not stellar at all, and never could be resolved into separate stars however great the optical power brought to bear on them.

Many of the ordinary clusters affect a globular shape, and amongst these are some of the largest, the names and positions of which are given in the following table:—

Name.	R.A.	Decl.
	h. m. s.	° ′
47 Toucani	0 19 9	−72 41
33 H VI. Persei	2 11 20	+56 38
ω Centauri	13 20 10	−46 44
3 M. Canum Venaticorum	13 37 3	+28 55
5 M. Libræ	15 12 57	+ 2 30
80 M. Scorpii	16 10 26	−22 43
13 M. Herculis	16 37 45	+36 40
92 M. Herculis	17 13 46	+43 15
22 M. Sagittarii . . .	18 29 28	−23 59
2 M. Aquarii	21 27 44	− 1 19

The nebulæ, properly so called, may be divided into 6 classes, as follows:—

(1) Annular nebulæ.
(2) Elliptic nebulæ.
(3) Spiral nebulæ.
(4) Planetary nebulæ.
(5) Nebulous stars.
(6) Large nebulæ of irregular form.

Of annular nebulæ there are scarcely a dozen in the whole heavens. The most remarkable one is Messier's

57th, which is situated about midway between β and γ Lyræ. It is large enough to be seen with a telescope of moderate power, but the peculiar details of its structure can only be traced with a very large telescope. Sir J. Herschel described it as "small and particularly well defined, so as to have more the appearance of a flat, oval solid ring, than of a nebulæ. The axes of the ellipse are to each other in the proportion of about 4 to 5, and the opening occupies about half, or rather more than half, the diameter. The central vacuity is not quite dark, but is filled in with faint nebula, like a gauze stretched over a hoop."


FIG. 102.—THE ANNULAR NEBULÆ IN LYRA.

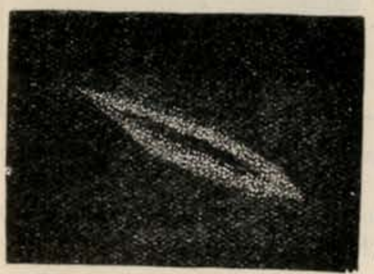


FIG. 103.—OBLIQUE RING NEBULA, 4058 H. DRACONIS (EARL OF ROSSE).

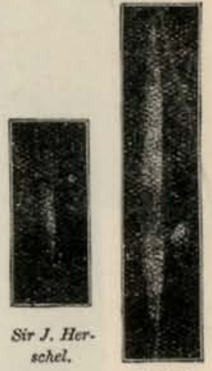
Elliptic nebulæ of various degrees of eccentricity are not uncommon. The "great nebula in Andromeda" is the largest and best known of these. Its ellipticity is considerable, and it has a bright central condensation sufficient to make it visible to the naked eye. A drawing by Bond, and photographs by Roberts, give indications of long rifts or channels in this nebulæ, of which no traces are to be found in Sir John Herschel's well-known engraving.

Fig. 103 represents a nebula which is simply elliptic, as it appears at the first glance, but which undoubtedly conveys the idea that the observer is looking at a foreshortened ring of nebulous matter.

Fig. 104 represents a bright and very much extended nebula found by Sir W. Herschel, and drawn by his son, and by the Earl of Rosse.

We owe the discovery of "Spiral" or "Whirlpool" nebulæ to the Earl of Rosse, and it may be said that only telescopes like his are capable of disclosing the spiral character of these objects.

The best known is Messier's 51st in the constellation Canes Venatici. To Admiral Smyth it presented the appearance of 2 detached circular patches of light, the larger of which had some nebulous fragments partly surrounding it. Sir John Herschel, seeing the circular patches very much as Smyth did, converted the outlying fragments into a complete ring, with an exterior appendage. Lord Rosse's telescope joined Smyth's two patches and Herschel's ring into one connected mass of nebulous matter, the whole taking the spiral form shown in Fig. 106.


Sir J. Herschel.

Earl of Rosse.

FIG. 104.—NEBULA, 42 ♅ V. COMÆ BERENICIS.

"Planetary" nebulæ derive their name from the fact that they are circular in form and with edges more or less sharply defined, which give them therefore somewhat the form of a faint planet, such as Uranus or Neptune. One of these objects, known as 37 ♅ IV. Draconis, yielded to Huggins a gaseous spectrum. Holden describes it as apparently composed of rings overlying each other, and he says it is difficult to resist the conviction that these are arranged in Space in the form of a true helix.

There are some peculiarities attaching to planetary nebulæ which would seem to be significant of something which we do not yet understand. In the first place they are, according to the spectroscope, mostly gaseous, and several are noticeably of a blue tinge. Three-fourths of those known are in the southern hemisphere. As regards the gaseous nebulæ, whether planetary or not, it was pointed out by D'Arrest in 1872 that nearly all of them are either in or very close to the Milky Way.

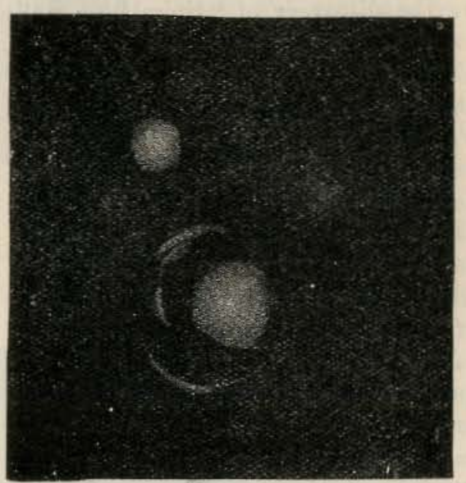


FIG. 105.—THE SPIRAL NEBULA, 51 M. CANUM VENATICORUM (SMYTH).

Nebulous stars are distinct stars surrounded by a faint nebulosity, usually of a circular form, and sometimes several minutes of arc in diameter. The best known nebulous star (and there are only a few of them) is ι Orionis.

We come now to the last division of nebulæ, those which are large in size and irregular in form. The following is a list of some of these :—

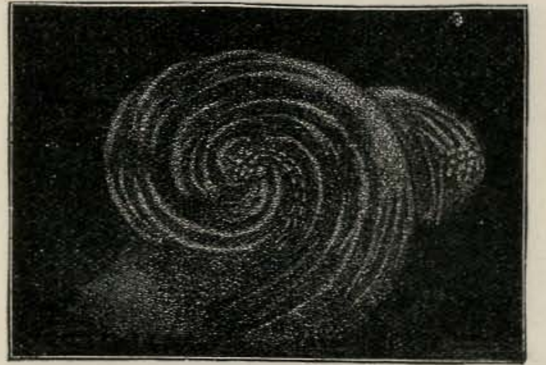


FIG. 106.—THE SPIRAL NEBULA, 51 M. CANUM VENATICORUM (EARL OF ROSSE).

Name.	R.A.	Decl.
	h. m. s.	° '
1 M. Tauri . . .	5 27 51	+21 56
42 M. Orionis . . .	5 29 52	− 5 27
30 Doradûs	5 39 9	−69 9
η Argûs	10 40 47	−59 6
20 M. Sagittarii . .	17 55 41	−23 2
8 M. Sagittarii . . .	17 57 8	−24 22
17 M. Scuti Sobieskii	18 14 16	−16 15
27 M. Vulpeculæ . .	19 54 48	+22 25

The nebula I M. Tauri is popularly known as the "Crab" nebulæ in Taurus, and Fig. 107 is a rough representation of the original description on which its common

FIG. 107.—THE "CRAB" NEBULA IN TAURUS.

name is based; but according to the observations published by the present Earl of Rosse the claw features so prominent in this engraving are non-existent. In telescopes

FIG. 108.—THE GREAT NEBULA IN ORION.

generally this nebula exhibits no more than a simple oval outline.

The great nebula in Orion may be regarded as the largest and finest of all the nebulæ in the heavens. It not only shows as such in every small telescope, but there seem grounds for supposing that it extends in all

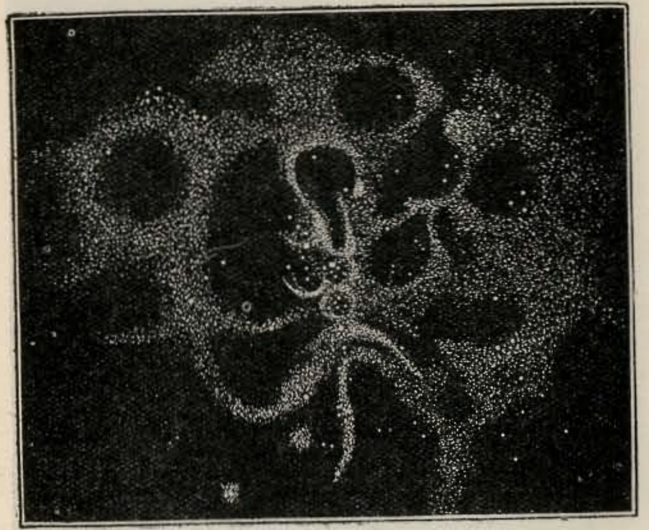


FIG. 109.—THE NEBULA 30 DORADÛS.

directions far away from the principal and most obvious patch of nebulous matter. The star ε in the belt of Orion was thought by Sir John Herschel to be surrounded by nebulous matter which was an off-shoot from the great nebula. Whether or not ε can actually be deemed a nebulous star is doubtful, but there can be no doubt of the extensive ramifications of the great nebula itself.

Independently of the actual nebulosity, this nebula contains within its limits the striking multiple star θ Orionis, described on a previous page.

The two next objects in the list, 30 Doradûs and η Argûs, both belong to the southern hemisphere, and are both very large and extraordinary objects. The central

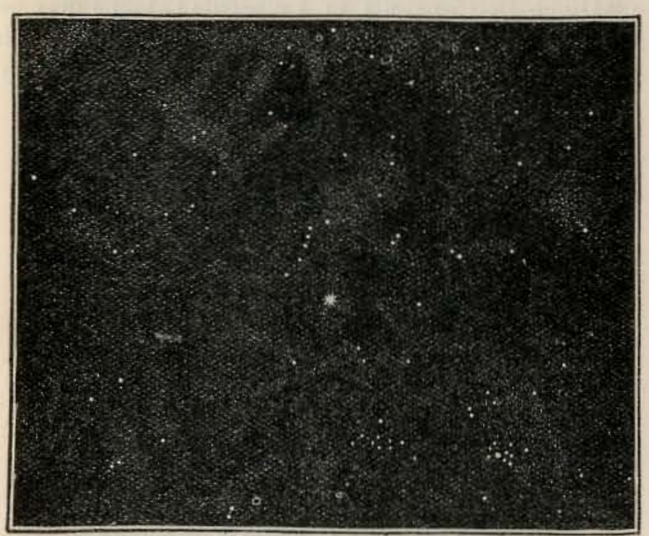


FIG. 110.—THE NEBULA SURROUNDING η ARGÛS.

feature of the great nebula in Argo is the star η, which is a variable, changing from the 1st to the 6th or 7th magnitude during a period which is very uncertain, but which may be about 70 years. Though the period and circumstances of this star are not clearly understood, there can be no doubt whatever that it is variable. It should here be added that some years ago a warm controversy arose as to whether the nebula as a whole was not variable both in brightness and shape. Though the arguments adduced emanated from two observers, the preponderance of the evidence was distinctly in the negative.

The "Horseshoe" nebula, 17 M. Scuti Sobieskii, and the "Dumb-Bell" nebula in Vulpecula (27 M.) may be mentioned as two objects of remarkable shape, both visible as mere nebulæ in small telescopes, though very large ones indeed are required to bring out the striking details from which these objects have received their names. The former may be said to resemble in an ordinary telescope a swan without legs, but under great optical power the whole object developes into the figure of two capital Greek omegas connected at their bases. The "Dumb-Bell" nebula fairly answers to its name in small telescopes, but this feature disappears in very large instruments, such as Lord Rosse's, the great power of

FIG. 111.—THE "DUMB-BELL" NEBULA (SIR J. HERSCHEL).

which destroys the symmetrical outlines which are visible in smaller instruments.

A curious feature about the clusters and nebulæ is their unequal distribution in the heavens. They are

FIG. 112.—THE "DUMB-BELL" NEBULA (EARL OF ROSSE, 3-FT. REFLECTOR).

especially abundant in a zone which crosses the Milky Way at right angles; and the constellation Virgo in particular is rich in them. Taking the 5079 objects catalogued in 1864 by Sir J. Herschel, it will be found that whilst Hour XIX. comprises only 79 objects, Hour XII., which includes the constellation Virgo, contains 686.

The first observer who systematically searched for and recorded clusters and nebulæ was the French astronomer Messier. Practically the whole of the more conspicuous of these bodies were included in his well-known though small catalogue of 103 nebulæ published in 1784. But it was Sir William Herschel, and after him Sir John Herschel, who must be regarded as the great discoverers of clusters and nebulæ. Many of the objects which they found were afterwards critically examined by the late Earl of Rosse, and by his son, the present Earl. Hence the numerous references which occur in books on Astronomy to the Rosse telescopes and observations. Sir W. Herschel divided all his nebulæ into 8 classes, and these classes are still recognized, and are indicated by a combined symbol, thus :—45 ♅ IV. Geminorum, which means the 45th object in the 8th class, and which is to be found in the constellation Gemini.

It has already been explained that a certain considerable number of stars undergo fluctuations of light, in virtue of which we call them "variable" stars. It was at one time thought that a few nebulæ had been found variable, but it cannot now be said that the available evidence is sufficient to support the assertion.

There yet remains for our consideration the largest and most interesting cluster in the heavens. This is best known as the Milky Way, but it has received amongst different peoples at different times a variety of fanciful names, many of them by the way involving some associations with spilt milk! Of these various appellations the one of Greek origin, "Galaxy," itself the parent of the term Milky Way, is the only one which may be said to be in use now as an alternative designation.

The Milky Way is a luminous zone, of a whitish hue, and with irregular edges, which divides the celestial sphere into two nearly equal parts. It marks on that sphere almost a great circle. But a bifurcation commences at a certain point, whence there results a secondary arc, which, remaining separated from the principal arc through an angular extent of about 120°, then rejoins the main circle. The breadth of this zone varies between 5° and 16°; but where the 2 streams are found, their joint breadth over all exceeds 22°. Sir W. Herschel regarded the Milky Way as composed of an immense number of stars, which to the naked eye appeared as nebulous matter, but which with a telescope could be separated into individual stars. This part of the heavens may, therefore, be looked upon as a gigantic resolvable nebula, in or near the centre of which our Sun is located. Herschel regarded the stars of the Milky Way as placed at tolerably equal distances from one another, and form-

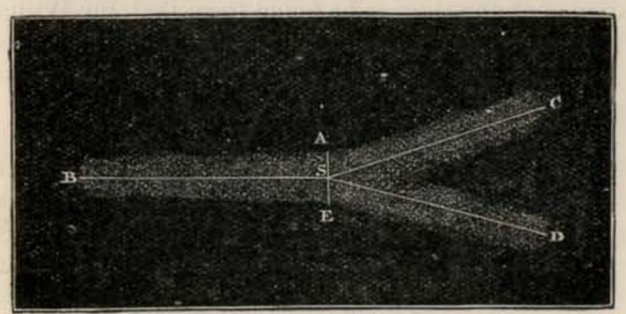


FIG. 113.—HERSCHEL'S "STRATUM THEORY" OF THE MILKY WAY.

ing a bed or stratum included between 2 nearly plane surfaces, more or less parallel, but extending in either direction to an immense distance. This so-called stratum, having the general form of a mill-stone, is comparatively thin, having regard to the infinite distances to which the 2 plane surfaces which bound it extend.

It is obvious that speculations on such a matter as this cannot under the best of circumstances be very profitable; but it was from considerations based upon the distribution of the stars as he found them that Sir William Herschel was led to regard the starry heavens as disposed in a fashion of which it has been thought that the annexed diagram would convey some general idea.

S is intended to represent the Sun (or the Earth), occupying a place somewhere near the middle of the starry stratum, and near the point where it subdivides into 2 principal streams inclined to each other at a small angle. To an eye viewing the stars from S, and looking in the direction S A or S E, they would appear to be comparatively few in number; but they would rapidly increase as the line of vision was brought round on either side from S A towards S B, or from S A towards S C. In the directions S B, S C, and S D, the stars would appear to be most densely crowded; points intermediate between, say, S A and S C, yielding stars of intermediate but gradually increasing degrees of density. Sir W. Herschel's "Stratum Theory of the Milky Way," as it has been called, has often excited controversy and discussion; and how far it ought to be accepted is still a moot point.

With respect to the number of the stars visible in the Milky Way, whilst all estimates must necessarily be hazardous and incapable of proper proof, yet it may here be stated, illustratively, that on one occasion Sir W. Herschel calculated that 116,000 stars passed through the field of his telescope in ¼ hour; and, on another occasion, 258,000 stars in 41 minutes. Consideration of facts such as these led him to set down the number of the stars in the Milky Way at 50 millions or more.

CHAPTER XIII.

TELESCOPES.

THE telescopes used by astronomers are of 2 kinds as regards the optical principles of their construction, whilst the stands upon which they are mounted may be ranged under several heads.

A telescope, regarded as an optical instrument, may be either a refractor or a reflector. In the former the image of the object to be looked at is produced by a converging lens of glass, which brings the object to a point called the "focus," where it is magnified by a subsidiary lens, called the eye-lens, which acts as a simple magnifying glass. In a reflecting telescope the rays of light coming from the object viewed are gathered together by a concave reflector, instead of being collected by a convex lens, as in a refractor. The image formed by the reflector is, however, magnified by a magnifying glass as before.

The foregoing account deals only with the general optical principles involved in these 2 classes of telescopes; but the time has long since gone by for telescopes to be constructed in the simple fashion just described. It is, however, in the case of the refractors that the greatest alteration has taken place. The simple object-glass of one double convex lens is now replaced by a compound object-glass formed of 2 lenses, one a double convex lens, and the other a double concave lens; whilst the simple magnifying glass is replaced by a combination of several lenses, forming together what is called an "eye-piece," but which may really be regarded as in some sense a microscope. There has, however, been no corresponding developement in the *principle* of the reflecting telescope, which remains almost exactly where it was 200 years ago, except that it also now has a compound eye-piece, instead of the simple eye-lens formerly used.

Whilst a refracting telescope can, indeed, be made with as few as 2 pieces of glass, called lenses, yet such an instrument is not suitable for astronomical purposes. The image formed by the largest and principal lens does not come to a sharp focus; the focus given by the centre of the lens does not exactly coincide with that given by the edges. Hence there results an irregularity, which is called the "spherical aberration." Moreover, the image is not colourless; hence another inconvenience, called the "chromatic aberration." Opticians and astronomers were long in despair as to how they could get over these annoyances which hindered the construction of achromatic telescopes of sizes likely to lead to new astronomical discoveries; but about the year 1758 a London optician named Dollond, by examining various sorts of glass, found that different kinds dispersed the colours of the spectrum differently; and the idea entered his head that, by using 2 different sorts of glass, as it were playing the one off against the other, he could neutralise the shortcomings of both. From this simple conception great results flowed, and the way was paved for the construction of those large telescopes of which we hear so much in these days. The refracting telescope appears to have been invented in Holland about the year 1610, though much controversy has arisen on the point, and Galileo has some claims to be regarded as an independent inventor. Galileo's optical efforts, however, were of a very modest character, and he seems to have done no more than con-

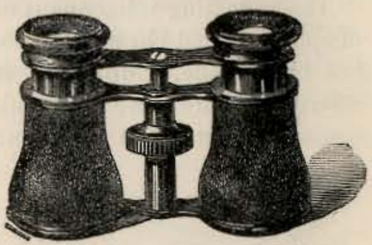


FIG. 114.—THE GALILEAN OPERA-GLASS.

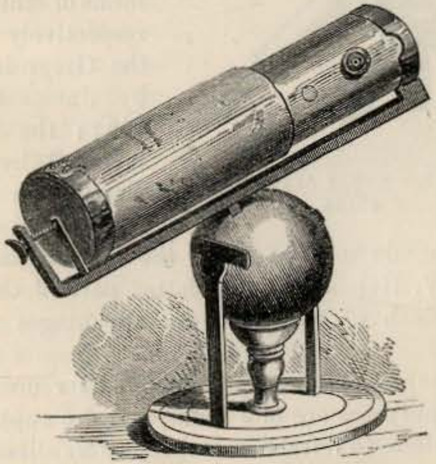


FIG. 115.—REFLECTING TELESCOPE.

struct what we should call a single tube opera-glass. The common opera-glass now in use is simply a pair of Galilean telescopes.

The reflecting telescope is exempt from the drawbacks of spherical and chromatic aberration to which reference has been made. Moreover, in their larger sizes, these instruments are more easy and, therefore, more cheap to construct; hence the preference given to them by some observers. But, on the other hand, they are much less convenient to work with than refractors.

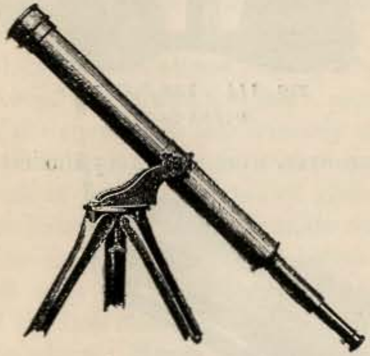


FIG. 116.—SIMPLE ALTAZIMUTH STAND.

There are 4 principal forms of reflectors in use, respectively known as the Gregorian, invented by James Gregory in 1663; the Newtonian, invented by Sir Isaac Newton in 1669; the Cassegrainian, invented by Cassegrain in 1672; and the Herschelian, invented by Sir W. Herschel in the latter part of the last century. Each of these has its advantages and disadvantages.

The stands of telescopes intended for ordinary astronomical purposes are of 2 kinds, and are applicable, with modifications, to refractors and reflectors alike. The most simple stand is that which permits of the telescope having 2 motions imparted to it; an up and down motion, technically called motion in "altitude," and a right and left motion in a horizontal direction, technically called motion in "azimuth."

A telescope mounted on such a stand, and which is often called an Altazimuth stand, whilst it is suitable enough when the telescope is used for terrestrial purposes, is not convenient for astronomical purposes in following objects which are incessantly in motion. From what has been explained in a previous chapter with respect to the apparent movements of the stars across the heavens, it will be understood that whilst they are travelling across the sky in virtue of the Diurnal Movement, they are also constantly changing their altitudes above the horizon. Nevertheless their actual motion is in a single direction; and therefore they cannot be followed with a telescope mounted on an Altazimuth stand unless the observer incessantly imparts to his telescope both motion in a horizontal direction from east to west, and motion up and down from south to north, or from north to south, as the case may be. To be perpetually pushing a telescope in two directions, and with such evenness as always to keep a planet or star in the centre of the field, is a matter of extreme difficulty, and so distracts the observer in trying

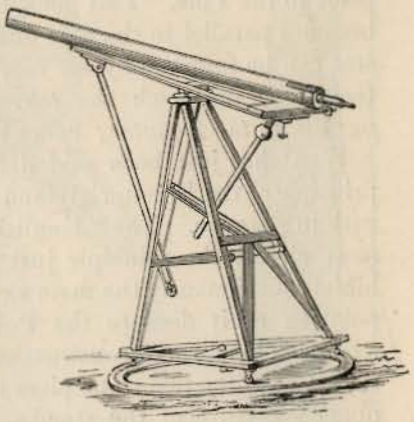


FIG. 117.—A "VARLEY" STAND.

to make his observations that for star-gazing purposes an Altazimuth telescope is well-nigh intolerable.

The remedy for this is in a form of mounting called the "Equatorial," in which matters are so arranged that it is only necessary to impart to the telescope an impulse in one direction when the telescope can be made to follow the object continuously. In the Equatorial stand the vertical axis of the Altazimuth is tilted over so as to point to the Pole. This done, the axis which was vertical becomes parallel to the axis of the Earth, and so a given star can be followed by one movement, in virtue of which the plane in which the *telescope* moves is constantly *parallel to the Equator;* hence the origin of the name.

What has just been said defines in a few words the principle of the Equatorial stand; but 2 forms of it are met with in practice. The "English" Equatorial brings out most clearly the principle just unfolded, because it exhibits conspicuously the main axis of the telescope, which, pointing as it does to the Pole, is called the "Polar axis." This form of construction is open to the objection that it requires two stone piers to be built to receive the upper structure of the stand. In the German form of mounting, which is represented in Fig. 121, one pier only is needed, the working parts of the stand being concentrated in a way which not only saves materials and weight, but considerably facilitates the use of the instrument.

Fig. 118 represents an English Equatorial in its simplest form; *a b* is the polar axis supported on the piers *h* and *i*, the curved portion of *i* being generally of iron. The motion in altitude of the telescope is obtained by its being made to turn on an axis called the "Declination Axis,"

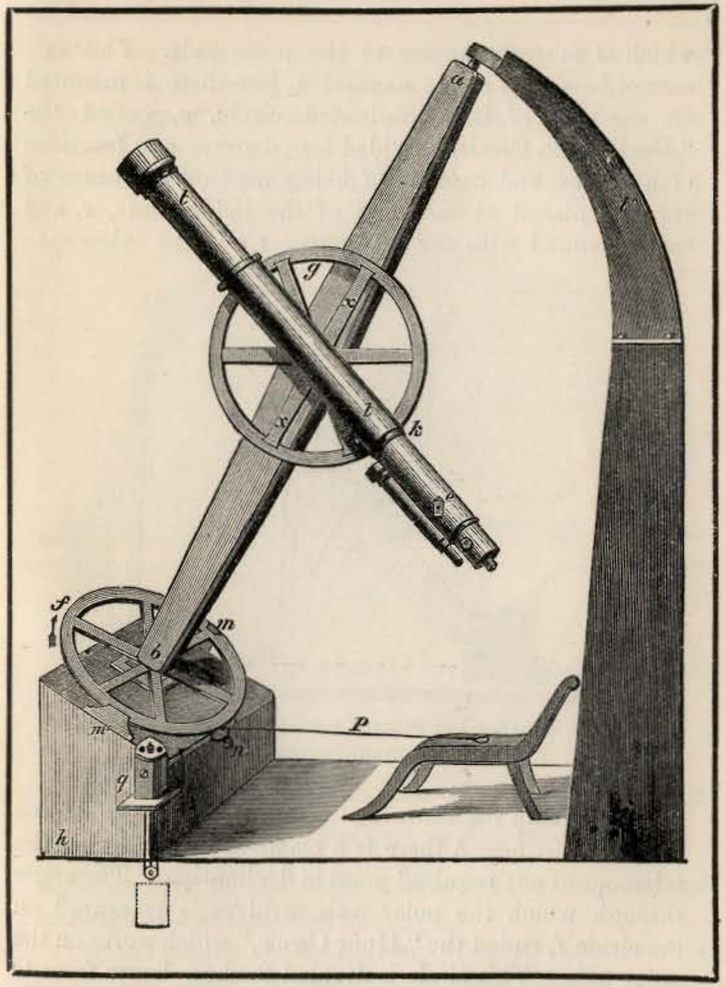


FIG. 118.—AN "ENGLISH" EQUATORIAL.

which is at right angles to the polar axis. This axis cannot be shown in the engraving, but there is mounted on one end of it a graduated circle, *g*, called the "Declination Circle," divided into degrees and fractions of a degree, and capable of being read off by means of verniers placed at each end of the index plate, *x*, and carried round with the telescope. *t t* is the telescope; *e* a little lamp for throwing light into the inside of the tube; whilst near *k* there is a clamp-screw for fixing the telescope at any required point in declination. The angle through which the polar axis revolves is measured on the circle *f*, called the "Hour Circle," which works on the polar axis. This circle is divided to show hours from O to XXIV, and is sub-divided again into minutes of time, which can be further sub-divided by verniers at *m* and *m*.

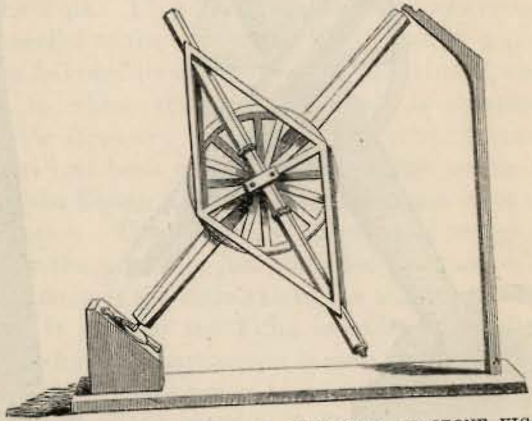


FIG. 119.—ENGLISH EQUATORIAL FORMERLY AT STONE VICARAGE, BUCKINGHAMSHIRE.

By the aid of clockwork, *q*, the observer having found the object he is in search of can cause motion to be imparted to the telescope, his hands being thereby set free. Or when he does not require to push the telescope through any considerable arc, he can by the handle, *p*, impart a slight motion to the whole instrument by means of an endless screw mounted at *n*.

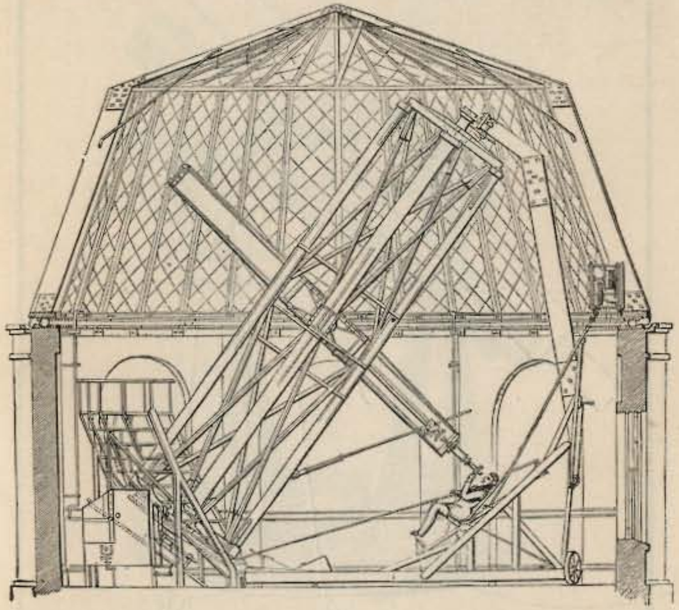


FIG. 120.—THE "NORTHUMBERLAND" EQUATORIAL AT CAMBRIDGE.

Fig. 121 represents the ordinary German Equatorial in its simplest form. A detailed description would occupy more space than can here be given to it. Suffice it then to say that *a* is the Polar axis, *b* the Hour circle attached

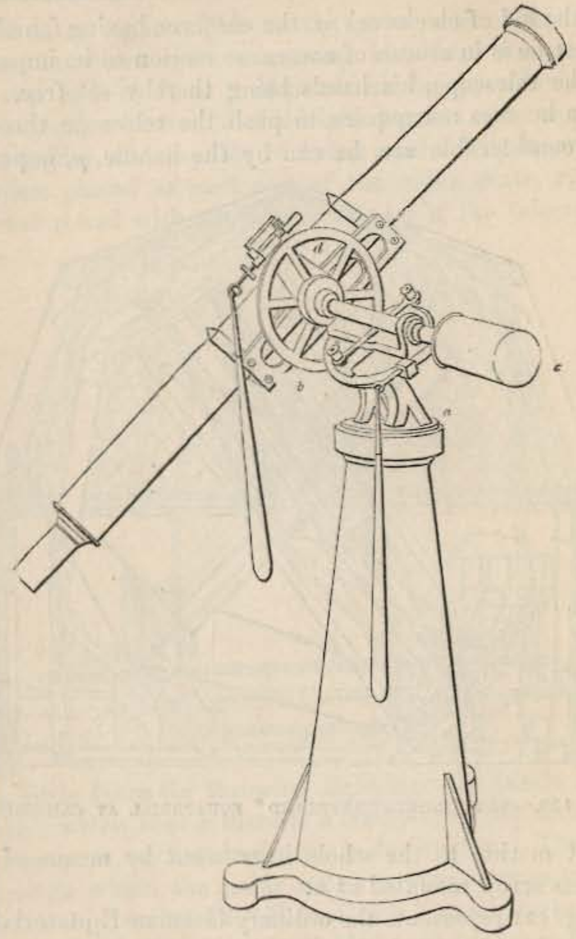


FIG. 121.—A GERMAN EQUATORIAL.

thereto, *c* the Declination axis, and *d* the Declination circle.

A few words must now be said about certain other astronomical instruments, which are telescopes, generally of small size, and mounted in different ways according to the purposes for which they are intended to be used.

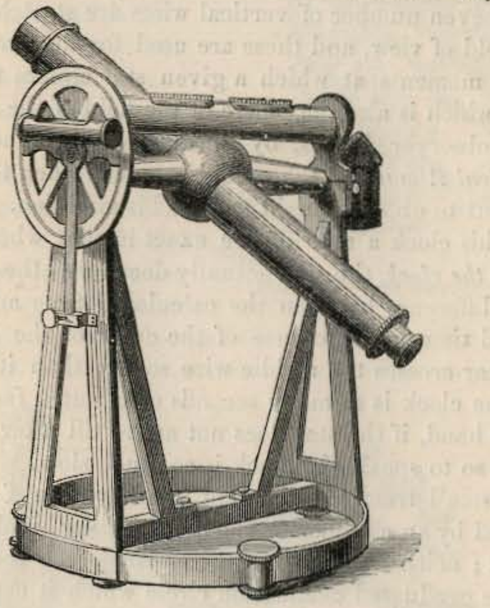


FIG. 122.—THE PORTABLE TRANSIT INSTRUMENT.

Of these miscellaneous instruments, the one most commonly met with is the Transit Instrument, the simplest form of which is represented in Fig. 122. The smaller sizes are used astronomically for no other purpose than that of taking the time. The telescope itself is mounted on trunnions, not unlike in appearance the trunnions of a heavy gun. The telescope is accurately placed in the meridian, and having no azimuthal movement, can only move in one way, that is, in altitude, or up and down. An uneven number of vertical wires are stretched across the field of view, and these are used for determining the exact moments at which a given star crosses the centre wire, which is also the centre of the field of the telescope. The observer knows, by information furnished in his *Nautical Almanack*, the precise moment when the star he is about to observe ought to cross his meridian. He takes from his clock a note of the exact instant when, *according to the clock*, the star actually does cross the meridian. The difference between the calculated time and the observed time is a measure of the error of the clock. If the star crosses the middle wire sooner than it ought to do, the clock is so many seconds or minutes fast; on the other hand, if the star does not arrive till after its proper time, so to speak, the clock is so much slow.

A small transit instrument, costing from £10 to £30 is used by an astronomer solely for setting his observatory clock; neither the size of the telescope nor the accuracy of the graduated declination circle which it carries being sufficient for exact measurements of angular distances for the determination of the places of stars. But large transit instruments, entirely identical in principle with the small ones just spoken of, and costing many hundreds of pounds, are employed in large observatories for refined and exact observations of the Right Ascensions and Declinations of stars of various magnitudes. Such instruments in their most perfected forms are generally called "Transit Circles" in England, or "Meridian Circles" on the Continent.

The Sextant is an instrument of astronomical origin, so to speak, but not actually much used by astronomers. From the engraving annexed it will be seen that it comprises a small telescope mounted on a frame in the form of the sixth part of a circle, whence the name "Sextant." The sextant is primarily designed for use at sea for determining latitudes and longitudes by observations of the Sun, Moon, and stars; but sometimes an astronomer, when unprovided with a transit instrument, will fall back upon a sextant for ascertaining his time.

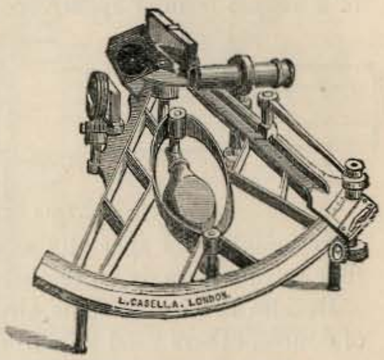


FIG. 123.—THE SEXTANT.

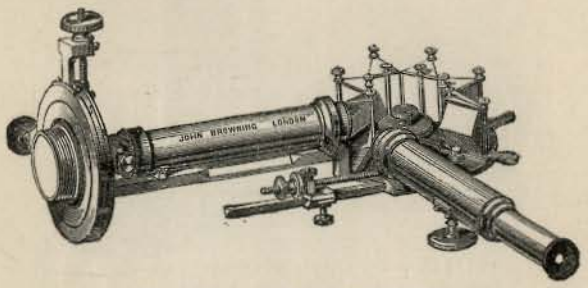


FIG. 124.—THE SPECTROSCOPE.

The Spectroscope, though of late years much applied to astronomical purposes, was not originally an astronomical instrument, but a physical one, used in connection with the science of optics. Fig. 125 represents a section of a simple form of spectroscope; and another form, yet more simple, and specially adapted for the use of amateur astronomers, is represented in Fig. 126.

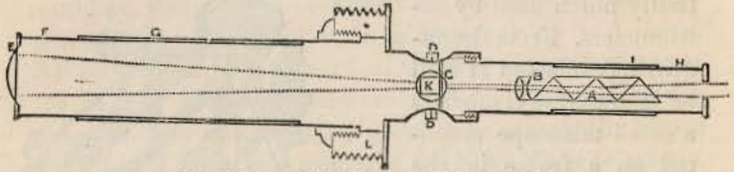


FIG. 125.—SECTION OF A SPECTROSCOPE.

Besides the instruments already mentioned, there are, of course, others used in astronomical observatories; but many of them are merely varied adaptations of the principles of construction embodied in those which have been named. Amongst the instruments which might be included under such a head as "Miscellaneous" are the Heliometer, the Altazimuth, the Comet-seeker, the Astro-photo-Heliograph, Airy's Orbit-sweeper, the

FIG. 126.—McCLEAN'S STAR SPECTROSCOPE.

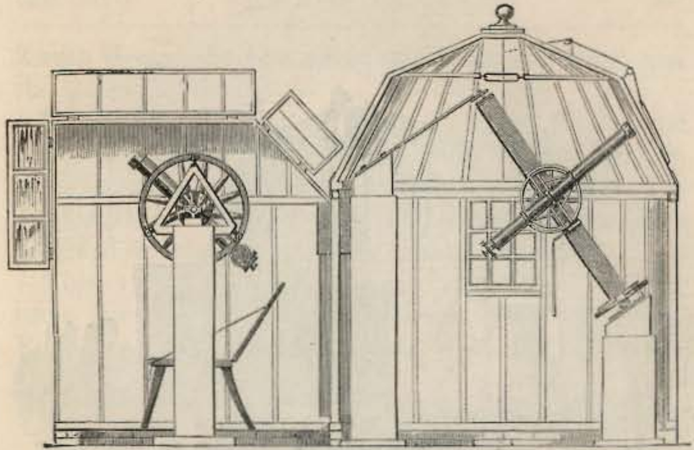


FIG. 127.—THE LATE MR. DREW'S OBSERVATORY AT SOUTHAMPTON.

FIG. 128.—THE LATE MR. SNOW'S OBSERVATORY AT ASHURST, KENT.

FIG. 129.—THE "NORTHUMBERLAND" OBSERVATORY AT CAMBRIDGE.

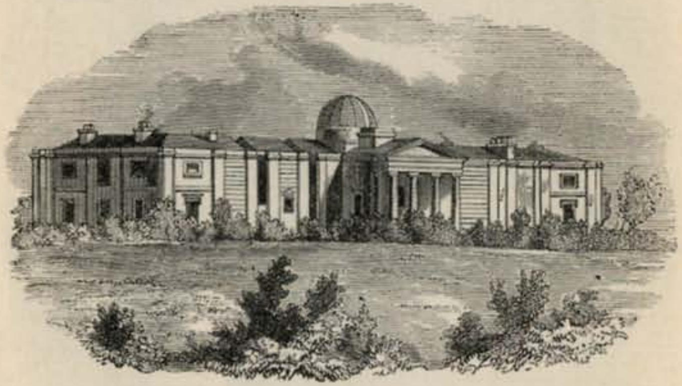


FIG. 130.—THE UNIVERSITY OBSERVATORY AT CAMBRIDGE.

Zenith Sector, the Siderostat, the Reflecting-circle, and the Repeating-circle.[1]

To get the most out of a telescope, and in the most convenient and pleasant way, it ought to be housed in an observatory, which may be either a top-room of a dwelling-house specially adapted for the purpose, or a detached structure erected, say in a back garden.

Figs. 127—8 represent the interiors of two observatories formerly used by well-known amateurs, whilst Figs. 129—30 are exterior views of 2 observatories at Cambridge.

CHAPTER XIV.

THE SPECTROSCOPE AS APPLIED TO ASTRONOMY.

THE spectroscope has already been introduced to the reader as originally a non-astronomical instrument; it remains now to be stated how it has been applied to, and what it has done for, Astronomy.

In 1672 Sir I. Newton presented to the Royal Society a paper on Optics, in which he described some experiments on a beam of sunlight conducted by means of a prism. He admitted a beam of light into a darkened room through a round hole, and fixing a prism close to

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[1] For a description of these instruments reference must be made to larger works, such as vol. ii. of my *Handbook of Descriptive and Practical Astronomy*, Loomis's *Practical Astronomy*, Chauvenet's *Practical Astronomy*, and other works of that character; and various Cyclopædias, *passim*.

the hole, he placed a screen of white paper on the opposite side of the room to receive the rays. With the prism not in its place, the light followed a straight course, and formed a round white spot on the screen. But when the prism was interposed the direction of the beam of light was changed, and it was spread out on the screen into an oblong and rainbow-tinted band, equal in width to the diameter of the round white spot, but nearly 5 times as long.

This coloured streak Newton called the "Solar Spectrum," and hence the term spectrum has come into general use to indicate the image formed by the light given off by any luminous body after that light has passed through a prism.

What Newton accomplished by thus applying his prism to the beam of white light was to break it up, a process which has received the technical name of "dispersion." And this proved also that the various colours which go to make white light are not equally refrangible; Violet, for instance, being bent more out of its course by a prism than Green is, and this, again, more than Red. It is commonly said that the spectrum comprises 7 colours, namely, Violet, Indigo, Blue, Green, Yellow, Orange, and Red, of which Violet is most bent, and Red least bent after transmission through a prism.

The inquiry started by Newton virtually went to sleep for more than a century. It was then resumed by Wollaston, with the object of ascertaining whether the 7 colours of the spectrum were separated from one another by any distinct boundaries. For the round aperture used by Newton, Wollaston substituted a narrow slit, and he at once perceived 7 gaps or dark lines in the solar spectrum. From this the conclusion was obvious that the Sun does not send light of every degree of refrangibility, there being apparently some refractive angles for which there is no light available.

Wollaston made no further progress, and the next investigator was a German optician named Fraunhofer, who in 1814 achieved some very important results. Wollaston had examined his spectrum only with the naked eye, but Fraunhofer employed a small telescope, and therewith discovered that the entire spectrum was crowded with dark lines; he actually counted 574 between the Red and the Violet ends. The darkest of these he distinguished by letters of the alphabet, and as this method of designating them is still in use, it is important to remember what and where they are. A is a thick dark line at the extreme Red end; B is also a broad line; between the two is a cluster of several lines called collectively *a*; C is a dark and fine line. All 4 of these letters belong to the red. D is a very close pair of dark lines in the Orange-yellow; E is the middle and darkest of a group in the yellowish-Green; *b* is a group of 3 dark lines where the Green becomes more of an emerald tint; F seems to be about the boundary between

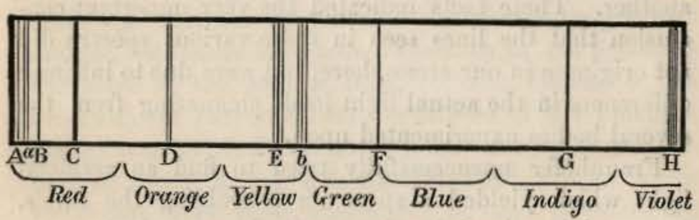

FIG. 131.—THE SOLAR SPECTRUM.

the Green and the Blue; G is in a crowded cluster in the Indigo; finally, H is a pair of bands near the extreme end of the Violet.

Fraunhofer proved that the same lines were seen whatever prism he used, and that their relative positions were invariable. He also found that his results were the same whether he used direct sunlight or sunlight reflected from clouds, the Moon, or the planets. On the other hand, whilst the stars yielded spectra which were also crossed by dark lines, these spectra were not only not like the spectrum of the Sun, but they differed from one another. These facts indicated the very important conclusion that the lines seen in these various spectra did not originate in our atmosphere, but were due to intrinsic differences in the actual light itself emanating from the several bodies experimented upon.

Fraunhofer unsuccessfully tried to find an artificial light which yielded a spectrum resembling the Sun's. In examining the light of a candle he remarked a very curious circumstance. He obtained a continuous spectrum crossed by no dark lines, but in the Orange, just in the place of the 2 dark D lines of the solar spectrum, he saw a pair of bright lines. These were ascertained in after years to be due to the presence of sodium. This coincidence of position between the solar D lines and the sodium lines was long asserted, but it was not finally established until 1859. In that year Kirchhoff of Heidelberg tried the following experiment. He obtained a tolerably bright solar spectrum, and then brought in front of the slit a flame coloured by sodium vapour. He then saw the dark D lines of the Sun change into bright ones. The flame of a Bunsen lamp threw the bright

sodium lines upon the solar spectrum with unexpected brilliancy. In order to find out how far the intensity of the solar spectrum could be increased without impairing the distinctness of the sodium lines, he allowed full sunlight to shine through the sodium flame, and found to his astonishment that the dark D lines appeared with extraordinary clearness. Finding thus that the bright sodium flame, so far from supplying the absence of light, of which the D lines were the proof, only intensified the darkness, Kirchhoff proceeded to vary his experiment by using the limelight instead of sunlight. When this light was transmitted through a flame coloured with sodium, dark lines were seen to occupy in the spectrum the place of the sodium lines, so that, instead of the brilliancy of the continuous spectrum of the limelight being increased in the yellow by the interposition of the sodium flame, it was actually darkened, and as far as these two lines were concerned, he had produced an artificial solar spectrum. These two experiments, properly interpreted, indicate the principle upon which the application of Spectroscopy to Astronomy rests. Roscoe thus states it:—"Every substance which emits *at a given temperature* certain kinds of light, must possess the power at that same temperature of absorbing the same kinds of light." Hence it follows, that if light from a source yielding a complete and continuous spectrum passes through a sufficient depth of glowing vapour or gas giving a spectrum of bright lines, those rays of the light which correspond to the bright lines will suffer absorption, for to them the gas will be opaque, and only the remaining rays will pass through.

It is easy enough to see that once the idea took possession of men's minds that so simple an adjunct to a telescope as a glass prism was capable of yielding different optical effects, so to speak, which would vary as the source of light experimented upon varied, it soon came to be realized how vast a field was opened up to the experimental physicist, whether working in his laboratory on objects terrestrial, or in the observatory on objects astronomical.

Naturally the first astronomical body attacked was the Sun as a whole; then the spots were tried; but the special feature of the Sun most vigorously taken in hand, and yielding the most important results, was the Corona and the Red Flames or Prominences visible during total eclipses of the Sun.

The spectroscope tells us comparatively little about the planets, for the reason that their light is practically nothing but reflected sunlight.[1] Yet refined observation with instruments of special power show that the influence of the Earth's atmosphere and the influence of a planet's atmosphere afford indications of their presence which cannot be ignored.

The application of the spectroscope to comets has yielded some very remarkable and unexpected results; and it seems not improbable that in looking at a comet we see two sources of light merged in one. It has already been stated that comets, speaking generally, are self-luminous, and that the existence in them of phases ascribable to their shining by reflected sunlight has never been clearly proved, yet the spectroscope has given some hints that a portion of the light of certain comets was reflected sunlight. But be that as it may, a large number of comets observed of late years have led astronomers to the conclusion that the inherent light of most comets is naught else than glowing hydro-carbon vapour, to wit, olefiant gas.

Thanks to the labours of two celebrated English physicists, Huggins an astronomer, and Miller a chemist, Kirchhoff's investigations on the Sun were soon turned to account for the purpose of carrying out experiments with respect to the stars. It would now seem that the elements sodium, magnesium, and hydrogen, are to be found very generally in nearly all the larger stars. Sirius, Vega, and Pollux give indications of iron also; whilst Arcturus shows calcium and chromium in addition. It would seem, therefore, that we are justified in asserting that the larger stars so far resemble our Sun that they possess a photosphere giving a continuous spectrum, and are surrounded by the absorbent vapours of certain elements already well known to us on the Earth.

When the spectroscope came to be diligently and systematically applied to the stars it was soon found that there existed well-marked differences in the spectra of the stars, and Secchi pointed out the possibility of grouping them in 4 classes, which he called "Types." Secchi's 4 types are briefly described in the following paragraphs.

(1) White stars, such as Sirius and Vega, yielding spectra, crossed by 4 dark lines due to hydrogen, and showing likewise, but less prominently, the sodium and magnesium lines.

(2) Almost all the other large stars, which are yellow, exhibiting the hydrogen lines much less conspicuously,

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[1] A possible exception to the literal truth of this statement has already been pointed out in speaking of Jupiter. (See p. 83, *ante*.)

but numerous metallic lines, those of magnesium being often very distinct. Aldebaran, Capella, Pollux, Arcturus, and α Cygni are stars of this class.

(3) Stars with exceedingly beautiful spectra, crossed sometimes by as many as 10 dark bands, each very dark and sharp towards the violet. α Herculis, α Orionis, and Antares, are the principal stars of this type.

(4) Red stars showing 3 broad dark bands shaded in the reverse direction to those of the 3rd type. These bands coincide with the 3 well-known hydro-carbon bands so readily obtained from a Bunsen flame. This type of spectrum is the ordinary cometary spectrum reversed, the presence of the carbon being made evident by its absorption instead of by its emission.

So much for Secchi's 4 particular types; but he himself pointed out the existence of a small residuum of bright stars which seemed to constitute a 5th class. These stars show bright lines. There are not many of them in number, and γ Cassiopeiæ, β Lyræ, and η Argûs, are the brightest.

Secchi's system of classification seems to meet the present necessities of the case, though Vogel and, more recently, Lockyer, have thought they could improve upon it by amplifying it.

The spectroscope has also been applied to the nebulæ, and to the zodiacal light, with the result that whilst most of the nebulæ are probably aggregations of stars so close together as to defy separation by our largest telescopes, yet some there are which are presumably gaseous—masses of incandescent gas, though why their appearance should continue visibly unchanged and apparently unchangeable none of the spectroscopists have been able to tell us. The spectroscopic observations of the zodiacal light have yielded very uncertain results, but the balance of testimony seems to show that its spectrum is, on the whole, continuous.

CHAPTER XV.

THE HISTORY OF ASTRONOMY.

EVERY science has a history, and it will often happen that a due presentation of the facts of that history and a due comprehension of their bearing will greatly aid an intelligent reader in his study of the particular science in its modern aspects. All this is particularly true of Astronomy. A student who has mastered the facts appertaining to its origin in early times, and to its subsequent developement down to the present epoch, should have acquired a considerable general knowledge of the science itself as a whole.

Poetry and romance have always talked about the Chaldean shepherds as the first astronomers. I can neither affirm nor deny the idea. But when one considers how much time men of the shepherd class spend out in the open air, and how accurate their anticipations of the weather generally are, it seems not unreasonable to think that such men as the shepherds of Eastern lands may have been in a certain general sense the earliest astronomers.

This conception naturally suggests the question, "Do we find any allusions to astronomical matters in the Holy Scriptures?" To this the answer must be in the affirmative. Of historical events there are 2, the astronomical import of which is very obvious:—(1) The standing still of the Sun and Moon, as so stated, at the command of Joshua;[1] and (2), The going back of the shadow of the Sun for King Hezekiah's sake on the dial of Ahaz.[2]

The former of these events has never been adequately explained, and it can only be regarded as having been a miracle in the proper sense of the word. With respect, however, to what happened in the case of Hezekiah there seems reason to believe that the observed facts may be reconcilable with the circumstances of a partial eclipse of the Sun, visible as such at Jerusalem on January 11, 689 B.C. This eclipse is known to have happened nearly at noon, and if we may suppose the words "dial of Ahaz" to apply to a large gnomon or sundial formed of masonry, and similar in character to such a structure as that which still exists at the ruined Hindù observatory at Benares, we may understand that a shadow caused by an uneclipsed Sun might be brought back, on the upper part of the Sun's disc suddenly ceasing for an hour or so to be a source of light.[3]

Passing from Asia into Europe we come to the Greeks, of whom it may be said generally that they were great astronomers as well as physicists. The names of Thales, Pythagoras, Anaximenes, Meton, Eudoxus, Philolaus, Aristotle, Calippus, Archimedes, Aratus, Aristarchus, Eratosthenes, Apollonius, and Hipparchus will readily occur to the mind. They were perhaps not all Greeks in the strict literal sense of the word, but may virtually be regarded as such, bearing in mind the school of thought (to use a hideous modern term) to which they belonged. Two or 3 of those mentioned, such as Thales, Aristotle, and Hipparchus, were giants in science, comparable with the Humboldts and Herschels of the present century. This remark is peculiarly true of Hipparchus. The work which he performed really laid the foundations for the science of exact astronomy as distinguished from mere star-gazing.

The labours of Hipparchus were as varied as they were important. He discovered the Precession of the Equinoxes; was the first to use Right Ascensions and Declinations; probably invented the stereographic projection of the sphere; suspected that inequality in the Moon's motion afterwards discovered by Ptolemy, and known as the Evection; calculated eclipses; and formed the first regular catalogue of stars in consequence of having observed a temporary star burst forth in 131 B.C.

After the Christian Era the first illustrious name which appears on the pages of Astronomical History is that of Ptolemy of Alexandria, who lived from 100 A.D. to 170 A.D. He was both a writer and an observer. His great work was the celebrated Μεγάλη Σύνταξις, better known by its Arabian designation of *The Almagest*. This work contains, amongst other things, a review of the labours of Hipparchus; a description of the heavens, including the Milky Way; a catalogue of stars; sundry arguments against the motion of the Earth, and notes on the length of the year. To Ptolemy we owe the discovery of the Lunar Evection, of the refractive properties of the atmosphere, and of the theory of the universe which bears his name.

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[1] Joshua x. 13.

[2] II. Kings xx. 11.

[3] All the details of this are very well worked out in Mr. J. W. Bosanquet's *Messiah the Prince*, 8vo, London, 1869, p. 176, *et seq.*

It is a remarkable fact that, great as they were in almost every department of life, the Romans utterly failed as men of science. Perhaps it would be more accurate to say that they never tried their hands at physical science. This is the more remarkable when we remember how great they were in everything else. They were great lawyers, great engineers, great statesmen, great generals, great scholars, great poets, great even in medicine and surgery, but as sailors they obtained but moderate success, whilst for physical science they have left us nothing to show.

During the first half-dozen centuries of the Christian Era, Alexandria may be regarded as having been the great centre whence astronomical knowledge was disseminated throughout the world. But in 640 A.D., the Alexandrian school was broken up by the Saracens under Omar. In the following century, on the building of Bagdad by the Caliph Al-Mansar, that place became the great centre of astronomy, and continued to be such for 400 or 500 years.

The names which have come down to us in this connection are not numerous, but they are individually weighty. Grouping together various writers and workers under the general name of Arabic or oriental astronomers, we fall in with the following:—Albategnius, Alfraganus, Al-Sufi, Ebn Yunis, and Abùl Wefa. Albategnius (*circa* 880 A.D.) may be regarded as the most distinguished astronomer between Hipparchus and Tycho Brahe. He discovered the motion of the solar apogee, corrected the value of precession and of the obliquity of the ecliptic as previously received, formed a catalogue of stars, and was the first to use sines and chords. Al-Sufi (d. 986 A.D.) was a distinguished Persian astronomer, who left behind him a very curious and interesting catalogue of stars, of which a translation into French was published by Schjellerup at St. Petersburg, in 1874. Ebn Yunis and Abùl Wefa both lived about the year 1000 A.D., and greatly developed the use of trigonometry. The latter is thought by some to have discovered the Lunar inequality known as the Variation.

In 1079, we find a Persian astronomer of the name of Omar proposing to reform the Calendar by interpolating one day in every fourth year, but postponing to the 33rd year the interpolation belonging to the 32nd year. This would have produced an error of only one day in 5000 years, whereas the error arising in the Gregorian Calendar, adopted 5 centuries later, and which we now use, amounts to one day in 3846 years. The acuteness and research of this Persian philosopher may well excite our surprise and admiration.

The translation of Ptolemy's *Almagest* from Arabic into Latin, and the work done in Spain under the patronage of Alphonso X., King of Castile, indicate a movement of astronomical knowledge in a western direction over Europe. Accordingly, the revival of letters, the invention of printing, and the taste for geographical research, cultivated especially by the English, the Portuguese, and the Spaniards, gave a great impulse to the exact sciences, and of course to astronomy amongst them. Hence it follows that work and workers multiply all over Western Europe, Germany taking the lead. The names of several of the famous men of the 16th and following centuries have already occurred in these pages in connection with particular items of work which they did and with the results which they left behind. It may serve to fix some of these names in the mind of the reader if I enumerate a few of these men, and the centuries in which they died.

During the 16th century we have Regiomontanus, Copernicus, and Jordanus Brunus. The two first were working astronomers in the fullest sense, but Jordanus Brunus was rather a philosophical speculator on astronomical subjects than, strictly speaking, a working astronomer.

In the 17th century we find Tycho Brahe (d. 1601), Fabricius (d. 1616), Kepler (d. 1630), Galileo (d. 1642), Torricelli (d. 1647), Descartes (d. 1650), Gassendi (d. 1655), Hevelius (d. 1687), and C. Huygens (d. 1695). This century produced the first star atlas, by Bayer, a work which constituted a new departure in astronomical records ; the refracting telescope ; the discovery of spots on the Sun ; the discovery of the satellites of Jupiter and of Saturn ; observations of transits of Venus and Mercury ; pendulum clocks ; the reflecting telescope ; the discovery of the progressive transmission of light ; and important investigations into the theory of the Moon. In 1666 Flamsteed commenced observations at Greenwich Observatory, and by so doing laid the foundations for that great and prolonged developement of scientific work there which inspired Bessel, half a century ago, to say that if all the books on astronomy in the world, and all the observatories in the world, except Greenwich, were destroyed by some great catastrophe of nature, the whole science could be re-constructed from its foundation by means of the knowledge gathered up and stored at the Greenwich Observatory.

All things considered, the 18th century did not show such an advance over the 17th as the progress of learning and the multiplication of telescopes might have led us to expect. Although Newton lived on till the year 1727, yet he belonged much more to the previous century, his immortal *Principia* having been published as far back as 1687. The first and greatest of the 5 generations of the Cassini family who have left their mark on French astronomy (Jean Dominique), though he died in 1712, yet performed all his important work (and very important it was) during the second half of the 17th century. The names which should be picked out and attached to the 18th century are only Leibnitz (d. 1716), who was more a mathematician than a scholar, Flamsteed (d. 1719), J. P. Maraldi (d. 1729), Halley (d. 1742), Bradley (d. 1762), La Caille (d. 1762), Ferguson (d. 1776), Pingré (d. 1796), and Le Monnier (d. 1799). A detailed inquiry into the circumstances of the 18th century discloses the general fact that the French came very much to the front as observers and mathematicians ; that the Italians to a considerable extent, and the Germans almost entirely, receded into the background ; whilst the progress of the English was chiefly in regard to practical matters, such as nautical astronomy and navigation, clocks, chronometers, and time appliances generally, and the construction of astronomical instruments of precision. But we must not pass away from the 18th century without noting two very prominent points of progress, the invention of the achromatic object-glass by Dollond, and Sir W. Herschel's success in the manufacture of the reflecting telescopes, and in the use of them.

The progress of astronomy during the 19th century has been so absolutely great, that it is quite hopeless to give even a sketch of it. However, nearly all the facts which belong to this century, together with the names of the men, and some of the dates, have already been brought before the reader in previous chapters. The only points which it seems possible to specify are:—the great progress in the construction of large astronomical instruments, and the application of photography and of the spectroscope to astronomical purposes. But besides these general points, it is impossible not to be struck with the remarkable growth of the science in England in the hands of amateurs; in Germany, in the hands of government establishments; and in America, in connection with universities, colleges, and semi-public observatories endowed by deceased benefactors. These are 3 well-marked national differences of *modi operandi* on which a political astronomer would probably feel inclined to comment at length, and draw moral lessons from.

CHAPTER XVI.

CONCLUDING OBSERVATIONS ON THE USEFULNESS OF ASTRONOMY.

IT is much the fashion now to inquire very closely into the commercial and utilitarian aspects of the sciences which we are asked to teach or to study. Tested by such standards Astronomy has nothing to fear.

In these days nearly everybody uses a clock, or wears

a watch, and on the accuracy with which these go depend an infinite number of the duties and occupations of daily life. These clocks and watches are, of course, made by mechanics, none of whom probably, from year's end to year's end, come in contact with an astronomer, or an astronomical event or operation. But, however well these workmen might do their work, the finished result would be absolutely useless, both to them and to the public, were it not for the self-denying labours of the astronomer in sitting up, night after night, making the time records, to be distributed subsequently through appropriate channels, very much on the same principle as gas and water companies distribute their gas and water.

Every year almost every educated Englishman buys an almanack, and frequently also a diary. The very groundwork of these publications are the facts relating to the Sun, Moon, and planets, which the astronomer supplies to the printers and publishers of these works, and for which by the way he is, as a rule, very inadequately paid.

Let me now say a word or two on another practical aspect of the science of astronomy, which is one of the very first importance to a maritime country like England. There is a book in daily use amongst certain sections of the community which is called the *Nautical Almanack*. It comprises 500 or more pages of figures with scarcely any text. Many thousands of copies are printed every year by the Government, and are sold at the nominal price of 2*s.* 6*d.* If the half-a-dozen gentlemen who all day long throughout the year are engaged in the calculations which are required for the purposes of this book were to adopt the fashionable methods in vogue for getting their wages raised, and were to indulge in a strike, and the *Nautical Almanack* were to cease to appear for any given year, then on the 1st of January of that year not an ocean-going ship dare leave London, Liverpool, or the other ports of England. The only exception to this statement which could be supposed would be based on the presumption that some of the captains of these ships had been able to obtain from France, Germany, Spain, or America, copies of the corresponding works issued by the governments of these nations.[1]

This matter as it affects navigation is entirely a question of the right time, so the problem of finding the time may be said to be one which concerns our very existence; certainly our existence as a busy nation on land and a powerful nation at sea. It was on this account that so many efforts were made during the last century by the English Government to obtain trustworthy chronometers for the Royal Navy, resulting in a certain watchmaker named Harrison winning in 1744 a Government prize of £10,000 for one which conformed to certain prescribed conditions.

The necessity to us as a nation of a correct knowledge of the time both on land and at sea can hardly be overestimated. How many railway accidents have been caused by a guard's watch or a signalman's clock going wrong, and thus trains arriving too late at junctions; or one train mistaken for another train, and collisions and loss of life the result!

In navigation much the same incidents have often presented themselves. How many ships have been lost by striking on invisible rocks in consequence of the captain being out of his reckoning—and this in consequence of his chronometer being either too fast or too slow! Happily these risks are being rapidly lessened, and the increasing facilities for distributing true time on our coasts by means of time-balls and time-guns, and inland by the Postal Telegraph system, are bearing fruit in the shape of fewer accidents and greater punctuality alike with our ships and on our railways. It ought, however, never to be forgotten that the visible prime impulse of all this improved accuracy as to time is due originally to the very insufficiently paid staff of workers at the Royal Observatory, Greenwich. Fig. 132 represents the means employed at Greenwich and at a few other places to convey to the public at large information as to the exact time. A ball is raised to the top of a mast daily at 12.55, and dropped exactly at 1.0.

The Post Office system does not, it is true, extend everywhere, but even in out-of-the-way country places there ought never to be any excuses now for the clock of the village Church or of the village Institute being wrong, for a little portable transit instrument, such as that devised by Mr. Latimer Clark, the eminent engineer, or Mr. Short's "Rating Instrument," should be regarded as an essential piece of furniture in every country parish, in the hands either of the squire or the parson.

The reader will by this time be able to realise the folly of that most extraordinary utterance once made by a distinguished scholar of the present generation, and a Chancellor of the Exchequer to boot—Sir George Cornwall Lewis. This well-known man once wrote a very remark-

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[1] *Connaissance des temps* (French); *Berliner Astronomisches Jahrbuch* (German); *Almanaque Náutico* (Spanish); *Ephemerides Astronomicas* (Portuguese); *American Nautical Almanack* (U.S.).

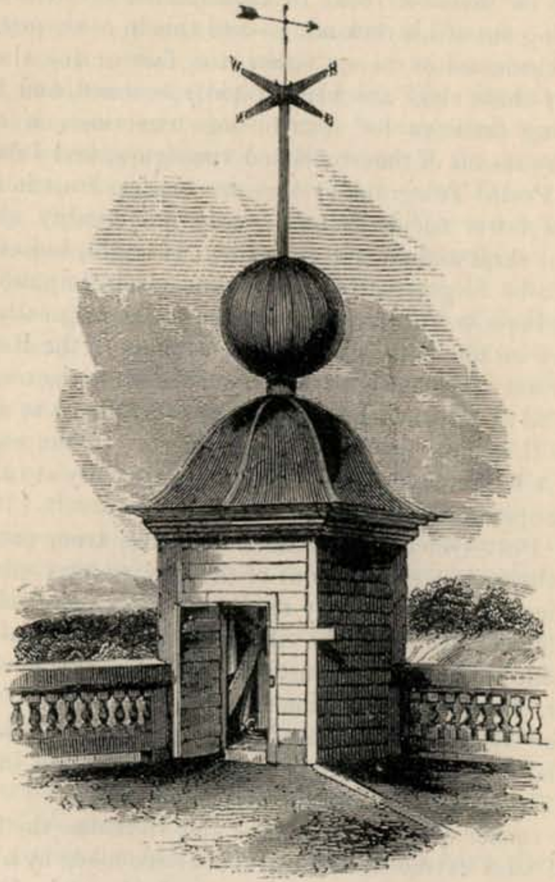

FIG. 132.—THE TIME-BALL AT GREENWICH.

able, yet cold and cheerless, book on the *Astronomy of the Ancients.* It was remarkable by reason of the number of the quotations from ancient authors which he had dug up and recorded: it was cold and cheerless by reason of the fact that, apparently knowing nothing of and caring nothing for the science of astronomy, he set himself the task of writing its early history. Under no other conceivable circumstances could it have come about that a scholar and statesman should have deliberately sat

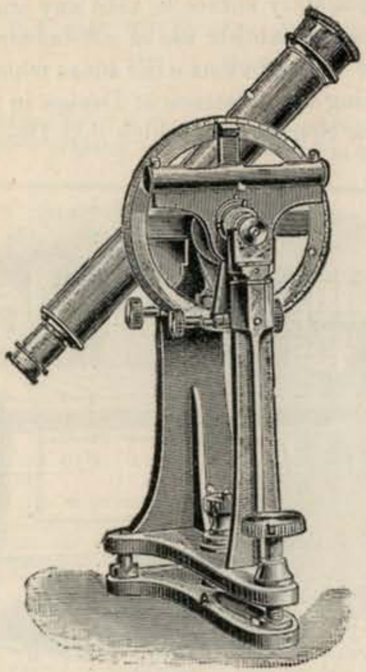

FIG. 133.—SHORT'S RATING INSTRUMENT.

down and have penned the astounding statement that astronomy is a science "of pure curiosity." The intimate bearings of astronomy on the computation of time, on the construction of almanacks, and on the navigation of ships, abundantly suffice to veto any such idea. But yet there remains another use of astronomy, and that by no means the least obvious—the ideas which it suggests to us respecting the existence of Design in Creation, and respecting the Source from which that Design proceeds.

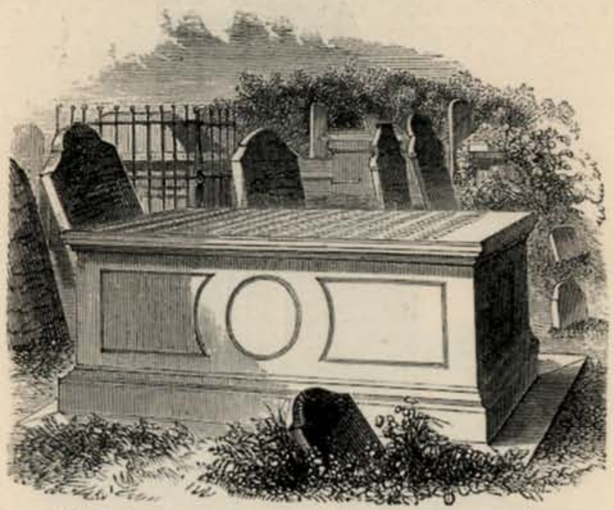

FIG. 134.—TOMB OF HALLEY IN LEE CHURCHYARD.

⁂ *The main slab was removed to Greenwich Observatory in 1854.*

APPENDIX.

TABLES OF THE PLANETS AND SATELLITES.

⁂ These Tables are based upon an assumed solar parallax of 8·80″, which is probably correct within 0·02″ or 0·03″.

Planet.	Symbol.	Inclination of Orbit.			Eccentricity of Orbit.	Semi-Axis Major. ⊕ = 1.	Daily Heliocentric Motion.			Sidereal Period.	
		°	′	″			°	′	″	d.	y.
Mercury .	☿	7	0	5	0·205	0·387	4	5	32	87·97	0·24
Venus . .	♀	3	23	29	0·006	0·723	1	36	7	224·70	0·61
Earth .	⊕	0	0	0	0·016	1·000	0	59	8	365·25	1 00
Mars .	♂	1	51	6	0·093	1·523	0	31	26	686·97	1·88
Jupiter . .	♃	1	18	52	0·048	5·202	0	4	59	4332·58	11·86
Saturn . .	♄	2	29	36	0·056	9·538	0	2	0	10759·21	29·45
Uranus . .	♅	0	46	28	0·046	19·182	0	0	42	30686·82	84·01
Neptune .	♆	1	46	59	0·008	30·036	0	0	21	60126 71	164·62
Sun . . .	☉		...		...	...		...		...	...
Moon . .	☽	5	8	40	0·054	—	13	10	35	27·32	0·08

Symbol.	Equinoctial Period.	Synodic Period.	Distance from Sun.		
			Max.	Min.	Mean.
	d.	d.	Miles.	Miles.	Miles
☿	87·96	115·8	43,347,000	28,569,000	35,958,000
♀	224·69	583·9	67,652,000	66,728,000	67,190,000
⊕	365·24		94,450,000	91,330,000	92,890,000
♂	686·92	779·8	154,714,000	128,358,000	141,536,000
♃	4330·61	398·8	506,563,000	460,013,000	483,288,000
♄	10746·73	378·0	931,033,000	841,097,000	886,065,000
♅	30589·35	369·7	1,865,107,000	1,698,781,000	1,781,944,000
♆	59742·71	367·5	2,816,094,000	2,767,406,000	2,791,750,000
☉	...	...	...	...	...
☾	27·32	29·5	From ⊕. 251,947	From ⊕. 225,719	From ⊕. 238,833

Symbol.	Distance from ⊕ at Sup. ☌ for Inf. Planets, or at ☍ for Sup. Planets.		
	Max.	Min.	Mean.
	Miles.	Miles.	Miles.
☿	137,797,000	119,899,000	128,848,000
♀	162,102,000	158,058,000	160,080,000
⊕	...	...	...
♂	249,164,000	219,688,000	234,426,000
♃	601,013,000	551,343,000	576,178,000
♄	1,025,483,000	932,427,000	978,955,000
♅	1,959,557,000	1,790,111,000	1,874,834,000
♆	2,910,544,000	2,858,736,000	2,884,640,000
☉	—	—	—
☽	—	—	—

Symbol.	Distance from ⊕ at Inf. ☌ for Inf. Planets, or at ☍ for Sup. Planets.		
	Max.	Min.	Mean.
	Miles.	Miles.	Miles.
☿	65,881,000	47,983,000	56,932,000
♀	27,722,000	23,678,000	25,700,000
⊕	...	...	...
♂	63,384,000	33,908,000	48,646,000
♃	415,233,000	365,563,000	390,398,000
♄	839,703,000	746,647,000	793,175,000
♅	1,773,777,000	1,604,331,000	1,689,054,000
♆	2,724,764,000	2,672,956,000	2,698,860,000
☉	—	—	—
☽	—	—	—

Symbol.	Apparent Diameter.				Real Diameter.		Surface.
	From ⊕.			From ☉			
	Max.	Min.	Mean.	Mean.	⊕ = 1.	Miles.	⊕ = 1.
	″	″	″	″			
☿	12·9	4·5	8·7	17·3	0·38	3,008	0·14
♀	65·2	9·5	37·3	23·0	0·94	7,480	0·89
⊕	...	...	...	17·6	1·00	7,926	1·00
♂	30·4	4·1	17·3	7·3	0·63	4,999	0·39
♃	49·9	30·4	40·1	37·7	11·15	88,439	124·53
♄	20·7	15·1	17·9	17·5	9·48	75,036	89·64
♅	3·5	3·2	3·4	3·6	3·89	30,875	15·17
♆	2·9	2·6	2·8	2·7	4·62	37,205	21·35
	′ ″	′ ″	′ ″				
☉	32 35	31 31	32 3	—	109·29	866,200	11946·33
☽	33 31	29 21	31 26	4·8	0·27	2,160	0·07

Symbol.	Volume.	Mass.		Density.	
	⊕ = 1.	☉ = 1.	⊕ = 1.	⊕ = 1.	Water. = 1.
☿	0·05	$\frac{1}{5000000}$	0·06	1·26	7·1
♀	0·84	$\frac{1}{425000}$	0·78	0·92	5·2
⊕	1·00	$\frac{1}{332260}$	1·00	1·00	5·6
♂	0·25	$\frac{1}{3093500}$	0·10	0·45	2·5
♃	1389·71	$\frac{1}{1048}$	317·04	0·23	1·2
♄	848·82	$\frac{1}{3502}$	94·87	0·11	0·6
♅	59·13	$\frac{1}{22600}$	14·70	0·25	1·4
♆	103·46	$\frac{1}{19380}$	17·14	0·17	0·9
☉	1,305,725·52	1·0	332,260·00	0 25	1·4
☽	0·02	$\frac{1}{24490744}$	0·01	0·63	3·5.

Symbol.	Apparent Diameter of ☉ to observer on Planet.			Light and Heat of ☉	Axial Rotation.			Inclination of Axis to Plane of Ecliptic.	
	′	″	⊕ = 1.	⊕ = 1.					
					h.	m.	s.	°	′
☿	82	49	2·58	6·67	24	5	30	63	?
♀	44	19	1·38	1·91	23	21	23	73	32
⊕	32	3	1·00	1·00	23	56	4	66	32
♂	21	2	0·65	0·43	24	37	23	61	18
♃	6	10	0·19	0·03	9	55	21	86	55
♄	3	22	0·10	0·01	10	29	17	61	50
♅	1	40	0·05	0·003	9	30	?	?	
♆	1	4	0·03	0·001		?		?	
					d.	h.	m.		
☉	...		...	...	25	7	48	82	30
☽	...		...	...	27	7	43	88	30

Symbol.	Polar Compression.	Force of Gravity.		Orbital Velocity.		Velocity of Rotation at Equator.
		Fall: Feet in 1 sec.	⊕ = 1.	Miles per hour.	⊕ = 1.	Miles per hour.
☿	$\frac{1}{29}$	7·6	0·4	107,012	1·60	392
♀	very small.	14·0	0·8	78,284	1·17	1,006
⊕	$\frac{1}{299}$	16·0	1·0	66,579	1·00	1,040
♂	$\frac{1}{55}$	4·4	0·3	53,938	0·81	638
♃	$\frac{1}{16\cdot8}$	40·9	2·5	29,203	0·43	28,001
♄	$\frac{1}{9\cdot22}$	18·5	1·1	21,560	0·32	22,476
♅	?	13·6	0·8	15,202	0·22	10,210
♆	?	12·9	0·8	12,156	0·18	?
☉	?	461·6	28·7	...	...	4,477
☽	?	2·4	0·1	2,273	0·03	10

THE SATELLITES OF MARS.

	Names.	Discoverer.	Mean Distance.	Sidereal Period.	Max. Elong. ♂ in ☊.	Appar. Star Mag.
			Miles.	d. h. m.		
1.	Phobos . . .	A. Hall, 1877, Aug. 17 . .	6000	0 7 39	12″	11½
2.	Deimos . . .	A. Hall, 1877, Aug. 11 . .	15000	1 6 18	32″	13½

THE SATELLITES OF JUPITER.

	Names (not in use).	Discoverer.	Mean Distance.		Sidereal Period.	Mean Appar. Diam.	Diam.	Diameter seen from ♃'s Equator.	Apparent Diam. of ♃, seen from Satellite.	Max. Elong. ♃ in ☊	Appar. Star Mag.
			Radii of ♃.	Miles.							
					d. h. m.	″	Miles.	′ ″	° ″	′ ″	
1.	Io . . .	Galileo, Padua, Jan. 7-13, 1610.	6·0	267,300	1 18 29	1·02	2390	38 11	19 49	2 15	7
2.	Europa . .		9·6	425,100	3 13 18	0·91	2120	17 35	12 25	3 35	7
3.	Ganymede.		15·3	678,300	7 4 0	1·49	3480	18 0	7 47	5 46	6
4.	Callisto. .		26·9	1,192,800	16 18 5	1·27	2970	8 46	4 25	9 45	7

The duration of an eclipse of the Ist is $2^h\ 20^m$
" " IInd 2 56
" " IIIrd 3 43
" " IVth 4 56
—*Nautical Almanack*, 1835.

THE SATELLITES OF SATURN.

	Names.	Order of Discovery.	Discoverer.		Mean Distance.		Sidereal Period.	Diam.	App. Diam. of ♄ seen from Satel.	Max. Elong. ♄ in ☊	App. Star Mag.
					Rad. of ♄	Miles.					
							d. h. m.	Miles.	°	′ ″	
1.	Mimas .	7	Sir W. Herschel.	1789, Sept. 17	3·0	115,100	0 22 37	1000	33	0 26	17
2.	Enceladus	6	"	1789, Aug. 28	3·9	147,750	1 8 53	?	26	0 34	15
3.	Tethys .	5	J. D. Cassini.	1684, March	4·8	183,000	1 21 18	500	21·2	0 42	13
4.	Dione .	4	"	1684, March	6·2	234,400	2 17 41	500	16·6	0 54	12
5.	Rhea. .	3	"	1672, Dec. 23	8·7	327,300	4 12 25	1200	12·0	1 16	10
6.	Titan .	1	C. Huygens.	1655, March 25	20·2	758,700	15 22 41	3300	5·2	2 56	8
7.	Hyperion	8	W. Bond and Lassell	1848, Sept. 19	24·4	916,700	21 7 7	?	4·2	3 33	17
8.	Iapetus .	2	J. D. Cassini.	1671, Oct. 25	58·9	2,221,100	79 7 53	1800	1·8	8 34	9

It is understood that Dawes claimed to share with Lassell the English discovery of Hyperion, those observers being in company on the said 19th of September, 1848.

"According to the best estimates of their magnitude, the 8 satellites, taken in their order from the planet, cover spaces on the Saturnian heavens which bear to the space covered by our Moon the respective proportions of about 2, 1, $1\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, $\frac{1}{100}$, $\frac{1}{40}$. In all, then, they cover an area about 6 times that of our Moon; and as, owing to their great distance from the Sun, they are illumined by only $\frac{1}{100}$th of the light which illuminates our Moon, they could only send back to the planet, if it were possible for them to be all full together, about $\frac{1}{16}$th part of the light we receive from the full Moon."—PROCTOR, *Other Worlds than Ours*, p. ·54.

THE SATELLITES OF URANUS.

	Names.	Order of Discovery.	Discoverer.		Mean Distance.		Sidereal Period.	Max. Elong. ♅ in ☍	Appar. Star Mag.
					Radii of ♅	Miles.	d. h. m.	″	
1.	Ariel . .	3	Lassell.	1847, Sept. 14	8·0	124,700	2 12 28	12	
2.	Umbriel .	4	O. Struve.	1847, Oct. 8	11·2	173,900	4 3 27	15	
3.	Titania . .	1	Sir W. Herschel.	1787, Jan. 11	18·4	285,300	8 16 55	33	
4.	Oberon . .	2	,, ,,	,, ,,	24·7	381,600	13 11 6	44	

Inclination	82°
Eccentricity	Small.
Direction of motion	Retrograde.

THE SATELLITE OF NEPTUNE.

	Discoverer.		Mean Distance.		Sidereal Period.	Max. Elongation. ♆ in ☍	Apparent Star Magnitude.
			Radii of ♆	Miles.	d. h. m.	″	
1.	Lassell.	1846, Oct. 10	12·0	223,000	5 21 3	18	14

A CATALOGUE OF CELESTIAL OBJECTS

SUITABLE FOR SMALL TELESCOPES.

THIS catalogue furnishes a series of objects for telescopes of about 3 in. aperture. Many of these objects which are visible in England have been examined with an instrument of this size.

PART I.—DOUBLE, TRIPLE, AND MULTIPLE STARS.

As a general rule, no stars are inserted which are less than 3″ or more than 45″ apart. Also, as a general rule, no principal star is included which is less than the 5½ magnitude, and no secondary one which is less than the 7½; but in some special cases these limitations have been disregarded. Many stars, double when examined with small telescopes, appear triple or quadruple in larger ones.

No.	Star.	R.A. 1890.	Decl. 1890.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
1	β Toucani ...	0 26 30	−63 34	both 5	28
2	π Andromedæ	0 31 0	+33 6	4½ and 9	35
3	η Cassiopeiæ	0 42 26	+57 13	4 and 7½	5·1 Binary.
4	ψ^1 Piscium ...	0 59 47	+20 53	both 5½	29·4
5	α Ursæ Min.	1 18 14	+88 43	2½ and 9½	18·4

No.	Star.	R.A. 1890.	Decl. 1890.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
6	γ Arietis ...	1 47 29	+18 45	4½ and 5	8·3
7	λ Arietis ...	1 51 47	+23 3	5½ and 8	37
8	α Piscium ...	1 56 21	+ 2 14	5 and 6	3·0
9	γ Andromedæ	1 57 8	+41 48	3½ and 5½	10·5; B double.
10	ι Trianguli ...	2 5 59	+29 47	5½ and 7	3·8
11	ι Cassiopeiæ	2 20 0	+66 54	4½, 7, and 9	2·1 and 7·5
12	112 P.II.Forn.	2 29 1	−28 42	5½ and 8	11
13	γ Ceti	2 37 36	+ 2 33	3 and 7	2·7
14	η Persei ...	2 42 40	+55 26	5 and 8½	28
15	θ Eridani ...	2 54 5	−40 44	5 and 6	8·5
16	12 Eridani ...	3 7 23	−29 26	3½ and 8	2·6
17	f Eridani ...	3 44 33	−37 57	5 and 5½	8·5
18	32 Eridani ...	3 48 46	− 3 16	5 and 7	6·7
19	ε Persei ...	3 50 28	+39 41	3½ and 9	8·4
20	τ Tauri... ...	4 35 38	+22 44	5 and 8	63
21	ι Pictoris ...	4 48 28	−53 39	5½ and 6½	12·3
22	14 Aurigæ ...	5 8 14	+32 33	5 and 7½	14·6
23	β Orionis ...	5 9 15	− 8 19	1 and 9	9·5
24	23 Orionis ...	5 17 3	+ 3 26	5 and 7	31
25	δ Orionis ...	5 26 23	− 0 22	2 and 7	53
26	λ Orionis ...	5 29 5	+ 9 51	4 and 6	4·3
27	ι Orionis ...	5 30 3	− 5 59	3½, 8, 11	11·2 and 49
28	σ Orionis ...	5 33 3	− 2 38	4, 8, and 7	12 and 42; multiple
29	ζ Orionis ...	5 35 12	− 2 0	3, 6½, 10	2·6, 57
30	11 Monocerotis	6 23 29	− 6 57	6½, 7, and 8	7·2, 9·6 (BC=2·5)
31	V Puppis ...	6 35 41	−48 7	5½ and 7½	13
32	38 Geminorum	6 48 26	+13 19	5½ and 8	6·3
33	γ Volantis ...	7 9 40	−70 19	5 and 7	13
34	α Geminorum	7 27 35	+32 7	3 and 3½	5·6
35	ζ Cancri ...	8 5 54	+18 0	6, 7, and 7½	1·0 and 5·7 (1886)
36	γ Argûs ...	8 6 8	−47 0	2 and 6	42
37	124 P.VIII. Canc.	8 33 32	+19 56	7, 7½, 6½	45 and 93

No.	Star.	R.A. 1890.	Decl. 1890.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
38	38 Lyncis ...	9 12 0	+37 16	4 and 7½	2·9
39	γ Leonis ...	10 13 54	+20 23	2 and 4	3·6
40	54 Leonis ...	10 49 39	+25 20	4½ and 7	6·4
41	ξ Ursæ Maj.	11 12 20	+32 9	4 and 5½	2·0 (1886)
42	ι Leonis ...	11 18 11	+11 8	4 and 7½	2·6
43	17 Crateris ...	11 26 49	−28 39	5½ and 7	8·7
44	90 Leonis ...	11 28 59	+17 24	6, 7½, 9½	3·5 and 63
45	15 P.XII.Cent.	12 8 13	−45 6	5½ and 7	4
46	α Crucis ...	12 20 28	−62 29	1½, 2, and 5	5, 90 quintuple.
47	17 Comæ Ber.	12 23 25	+26 30	4½ and 6	145 [use low power].
48	δ Corvi	12 24 11	−15 54	3 and 8½	23
49	γ Crucis ...	12 25 2	−56 29	2 and 5	120
50	24 Comæ Ber.	12 29 36	+18 58	5½ and 7	20
51	γ Virginis ...	12 36 5	− 0 50	both 4	5·3 (1885)
52	α Can. Venat.	12 50 53	+38 54	2½ and 6½	20
53	ζ Ursæ Maj.	13 19 29	+55 30	3 and 5	14·4; Alcor, mag. 5, is distant 11¾′.
54	ι Boötis ...	14 12 17	+51 52	4½ and 8	38
55	5893 Lac.Cent.	14 14 44	−57 57	6, 8½, 11	9·6 and 35
56	α Centauri ...	14 32 7	−60 22	1 and 2	14·0 (1885)
57	π Boötis ...	14 35 33	+16 53	3½ and 6	5·9
58	54 Hydræ ...	14 39 39	−24 58	5½ and 7½	9·0
59	ε Boötis ...	14 40 11	+27 32	3 and 7	2·7; fine colours.
60	ξ Boötis ...	14 46 18	+19 33	3½ and 6½	3·3 (1887)
61	44 Boötis ...	15 0 11	+48 5	5 and 6	4·7
62	κ Lupi	15 4 16	−48 19	5½ and 7	27
63	μ Lupi	15 10 52	−47 28	5, 6, and 8	2·1 and 20
64	μ Boötis ...	15 20 21	+37 45	4 and 8	108; B also double (0·7″).
65	δ Serpentis ...	15 29 33	+10 54	3 and 5	3·4

No.	Star.	R.A. 1890.	Decl. 1890.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
66	ζ Coronæ ...	15 35 14	+36 59	5 and 6	6·2
67	ξ Scorpii ...	15 58 19	−11 4	4½ and 7½	7·1; A also double (1·1″).
68	β Scorpii ...	15 59 2	−19 30	2 and 5½	13·6; A also double (0·9″).
69	κ Herculis ...	16 3 6	+17 20	5½ and 7	30
70	ν Scorpii ...	16 5 36	−19 10	4 and 7	40; both double; 0·7″, 2·0″.
71	σ Scorpii ...	16 14 30	−25 16	4 and 9½	20
72	ρ Ophiuchi ...	16 18 59	−23 11	5 and 7½	3·4; two stars near make a trio.
73	17 Draconis...	16 33 37	+53 8	6, 6½, and 6	3·7 and 90
74	μ Draconis ...	17 3 3	+54 37	4 and 4½	2·6
75	36(A)Ophiuchi	17 8 34	−26 25	4½ and 6½	4·6
76	α Herculis ...	17 9 38	+14 30	3½ and 5½	4·7
77	39 Ophiuchi...	17 11 18	−24 9	5½ and 7½	10·8
78	ρ Herculis ...	17 19 53	+37 14	4 and 5½	3·9
79	ν Draconis ...	17 30 0	+55 15	both 5	62
80	ψ^1 Draconis...	17 43 54	+72 12	5½ and 6	31
81	67 Ophiuchi...	17 55 8	+ 2 56	4 and 8	55
82	95 Herculis ...	17 56 50	+21 35	5½ and 6	6·1
83	70 Ophiuchi...	17 59 53	+ 2 32	4 and 6	2·0 (1886)
84	40 Draconis...	18 8 16	+79 59	5½ and 6	20
85	ε Lyræ	18 40 41	+39 33	5, 6½, 5, 5½	3·4 and 2·5: A C 207.
86	ζ Lyræ	18 40 59	+ 37 29	5 and 5½	44
87	β Lyræ	18 46 1	+33 14	3·5 (var.), 8, 8½, and 9	46, 60, and 71
88	θ Serpentis ...	18 50 45	+ 4 3	4½ and 5	21·7
89	β^1 Sagittarii...	19 14 44	−44 40	4½ and 8	29
90	β Cygni ...	19 26 17	+27 43	3 and 7	34
91	o^2 Cygni ...	20 10 10	+46 24	4, 7½, 5½	107 and 338
		h. m. s.	°		″
92	α^2 Capricorni	20 11 57	−12 53	3 and 4	376 [use low power].
93	κ Cephei ...	20 12 35	+77 22	4½ and 8½	7·2
94	β^2 Capricorni	25 14 50	−15 7	3½ and 7	205
95	γ Delphini ...	20 41 33	+15 43	4 and 6½	11·3
96	ε Equulei ...	20 53 35	+ 3 52	5½ and 7½	10·6; A double (1·0″).
97	61 Cygni ...	21 1 57	+38 12	5½ and 6	20 (1884)
98	1 Pegasi ...	21 17 0	+19 24	4 and 9	37
99	β Cephei ...	21 27 14	+70 4	3 and 8	13·3
100	248 P. XXI. Cephei	21 35 33	+56 59	6, 8½, 8½	11·7 and 20
101	μ Cygni ...	21 39 12	+28 15	5, 6, and 7½	3·9 and 208
102	ξ Cephei ...	22 0 35	+64 5	5 and 7	6·6
103	11 P. XXII. Cephei	22 4 52	+58 45	6 and 6½	21; B double (0·6″).
104	33 Pegasi ...	22 18 21	+20 17	6½, 10, and 8	1·9 and 63
105	ζ Aquarii ...	22 23 9	− 0 35	4 and 4½	3·2 (1879)
106	δ Cephei ...	22 25 5	+57 51	4½ and 7	40: A var.
107	8^2 Lacertæ ...	22 30 58	+39 3	6½, 6½, 11, 10	Two nearest, 23
108	γ Piscis Aust.	22 46 25	−33 27	5 and 9	3·5

PART II.—CLUSTERS AND NEBULÆ.

Many clusters and nebulæ are *visible* with small telescopes, which cannot in any satisfactory way be examined by such instruments. The largest and brightest only have been selected for insertion in this list; and many of these will be found disappointing.

In the column of Synonyms—

D refers to Dreyer's New General Catalogue of 1888.
M „ Messier's Catalogue.
S & C „ Smyth and Chambers's *Cycle of Celestial Objects* (2nd ed. 1881. Clarendon Press).

No.	Name or Constellation.	Synonym in various Catalogues.			R.A. 1890.	Decl. 1890.
		D	M	S & C	h. m. s.	° ′
1	47 Toucani	104	...	17	0 19 9	−72 41
2	Andromeda	224	31	35	0 36 47	+40 40
3	Nubecula Minor ...	292	...	...	0 48 41	−73 58
4	Toucan	362	...	...	0 58 31	−71 26
5	Cassiopeia...	581	103	78	1 25 56	+60 7
6	Triangulum	598	33	80	1 27 38	+30 6
7	Perseus	869	...	133	2 11 20	+56 38

1 Superb globular cluster, 15′ to 20′ in diameter. Central stars pale rose colour; outer ones white.
2 The great nebula; an elongated ellipse 2° long.
3 Visible to the naked eye.
4 A highly condensed cluster, 4′ in diameter.
5 A fine field.
6 Large roundish faint oval nebula, 40′ in diameter ±; resolvable into stars.
7 The magnificent double cluster in the sword-handle of Perseus: stars 7 to 14 mag.

No.	Name or Constellation.	Synonym in various Catalogues.			R.A. 1890.	Decl. 1890.
		D	M	S & C	h. m. s.	°
8	Perseus	1039	34	152	2 34 57	+42 15
9	η Tauri	...	...	218	3 40 56	+23 45
10	γ Tauri	...	...	241	4 13 31	+15 21
11	Columba	1851	...	...	5 10 29	−40 10
12	Auriga	1912	38	329	5 22 2	+35 44
13	Nubecula Major ...	...	...	...	5 24 6	−69 34
14	Taurus	1952	1	341	5 27 51	+21 56
15	Auriga	1960	36	343	5 29 2	+34 4
16	Orion	1976	42	348	5 29 52	− 5 27
17	Orion	1981	...	350	5 30 4	− 4 25
18	30 Doradûs	2070	...	367	5 39 29	−69 9
19	Auriga	2099	37	376	5 45 2	+32 31
20	Gemini	2168	35	388	6 2 4	+24 26
21	Canis Major	2287	41	437	6 42 13	−20 37
22	Monoceros...	2323	50	451	6 57 41	− 8 10
23	Puppis	2437	46	496	7 36 47	−14 27
24	Puppis	2477	..	509	7 48 23	−38 15
25	Argo Navis	2516	...	...	7 56 31	−60 34

8 A fine group of rather large stars.
9 The Pleiades.
10 The Hyades: a scattered group of rather large stars.
11 Bright globular cluster, 3′ in diameter.
12 Cruciform cluster. In same field, 30′ S., is 39 ♅ vii. In a rich neighbourhood.
13 Visible to the naked eye.
14 The "Crab" nebula. Large elliptical nebula, resolvable into stars.
15 A neat cluster of 9 to 11 mag. stars, near M 38, with double star in field, dist. 12″. Mags. 8 and 9.
16 The great nebula in Orion, with multiple star involved. The most magnificent of the nebulæ.
17 A brilliant field, 1° N. of δ.
18 Very large and irregular nebula.
19 Compact cluster of small stars.
20 Fine large cluster of 9 to 16 mag. stars. In same field to the N. is a neat cluster of small stars, 17 ♅ vi.
21 Large scattered cluster, 4° below Sirius.
22 Cluster; rather more than ⅓ from Sirius to Procyon.
23 Large loose cluster of small stars, 8 to 13 mag., with faint planetary nebula involved.
24 Superb cluster, 20′ in diameter.
25 Cluster of 200 or more stars, visible to the naked eye.

No.	Name or Constellation.	Synonym in various Catalogues.			R.A. 1890.	Decl. 1890.
		D	M	S & C	h. m. s.	° ′
26	Puppis	2547	...	527	8 7 25	−48 56
27	Cancer	2632	44	547	8 33 55	+20 19
28	Cancer	2682	67	558	8 45 10	+12 12
29	Carinæ	2932	...	606	9 31 13	−46 26
30	Ursa Major	3031	81	617	9 46 23	+69 38
31	Ursa Major	3034	82	617	9 46 27	+70 20
32	Carina	3114	...	623	9 59 8	−59 35
33	η Argûs	3372	...	658	10 40 47	−59 6
34	Centaurus	3532	...	684	11 1 50	−58 4
35	Ursa Major	3587	97	692	11 8 19	+55 36
36	Coma Berenices ...	4382	85	815	12 19 49	+18 47
37	Virgo	4472	49	825	12 24 8	+ 8 36
38	Virgo	4501	88	831	12 26 26	+15 1
39	Canes Venatici ...	4736	94	867	12 45 43	+41 43
40	κ Crucis	4755	...	870	12 47 7	−59 45
41	Coma Berenices ...	4826	64	879	12 51 19	+22 16
42	Coma Berenices ...	5024	53	897	13 7 30	+18 45
43	ω Centauri	5139	...	908	13 20 10	- 46 44

26 Large loose cluster, fully 20′ in diameter.
27 The fine cluster "Præsepe."
28 Large cluster of small stars, 10 to 15 mag.
29 Large rich cluster, upwards of 1° in diameter.
30 Bright elliptical nebula, 15′ long, 6′ wide ±. In same field is M 82.
31 Long narrow nebula, a bright ray, 7′ long, 1′ wide ±. In same field is M 81.
32 Large loose cluster.
33 A very large and remarkable nebula.
34 Large scattered cluster.
35 Large planetary nebula, 3½′ to 4′ diameter.
36 Round nebula; with attentive gaze, perhaps bi-nuclear; rather faint.
37 Round nebula, which becomes suddenly much brighter in the centre.
38 Large elliptical nebula, rather faint.
39 Bright, large, round nebula; resolvable. Much brighter in centre.
40 Rich loose cluster, containing many coloured stars.
41 Very large, bright, elliptical nebula, with stellar nucleus.
42 Very large, very fine, globular cluster of 12-mag. stars; 3′ diameter; very compressed.
43 Fine globular cluster.

No.	Name or Constellation.	Synonym in various Catalogues.			R.A. 1890.	Decl. 1890.
		D	M	S & C	h. m. s.	° ′
44	Canes Venatici ...	5194	51	913	13 25 13	+47 45
45	Canes Venatici ...	5272	3	928	13 37 3	+28 55
46	Libra	5904	5	1023	15 12 57	+ 2 30
47	Scorpio	6093	80	1080	16 10 26	−22 43
48	Scorpio	6121	4	1089	16 16 53	−26 14
49	Hercules	6205	13	1115	16 37 45	+36 39
50	Ophiuchus...	6218	12	1121	16 41 31	− 1 45
51	Ophiuchus...	6254	10	1136	16 51 22	− 3 56
52	Scorpio	6266	62	1139	16 54 14	−29 55
53	Ophiuchus...	6273	19	1141	16 55 48	−26 6
54	Ophiuchus...	6333	9	1163	17 12 37	−18 24
55	Hercules	6341	92	1165	17 13 46	+43 15
56	Ara	6397	...	1185	17 31 43	−53 36
57	Ophiuchus...	6402	14	1184	17 31 50	− 3 11
58	Ophiuchus...	...	.	...	17 39 35	+ 5 45
59	Ophiuchus...	6494	23	1203	17 50 28	−18 58
60	Sagittarius	6514	20	1210	17 55 41	−23 1

44 Remarkably singular double neb., the larger 6′ diam. ±, and ring-shaped. Spiral neb.
45 Very superb globular cluster of 11-mag. stars, very condensed; brighter than, but not so large as, 13 M.
46 Very bright superb globular cluster of stars, 11 to 15 mags.; very compressed.
47 Globular cluster of 14-mag. stars (*Herschel*): a round bright nebula in ordinary telescopes.
48 Rather loose cluster, compressed in centre, but dim. Precedes *α* Scorpii by about 1½°.
49 Large superb globular cluster of stars, 11 to 20 mags. One of the finest of its class.
50 Fine globular cluster of small stars, 10 mag., much compressed.
51 Fine large globular cluster of small stars, 10 to 15 mags., much compressed.
52 Large bright globular cluster of very small stars, 14 to 16 mags.
53 Bright globular cluster of very small stars, 16 mag., very compressed.
54 Bright globular cluster of small stars, 14 mag., 2′ diameter ±.
55 Magnificent globular cluster of small stars, condensed in centre.
56 Globular cluster.
57 Fine large globular cluster of small stars, 15 to 16 mags., 4′ diameter ±.
58 Large group of bright stars, closely *nf* δ Ophiuchi. B.A.C. 6012.
59 Interesting group of small stars.
60 An open cluster of stars, superposed upon a singular trifid nebulous mass. Requires a large telescope.

No.	Name or Constellation.	Synonym in various Catalogues.			R.A. 1890.	Decl. 1890.
		D	M	S & C	h. m. s.	° ′
61	Sagittarius	6523	8	1214	17 57 8	−24 22
62	Scutum Sobieskii ...	6603	24	1238	18 11 44	−18 26
63	Scutum Sobieskii ...	6611	16	1239	18 12 34	−13 49
64	Scutum Sobieskii ...	6613	18	1240	18 13 30	−17 10
65	Scutum Sobieskii ...	6618	17	1242	18 14 16	−16 14
66	Sagittarius	6656	22	1257	18 29 28	−23 59
67	Antinous	6705	11	1280	18 45 13	− 6 24
68	Lyra	6720	57	1287	18 49 28	+32 53
69	Lyra	6779	56	1321	19 12 16	+29 59
70	Sagittarius	6838	71	1372	19 48 49	+18 29
71	Vulpecula	6853	27	1377	19 54 48	+22 25
72	Capricornus	6981	72	1446	20 47 24	−12 56
73	Pegasus	7078	15	1484	21 24 38	+11 40
74	Aquarius	7089	2	1489	21 27 44	− 1 19
75	Capricornus	7099	30	1493	21 34 7	−23 39
76	Lacerta	7243	...	1526	22 11 57	+49 19
77	Cassiopeia...	7789	...	...	23 51 35	+56 6

61 Irregular cluster with nebula adjoining. A pretty low-power field.
62 Globular cluster of small stars, 15 mag., in a superb field of stars.
63 A loose cluster with nebulous background.
64 Very rich field.
65 The "Horse-shoe" nebula. In ordinary telescopes more the shape of a swan.
66 Fine large globular cluster of stars, 11 to 15 mags.
67 Exceedingly beautiful aggregation of small stars of about 11 mag.
68 The "Annular" nebula in Lyra, midway between β and γ.
69 In a fine field; a globular cluster of small stars, 11 to 14 mags., 3′ diameter.
70 Cluster of small stars, 11 to 16 mags., 3′ diameter ±.
71 The "Dumb-bell" nebula; oval in shape; major axis 9′ long, minor axis 5′ ±.
72 Large mass of very small stars, 3′ diameter. A globular cluster.
73 Fine globular cluster of very small stars, 5′ diameter ±, much compressed in centre
74 Fine globular cluster of very small stars, 5′ diameter ±.
75 Globular cluster of small stars, 12 to 16 mags., 2′ diameter ±, rather faint.
76 A magnificent field of stars.
77 A superb cluster of small stars and star dust, 11 to 18 mags.

PART III.—MISCELLANEOUS OBJECTS.

The following list contains objects which are not within the scope of the two foregoing sections; to wit, coloured and variable stars not smaller (for the most part) than magnitude 7½, and, in the case of variables, of short periods:—

No.	Name.	R. A. 1890.	Decl. 1890.	Mag.	Notes.
		h. m. s.	° ′		
1	– Piscium	1 10 4	+25 11	7	Fiery red *.
2	R Sculptoris ...	1 21 54	−33 7	6	Beautiful orange-red *.
3	*o* Ceti	2 13 47	− 3 28	var.	Max. 2; generally invisible at minimum. Period 330^{d}. Fiery red at max.
4	*α* Ceti	2 56 31	+ 3 39	2½	Fine orange *, with a blue neighbour in the field to the N.
5	*β* Persei	3 1 2	+40 31	var.	Max. 2; min. 4; period, $2^{d}20\frac{3}{4}^{h}$.
6	65 Birm. Camelop.	3 32 21	+62 17	7	Pale crimson *.
7	W. B. IV. 585 Erid.	4 29 8	− 9 10	6	Fiery red *.
8	5 Orionis	4 47 38	+ 2 19	5½	Deep orange *. "Probably var."
9	R Leporis	4 54 36	−14 58	var.	Max. 6; min. 9; period 438^{d}; an intense crimson *.

No.	Name.	R.A. 1890.	Decl. 1890.	Mag.	Notes.
		h. m. s.	° ′		
10	899 H. P. Orionis	4 59 43	+ 1 1	7	Intense fiery red *.
11	– Leporis	5 6 38	–12 1	7½	Deep red *.
12	Arg. + 7 : 929 Orionis ...	2 27 16	+ 7 3	7¾	Very red *.
13	U Orionis	5 49 17	+20 9	6½	Fiery red * Period $\pm 365^d$.
14	5 Lyncis	6 17 12	+ 8 28	5½	Fiery red *. In a striking group.
15	144 Birm. Gemin.	6 19 11	+14 46	7	Reddish yellow *.
16	2139 B. A. C. Aur.	6 28 59	+38 32	6	Deep fiery red *.
17	μ Canis Majoris...	6 51 3	–13 54	5¼	Fiery red *.
18	14776 Lal. Puppis	7 28 44	–14 17	5	Fiery red *. Brilliant field *p*.
19	17576 Lal. Cancri	8 49 11	+17 39	7	Pale crimson *.
20	3121 B. A. C. Argûs	9 3 13	–25 24	4¾	Deep red *.
21	R Leonis	9 41 39	+11 56	var.	Max. 5; min. 10; period, 312^d; pale crimson *.
22	2874 Brisb. Antliæ	10 7 5	–34 46	7	Scarlet *.
23	3630 B. A. C. Ant.	10 30 20	–38 59	6½	"Orange, almost scarlet *."
24	3637 B. A. C. Hyd.	10 32 7	–12 48	6	Fiery red * "Var."
25	20918 Lal. Hydræ	10 46 16	–20 37	7	"Copper red *: most magnificent."
26	R Crateris	10 55 8	–17 44	var.	Red *; follows α $42\frac{1}{2}^s$ and 1′ S. Max. 8; min. 9.
27	4287 B. A. C. Can. V.	12 39 57	+46 2	5½	"Deep orange brown *."

No.	Name.	R.A. 1890.	Decl. 1890.	Mag.	Notes.
		h. m. s.	° ′		
28	291 Birm. Crucis	12 40 58	–59 5	8½	Intense blood-red *; in the field with β Crucis, a white *.
29	298 Birm. Drac....	12 52 5	+66 35	7	Pale crimson *.
30	328 Birm. Boötis	14 19 14	+26 12	7½	Vivid red *.
31	β Libræ	15 11 5	– 8 58	2½	Beautiful pale-green *.
32	347 Birm. Apodis	15 14 3	–75 32	7	"Very high red *."
33	39 Libræ	15 30 21	–27 46	4	Decided red *.
34	α Scorpii	16 22 39	–26 11	1	Fiery-red *: double dist. 3″.
35	W. B. XVII. 912 Ophi.	17 46 57	+ 1 20	6½	Fiery red *. Fine field.
36	422 Birm. Ophi....	17 52 39	+ 2 44	7½	Reddish *. "? Var."
37	35611 Lal. Aquilæ	18 58 32	– 5 50	7½	Very fine fiery red *. "? Var."
38	4 Vulpeculæ ...	19 20 38	+19 35	5¼	Orange *: fine field.
39	6702 B. A. C. Drac.	19 25 30	+76 21	6½	Strong fiery red *. "? Var."
40	36981 Lal. Sagit.	19 28 0	–16 36	7	Deep red *. ? Var. in colour.
41	6769 B. A. C. Cyg.	19 40 16	+40 26	6	Fiery red *.
42	χ Cygni	19 46 20	+32 38	var.	Max. 4; min. 0; period, 406^d. Fiery red when approach. max.
43	η Aquilæ	19 46 52	+ 0 43	var.	Max. 3·6; min. 4·7; period, $7{\cdot}17^d$.
44	526 Birm. Sagit.	20 0 12	–27 32	7	Deep red *.
45	545 Birm. Capric.	20 10 40	–21 38	7½	Decided red *.

No.	Name.	R.A. 1890.	Decl. 1890.	Mag.	Notes.
		h. m. s.	° ′		
46	U Cygni	20 16 12	+47 32	var.	Max. 7; min. 11 <; period, 461^d. Very red *: in striking contrast with a blue * *nf*.
47	61 P. XXI. Ceph.	21 9 59	+59 38	7½	Remarkably fiery red *. "? Var."
48	8745 Lac. Indi. ...	21 14 19	−70 11	6	Ruby-orange *.
49	589 Birm. Cygni	21 37 23	+35 0	7	Unmistakable fiery red *.
50	μ Cephei	21 40 8	+58 16	var.	Max. 4; min. 6; period, 5 or 6 years: "very fine deep garnet."
51	42431 Lal. Aquarii	21 40 50	− 2 43	6⅓	Decided red *.
52	Arg. + 65:1691 Cephei ...	21 54 22	+65 37	6½	Fiery red *. Blue * 6½ mag. near *p*.
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