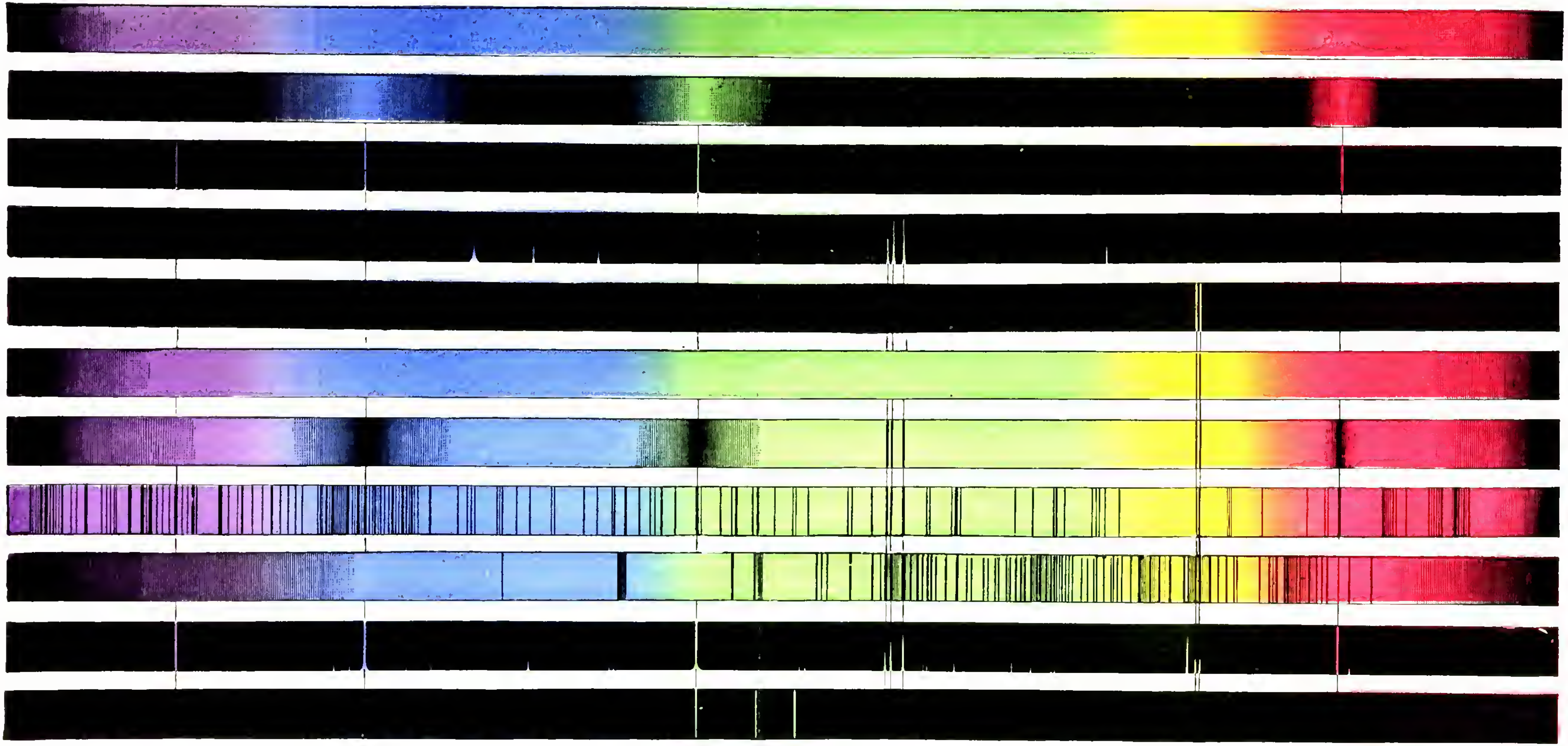
ELEMENTARY LESSONS

IN

ASTRONOMY

RADIATION AND ABSORPTION SPECTRA.



[For description, see back.

DESCRIPTION OF FRONTISPIECE.

1. Continuous Spectrum. 2. Spectrum of Hydrogen, Ordinary Pressure. 3. Spectrum of Hydrogen, very Low Pressure. 4. Spectrum of Magnesium Vapour, showing the Long and Short Lines. 5. Spectrum of Sodium Vapour, Low Temperature.	*Radiation.*
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10. Spectrum of Chromosphere. 11. Spectra of Nebula.	***Radiation.***

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IN

ASTRONOMY

BY

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D. E.

PREFACE TO THE 35TH THOUSAND.

THE present reprint has been revised throughout, and in the earlier portions of the work references have been made to the conclusions, having reference to the constitution of the heavenly bodies, that I have recently communicated to the Royal Society.

I have to express my obligations to Miss A. M. Clerke, and to Mr. A. Fowler assistant to the Solar Physics Committee, for their kind help in the revision and in the reading of proof sheets.

J. NORMAN LOCKYER.

SCIENCE SCHOOLS,
February 29, 1888.

PREFACE TO FIRST EDITION.

THESE "Elementary Lessons in Astronomy" are intended, in the main, to serve as a text-book for use in Schools, but I believe they will be found useful to "children of a larger growth," who wish to make themselves acquainted with the basis and teachings of one of the most fascinating of the Sciences.

The arrangement adopted is new; but it is the result of much thought. I have been especially anxious in the descriptive portion to show the Sun's real place in the Cosmos, and to separate the real from the apparent movements. I have therefore begun with the Stars, and have dealt with the apparent movements in a separate chapter.

It may be urged that this treatment is objectionable, as it reduces the mental gymnastic to a minimum; it is right, therefore, that I should state that my aim throughout the book has been to give a connected view of the whole subject rather than to discuss any particular parts of it; and to supply facts, and ideas founded on the facts, to serve as a basis for subsequent study and discussion. A companion volume to the present one—I allude to the altogether admirable "Popular Astronomy" from the pen of the late Astronomer Royal—may, from this point of view, be looked upon as a sequel to two or three chapters in this book.

It has been my especial endeavour to incorporate the most recent astronomical discoveries. Spectrum-analysis and its results are therefore fully dealt with; and distances, masses, &c., are based upon the recent determination of the solar parallax.

The use of the Globes and of the Telescope have both been touched upon. Now that our best opticians are employed in producing "Educational Telescopes," more than powerful enough for school purposes, at a low price, it is to be hoped that this aid to knowledge will soon find its place in every school, side by side with the black-board and much questioning.

All the steel plates in the book, acknowledged *chefs-d'œuvres* of astronomical drawing, have been placed at my disposal by my friend Mr. Warren De La Rue. I take this opportunity of expressing my thanks to him, and also to the Council of the Royal Astronomical Society, M. Guillemin, Mr. R. Bentley, the Rev. H. Godfray, Mr. Cooke, and Mr. Browning, who have kindly supplied me with many of the other illustrations.

I am also under obligations to other friends, especially to Mr. Balfour Stewart and Mr. J. M. Wilson, for valuable advice and criticism, while the work has been passing through the press.

J. N. L.

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INTRODUCTION.

GENERAL NOTIONS.—THE USES OF ASTRONOMY.

1. AT night, if the sky be cloudless, we see it spangled with so many **stars,** that it seems impossible to count them ; and we see the same sight whether we are in England, or in any other part of the world. The earth on which we live is, in fact, surrounded by stars on all sides ; and this was so evident to even the first men who studied the stars that they pictured the earth standing in the centre of a hollow crystal sphere, in which the stars were fixed like golden nails.

2. In the daytime the scene is changed : in place of thousands of stars, our eyes behold a glorious orb whose rays light up and warm the earth, and this body we call **the sun.** So bright are his beams that, in his presence, all the "lesser lights," the stars, are extinguished. But if we doubt their being still there we have only to take a candle from a dark room into the sunshine to understand how their feeble light, like that of a candle, is "put out" by the greater light of the sun.

3. There are, however, other bodies which attract our attention. **The moon** shines at night now as a crescent

and now as a full moon, sometimes rendering the stars invisible in the same way as the sun does, though in a less degree, and showing us by its changes that there is some difference between it and the sun : for while the sun always appears round, because we receive light from all parts of its surface turned towards us, the shape of the bright or lit-up portion of the moon varies from night to night, that part only being visible which is turned towards the sun.

4. Again, if we examine the heavens more closely still, we may see, after a few nights' watching, one, or perhaps two, of the brighter "stars" change their position with regard to the stars lying near them, or with regard to the sun if we watch that body closely at sunrise and sunset. These are the **planets**; the ancients called them "wandering stars."

5. But the planets are not the only bodies which move across the face of the sky. Sometimes a **comet** may by its sudden appearance and strange form awaken our interest and make us acquainted with another class of objects unlike any of those which we have previously mentioned.

6. Such are the celestial bodies ordinarily visible to us. Far away, and comparatively so dim that the naked eye can make little out of them, lie the **nebulæ,** so called because in the telescope they often put on strange cloud-like forms ; they differ as much from stars in their appearance as comets do from planets.

7. There are other bodies, to which we shall refer by and by, But we will, in this place, content ourselves with stating generally what Astronomy teaches us concerning star and sun, moon and planet, comet and nebula.

8. To begin then with the **stars**. So far from being fixed, and being stuck as it were in a hollow glass globe, which state of things would cause all to be at pretty nearly equal distances from us, they are all in rapid motion, and their distances vary enormously; although all of them are so very far away that they appear to us to be at rest, as a ship does when sailing along at a great distance from us. In spite, however, of their great and varying distances, science has been able to get a mental bird's-eye view of all the hosts of stars which the heavens reveal to our eyes, as they would appear to us if we could plant ourselves far on the other side of the most distant one. The telescope —an instrument which will be fully described further on— has, in fact, taught us that all the stars which we see, form, after all, but a cluster of islands as it were in an infinite ocean of space; so that we may think of all the stars which we see as forming our visible **universe**, and when we have got that thought well into our minds we may think of parts of space beyond our ken containing other universes, as there are other towns besides London in England.

9. Further, we know that our sun is one of the stars which compose this star-cluster, and that the reason that it appears so much bigger and brighter than the other stars is simply because it is the nearest star to us.

We all of us know how small a distant house looks or how feebly a distant gas-lamp or candle seems to shine; but the distant house may be larger than the one we live in, or the distant light may really be brighter than the one which, being nearer to us, renders the other insignificant. It is precisely so with the stars. Not only would they appear to us as bright as the sun, if we were as near to them, but we know for a fact that some of them are larger and brighter.

10. Now, why do the stars and the sun shine? They shine, or give out light, because they are *red or white hot.* At the surfaces of some, vapours of metals are mingling together with a heat more fierce than anything we can imagine. In others we have meteorites in collision, and the light is produced from these and the surrounding vapours.

11. What, then, are the **planets?** We may first state that they are comparatively small bodies travelling round our sun at various distances from him. Our earth is one of them. A moment's thought on what we have said about the sun and stars will, however, show us another important difference between the planets and the sun. We have seen that the sun is a white-hot body; our earth, we know, is, on the contrary, a cold one: all the heat we get is from the sun. Because the earth is cold it cannot give out light any more than a cold poker can. Astronomers have learnt that all the other planets are like the earth in this respect. They are all dark bodies—having no light in themselves—and they all, like us, get their light and heat from the sun. When, therefore, we see a planet in the sky, we know that its light is sunshine second-hand; that, as far as its light is concerned, it is but a looking-glass reflecting to us the light of the sun.

We have now got thus far: planets are dark or obscure, or non-self-luminous bodies travelling round the sun, which is a bright body—bright because it is white hot; and the sun is a star, one of the stars which together form our universe; the reason that it appears larger and brighter than the other stars being because we are nearer to it than we are to the others. It seems likely that the other stars have planets revolving round them, although astronomers have as yet no positive knowledge on the matter, as they are so very far away that the telescopes we possess at present are not powerful enough to show us their planets, if they have any.

12. We now come to the **moon**. What is it? The moon goes round the earth in the same way as we have seen the planets revolving round the sun: it is in fact a planet of the earth; it is to the earth what the earth is to the sun. Like the earth and planets, it is a dark body, and this is the reason it does not always appear round as the sun does. We only see that part of it that is lit up by the sun. In the moon we have a specimen of a third order of bodies called **satellites**, or companions, as they are the companions of the planets, accompanying them in their courses round the sun.

We have then to sum up again—(1) the sun, a star, (2) the planets revolving round the sun, and (3) satellites revolving round planets.

13. The **nebulæ** represent an early stage in the history of all stars. All the bodies in the universe are undoubtedly different aggregations of meteorites, and the differences between them are due to the different states of condensation. The light of the self-luminous bodies is due to the heat produced by collisions due to gravity. Nebulæ are the most sparse and scattered swarms of meteorites; the collisions are few and their light is consequently feeble. By the gradual condensation of the swarms, collisions become more numerous, the temperature is increased, and different orders of stars are formed.

Comets are similar in constitution to the nebulæ and some stars, and differ from them only in coming within the limits of our system. They rush for the most part from distant regions to our sun, and having gone round him they go back again, and we only see them for a small part of their journey.

14. Such, then, are some of the bodies with which the science of ASTRONOMY has to deal: but astronomers have not rested content with the appearances of these bodies: they have measured and weighed them in order to assign to them their true place. Thus they have found out that the sun is 1,305,000 times larger than the earth, and the earth 50 times larger than the moon. On the other hand, as we have seen, they have discovered that, while we travel round the sun, the moon travels round us, and at a distance which is quite insignificant in comparison. In other words, the moon travels round us at a distance of 238,000 miles, while we travel round the sun at a distance of 93,000,000 miles.

15. We thus see how it is that the greater size of the sun is balanced, so to speak, by its greater distance; the result being that the large distant sun looks about the same size as the small near moon.

16. We already see how enormous are the distances dealt with in astronomy, although they are measured in the same way as a land-surveyor measures the breadth of a river that he cannot cross. The numbers we obtain when we attempt to measure any distance beyond our own little planetary system convey no impression to the mind. Thus the nearest fixed star is more than 25,000,000,000,000 miles away, the more distant ones so far away that light, which travels at the rate of 186,300 miles in a second of time, requires thousands of years to dart from the stars to our eyes!

17. In spite, however, of this immensity, the methods employed by astronomers are so sure that, in the case of the nearer bodies, their distances, sizes, weights, and motions are now well known. We can indeed predict the place that the moon—the most difficult one to deal with—will occupy ten years hence, with more accuracy than we can observe its position in the telescope.

18. Here we see the utility of the science, and how upon one branch of it, PHYSICAL ASTRONOMY, which deals with the laws of motion and the structure of the heavenly bodies, is founded another branch, PRACTICAL ASTRONOMY, which teaches us how their movements may be made to help mankind.

19. Let us first see what it does for our sailors and travellers. A ship that leaves our shore for a voyage round the world takes with it a book called the "Nautical Almanac," prepared *beforehand*—three or four years in advance—by our Government astronomers. In this book the places the moon, sun, stars, and planets will occupy at certain stated hours for each day are given, and this information is all our sailors and travellers require to find their way across pathless seas or unknown lands.

20. But we need not go on board ship or into new countries to find out the practical uses of Astronomy. It is Astronomy which teaches us to measure the flow of time, the length of the day, and the length of the year:

without Astronomy to regulate them, clocks and watches would be almost impossible, and quite useless. It is Astronomy which divides the year into seasons for us, and teaches us the times of the rising and setting of the moon, which lights up our night. It is to Astronomy that we must appeal when we would inquire into the early history of our planet, or when we wish to map its surface.

21. Such, then, is Astronomy—the science which, as its name, derived from two Greek words (*ἀστήρ*, "star," and *νόμος*, "law,") implies, unfolds to us the laws of the stars.

CHAPTER I.

THE STARS AND NEBULÆ.

LESSON I.—*Magnitudes and Distances of the Stars. Shape of our Universe.*

22. THE first thing which strikes us when we look at the stars is, that they vary very much in brightness. All of those visible to the naked eye are divided into six classes of brightness, called "**magnitudes,**" so that we speak of a very brilliant one as "a star of the first magnitude:" of the feeblest visible as a star of the sixth magnitude, and so on. The number of stars of all magnitudes visible to the naked eye is about 6,000; so that the greatest number visible at any one time—as we can only see one half of the sky at once—is 3,000. If we employ a small telescope this number is largely increased, as that instrument enables us to see stars too feeble to be perceived by the eye alone. For this reason such stars are called telescopic stars. The stars thus revealed to us still vary in brightness, and the classification into magnitudes is continued down to the 12th, 14th, 16th, or even lower magnitudes, according to the power of the telescope; in powerful telescopes at least 20,000,000 stars down to the 14th magnitude are visible.

23. A star of the sixth magnitude is, as we have seen, the faintest visible to the naked eye. It has been estimated that the other stars are brighter than one of the sixth magnitude, by the number of times shown in the following table :--

	Times.
A star of the 5th magnitude	2
„ 4th „	6
„ 3d „	12
„ 2d „	25
„ 1st „	100
Sirius, the brightest of the 1st magnitude stars	400
The Sun, the nearest star to us	2,400,000,000,000

24. Now it is evident that these stars, as they all shine out with such different lights, one star differing from another star in glory, are either of the same size at very different distances, the furthest away being of course the faintest; or are of different sizes at the same distance, the biggest shining the brightest; or are of different sizes at different distances. Where the actual distances of the stars are known we can be certain; but from other considerations it is most probable that the difference in brilliancy is due to difference of distance, and not to size.

25. The distances of the stars from us are so great that it scarcely conveys any impression on the mind to state them in miles; some other method, therefore, must be used, and the velocity of light affords us a convenient one. Light travels at the rate of 186,300 miles in a second of time—that is to say, between the beats of the pendulum of an ordinary clock, light travels a distance equal to eight times round the earth.

26. In spite, however, of this great remoteness, the distances of some of them are known with considerable accuracy. Thus, leaving the sun out of the question, we find that the next nearest is situated at a distance which light requires four years and four months to traverse.

27. From the measurements already made, we may say that, on the average, light requires fifteen and a half years to reach us from a star of the first magnitude, twenty-eight years from a star of the second, forty-three years from a star of the third, and so on, until, for stars of the 12th magnitude, the time required is 3,500 years.

28. Winding among the stars, a beautiful belt of pale light spans the sky, and sometimes it is so situated, that we see that it divides the heavens into two nearly equal portions. This belt is the **Milky Way**; and the smallest telescope shows that it is composed of stars so faint, and apparently so near together, that the eye can only perceive a dim continuous glimmer.

29. We find the largest stars scattered very irregularly, but if we look at the smaller ones, we find that they gradually increase in number as their position approaches the portion of the sky occupied by the Milky Way. In fact, of the 20,000,000 stars visible, as we have stated, in powerful telescopes, at least 18,000,000 lie in and near the Milky Way. This fact must be well borne in mind.

30. Adding this fact to what has been said about the distances of the stars, we can now determine the shape of our **stellar system**. It is clear that it is most extended where the faintest stars are visible, and where they appear nearest together; because they appear faint in consequence of their distance, and because their close packing does not arise from their actual nearness to each other, but results from their lying in that direction at constantly increasing distances. Indeed, the stars which give rise to the appearance of the Milky Way, because in that part of the heavens they lie behind each other to an almost infinite distance, are probably as far from each other as our sun is from the nearest star.

31. The Milky Way, then, indicates to us, and traces for us, the direction in which the system has its largest dimensions; the absence of faint stars in the parts of the sky furthest from the Milky Way shows us that the limits of our system in that direction are much sooner reached than in the direction of the Milky Way itself. We gather, therefore, that its thickness is small compared with its length and breadth. This flat stratum of stars is split, as we might split a round piece of thick cardboard, in those regions where we see the Milky Way divided into two branches, and here its edge is double. Our sun is situated near the point at which the mass of stars begins to divide itself into two portions ; and, as there are more stars on the south side of the Milky Way than there are on the north, we gather that our earth occupies a position somewhat to the north of the middle of its thickness.

32. But although the Milky Way thus enables us to get a rough idea of the shape of our system as we might get a rough idea of the shape of a wood from some point within it by seeing in which direction the trees appeared densest and thickest together, and in which direction it was most easy to pierce its limits, still what the telescope teaches us shows that its boundaries are most probably very irregular.

33. The **Magellanic Clouds,** called the *Nubecula Major* and *Nubecula Minor*, visible in the southern hemisphere, are two cloudy oval masses of light, and are very like portions of the Milky Way, but they are apparently unconnected with its general structure.

LESSON II.—*The Constellations. Movements of the Stars. Movements of our Sun.*

34. We have in the last lesson considered our star-system as a whole ; we have discussed its dimensions, and given an idea of its shape. Before we proceed with a detailed examination of the stars of which it is composed, it will be convenient to state the groupings into which they have been arranged, and the way in which any particular star may be referred to.

35. The stars then, from the remotest antiquity, have been distributed into groups called **constellations,** each constellation being fancifully named after some object which the arrangement of the stars composing it was thought to suggest.

36. The first formal classification is due to Ptolemy of Alexandria, who about the year 150 A.D., arranged the 1,022 stars observed by Hipparchus, the father of astronomy, at Rhodes, about one century before our era. His catalogue contains 48 constellations; two were added by Tycho Brahe, and to these 50 (called the *ancient*) constellations have been added, in more modern times, 59, carrying the number up to 109.

37. The names of the ancient constellations and of the more important of the modern ones are as follows, beginning with those through which the sun passes in his annual round; these are called the **zodiacal constellations** (very carefully to be distinguished, as we shall see further on (Art. 361), from the signs of the zodiac bearing the same names). In English and in rhyme these are as under:

"The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin and the Scales,
The Scorpion, Archer, and He-goat,
The Man that bears the watering-pot,
And Fish with glittering tails."

And in Latin they run thus:

"*Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces.*"

38. The constellations visible above the zodiacal constellations, called the **northern constellations**, are as follows :

Ursa Major.	The Great Bear (The Plough).
Ursa Minor.	The Little Bear.
Draco.	The Dragon.
Cepheus.	Cepheus.
Boötes.	Boötes.
Corona Borealis.	The Northern Crown.
Hercules.	Hercules.
Lyra.	The Lyre.
Cygnus.	The Swan.
Cassiopea.	Cassiopea (The Lady's Chair).
Perseus.	Perseus.
Auriga.	The Waggoner.
Serpentarius.	The Serpent Bearer.
Serpens.	The Serpent.
Sagitta.	The Arrow.
Aquila.	The Eagle.
Delphinus.	The Dolphin.
Equuleus.	The Little Horse.
Pegasus.	The Winged Horse.
Andromeda.	Andromeda.
Triangulum.	The Triangle.
Camelopardalis.	The Cameleopard.
Canes Venatici.	The Hunting Dogs.
Vulpecula et Anser.	The Fox and the Goose.
Cor Caroli.	Charles' Heart.

39. The constellations visible below the zodiacal ones, called the **southern constellations**, are :

Cetus.	The Whale.
Orion.	Orion.
Eridanus.	The River Eridanus.
Lepus.	The Hare.
Canis Major.	The Great Dog.
Canis Minor.	The Little Dog.

Argo Navis.	The Ship Argo.
Hydra.	The Snake.
Crater.	The Cup.
Corvus.	The Crow.
Centaurus.	The Centaur.
Lupus.	The Wolf.
Ara.	The Altar.
Corona Australis.	The Southern Crown.
Piscis Australis.	The Southern Fish.
Monoceros.	The Unicorn.
Columba Noachi.	Noah's Dove.
Crux Australis.	The Southern Cross.

40. The whole heavens, then, being portioned out into these constellations, the next thing to be done was to invent some method of referring to each particular star. The method finally adopted and now in use is to arrange all the stars in each constellation in the order of brightness, and to attach to them in that order the letters of the Greek alphabet, using after the letters the genitive of the Latin name of the constellation. Thus *Alpha* (α) *Lyræ* denotes the brightest star in the Lyre; α *Ursæ Minoris*, the brightest star in the Little Bear. Some of the brightest stars are still called by the Arabian or other names they were known by in former times, thus, α *Lyræ* is known also as *Vega*, α *Boötis* as *Arcturus*, β *Orionis* as *Rigel*, α *Ursæ Minoris* as *Polaris* (the Pole star), &c.

41. All the constellations, and the positions of the principal stars, have been accurately laid down in Star-Maps and on Celestial Globes. With one or other of these the reader should at once make himself familiar. In star-maps the stars are laid down as we actually see them in the heavens, looking at them from the earth; but in globes their positions are reversed, as the earth, on which the spectator is placed, is supposed to occupy the centre of the globe, while we really look at the globe from the outside. Consequently the positions of the stars are reversed. So if we suppose two stars, the brighter one of them to the right in the heavens, the brighter one will be shown to the right of the other on a star-map, but to the left of it on a globe.

42. The twenty brightest stars in the heavens, or first magnitude stars, are as follows: they are given in the order of brightness and should be found on a map or globe.

Sirius,	in the constellation	Canis Major.
Canopus,	,,	Argo.
Alpha Centauri,	,,	Centaur.
Arcturus,	,,	Boötes.
Rigel,	,,	Orion.
Capella,	,,	Auriga.
Vega,	,,	Lyra.
Procyon,	,,	Canis Minor.
Betelgeuse,	,,	Orion.
Achernar,	,,	Eridanus.
Aldebaran,	,,	Taurus.
Beta Centauri,	,,	Centaur.
Alpha Crucis,	,,	Crux.
Antares,	,,	Scorpio.
Atair,	,,	Aquila.
Spica,	,,	Virgo.
Fomalhaut,	,,	Piscis Australis.
Beta Crucis,	,,	Crux.
Pollux,	,,	Gemini.
Regulus,	,,	Leo.

43. Now, although the stars, and the various constellations, retain the same relative positions as they did in ancient times, all the stars are, nevertheless, in motion; and in some of them nearest to us, this motion, called **proper motion**, is very apparent, and it has been measured. Thus Arcturus is travelling at the rate of *at least* fifty-four miles a second, or three times faster than our Earth travels round the sun, which is one thousand times faster than an ordinary railway train.

44. Nor is our Sun, which be it remembered is a star, an exception; it is approaching the constellation Hercules at the rate of four miles in a second, carrying its system of planets, including our Earth, with it. Here, then, we have an additional cause for a gradual change in the positions of the stars, for a reason we shall readily understand, if, when we walk along a gas-lit street, we notice the distant lamps. We shall find that the lamps we leave behind close up, and those in front of us open out as we approach them: in fact, the stars which our system is approaching are, generally speaking, slowly opening out, while those we are quitting are closing up, as our distance from them is increasing. We say "generally speaking," for it is found that the opening out and closing of the stars is not near so regular as that of the gas-lights, because all the stars themselves are moving about in different directions; but, by taking a large number of stars, their own motions counteract each other, and we can tell that we are moving just as well as if we were on a ship sailing amongst a number of others in motion in different directions.

45. The real motions of the stars,—called as we have seen, their *proper motions*,—and the one we have just pointed out, however, are to be gathered only from the most careful observation, made with the most accurate instruments. There are **apparent motions**, which may be detected in half an hour by the most careless observer.

46. These *apparent* motions are caused, as we shall fully explain by and by (Chap. IV.), by the two real motions of the Earth, first round its own axis, and secondly round the Sun.

LESSON III.—*Double and Multiple Stars. Variable Stars.*

47. A careful examination of the stars with powerful telescopes, reveals to us the most startling and beautiful appearances. Some stars which appear single to the unassisted eye, appear double, triple, or quadruple; and in some instances the number of stars revolving round a centre common to all is even greater. Because our Sun is an isolated star, and because the planets are now dark bodies, instead of shining, like the Sun, by their own light, as they once must have done, it is difficult, at first, to realize such phenomena, but they are among the most firmly established facts of modern astronomy. A beautiful star in the constellation of the Lyre will at once give an idea of such a system, and of the use of the telescope in these inquiries. The star in question is Epsilon (ϵ) Lyræ, and to the naked eye appears as a faint single star. A small telescope, or opera-glass even, suffices to show it double, and a powerful instrument reveals the fact that each star composing this double is itself double; hence it is known as "the Double-double." Here, then, we have a system of four suns, each pair, considered by itself, revolving round a point situated between them; while the two pairs considered as two single stars, perform a much larger journey round a point situated between them. (See Fig. 2.)


FIG. 1.—Orbit of a Double Star.

It may be stated roundly that the wider pair will complete a revolution in 2,000 years; the closer one in half that time; and possibly both double systems may revolve round the point lying between them in something less than a million of years.[1]

48. Nearly 12,000 double stars are now known, and in about 600 of these orbital motion has been ascertained, the motion in some cases being very rapid. In some cases the brilliancy of the component stars is nearly equal, but in others the light is very unequal. For instance, a first magnitude star may have a companion of the fourteenth magnitude. Sirius has, at least, one very faint

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[1] Admiral Smyth.

companion. Here is a list of some double stars, showing the time in which a complete revolution is effected:

	Years.
Zeta (ζ) *Herculis*	35
Eta (η) *Coronæ Borealis*	42
Sirius	49½
Zeta (ζ) *Cancri*	62
Alpha (α) *Centauri*	88½
Gamma (γ) *Coronæ Borealis*	95
Omega (ω) *Leonis*	111
Delta (δ) *Cygni*	336
Gamma (γ) *Leonis*	403
61 *Cygni*	783

49. Here, then, there can be no doubt that the stars are connected, and such pairs are called *physical couples*, to distinguish them from the *optical couples*, in which the component stars are really distant from each other, and have no real connexion; their apparent nearness to each other being an appearance caused by their lying in the same straight line, as seen from the Earth.

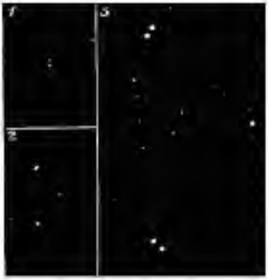


FIG. 2.—The Double-double Star in the constellation Lyra. 1. As seen in an opera-glass. 2. As seen in a small telescope 3. As seen in a telescope of great power.

50. Where the distance of a physical double star is known, we can determine the dimensions of the orbit of one star round the other, as we can determine the Earth's orbit round the sun. Thus we know that the distance between the two stars of 61 *Cygni* is 5,658,000,000 miles, and yet the two stars seem as one to the naked eye.

51. The stars are not only of different magnitudes (Art. 22), but the brilliancy of some particular stars changes from time to time. If the variation in the light is, as it is generally, slow, regular, and within certain limits, stars in which this is noticed are called **variable stars,** or shortly, **variables.** In some cases, however, the increase and decrease have been sudden, and in others the limits of change have been unknown; and hence we read of **new stars, lost stars,** and **temporary stars,** in addition to the more regular variables. In some cases of variability the effect is produced by increase of light accompanied by higher temperature, in others we have only obscuration.

52. The variation is, of course, measured by the different magnitudes of the stars at different times, and the amount of variability is measured by the extreme magnitudes. The *period* of the variability is generally the time that elapses between two successive greatest brightnesses.

53. We give a table of a few variable stars, in order that the foregoing may be clearly understood:

	Change of Magnitude from	to		Period of Change
η *Argûs*	1	7½	about	70 years.
R *Cephei*	5	11		73 „
R *Cassiopeæ*	6	lower than 14		425 days.
o *Ceti*	1 or 2	10		333 „
β *Lyræ*	3¼	4½		13 „
S *Cancri*	8	12		9½ „
β *Persei*	2¼	4		2 9/10 „
U *Cephei*	7	9		2½ „

54. The fourth star on our list is a very interesting one, and a picture of its changes is given in Fig. 3. At its period of greatest brightness it sometimes nearly reaches the first magnitude, sometimes stops at the fifth, while at minima it falls below the ninth magnitude. Among the acknowledged variables however β *Persei* is perhaps the most interesting, as its period is so short, and, unlike *o Ceti*—(called also *Mira*, or the Marvellous)—it is never invisible to the naked eye. The star in question shines as a star of the second magnitude for two days, thirteen hours and a half, and then *suddenly* loses its light and in three hours and a half falls to the fourth magnitude; its brilliancy then increases again, and in another period

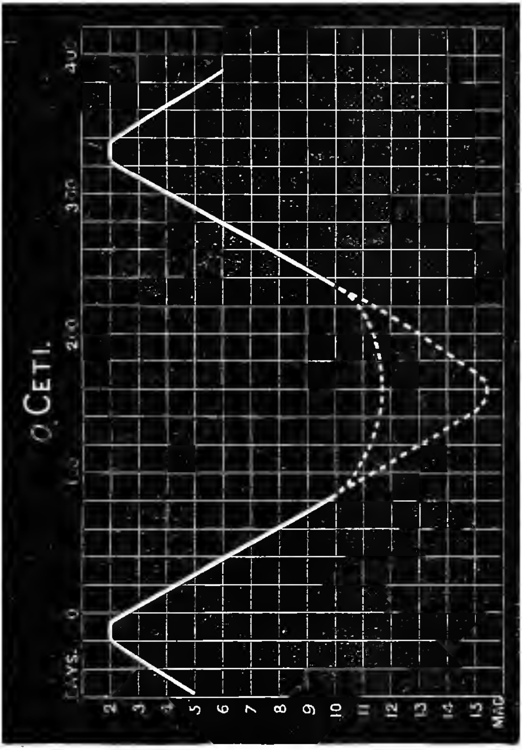


FIG. 3.—Light-curve of Mira.

of three hours and a half it re-attains its greatest brightness—all the changes being accomplished in less than three days.

55. Among the new, or temporary stars, those observed in 1572, 1866, 1876, and 1885, are the most noticeable. The first appeared suddenly in the sky and was visible for seventeen months; its light at first was equal to that of the planets at their greatest brilliancy; so bright was it, indeed, that it was clearly visible at noonday. It was long admitted without inquiry, on the unsupported assertion of an old writer named Leowitz, that in the years 945 and 1264 something similar had been observed in the same region of the sky (in *Cassiopeia*) in which this star appeared. But if we explain all these phenomena by the presence of a long-period variable star which is very bright at its maximum and fades out of view at its minimum, a reappearance of the star about the year 1880 might have been expected. Since this did not occur, the two earlier outbursts may the more readily be supposed apocryphal.

56. We now come to the *new star* of 1866, in the constellation of *Corona Borealis*, T, which was observed with much minuteness and with powerful methods of research not employed before. This star had been recorded some years previously as one of the ninth magnitude. On the 12th of May, 1866, however, it suddenly flashed up as a star of the second magnitude. On the 14th it had descended to the third magnitude; the decrease of brightness was for some time at the rate of about half a magnitude a day, but became less rapid towards the end of May. There is every reason to believe that this increased brilliancy was due to the sudden collision of one swarm of meteorites with another, a very high temperature and evolution of hydrogen being produced by the collisions.

56(*a*). A similar apparition took place in the constellation *Cygnus* on the 24th of November, 1876. In this instance the existence of the star had never been recorded until an abrupt accession of light raised it to the third magnitude.

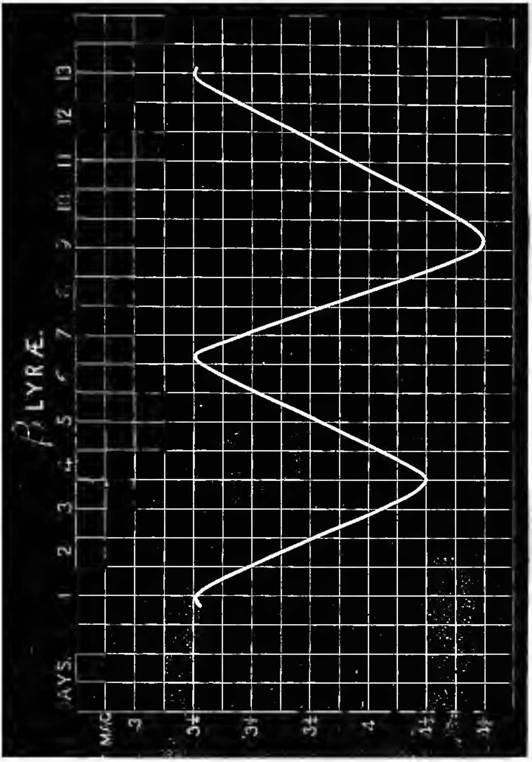


FIG. 4.—Light-curve of β Lyræ.

It can now be discerned only by the most powerful telescopes. Stranger still was the outburst of a new star near the very heart of the great nebula in Andromeda.

When first perceived, August 17, 1885, it was of ninth magnitude, but had brightened to the seventh by August 30, after which it declined in a few months to apparent extinction. A close parallel to this phenomenon was found in a brief stellar blaze observed in a nebula in

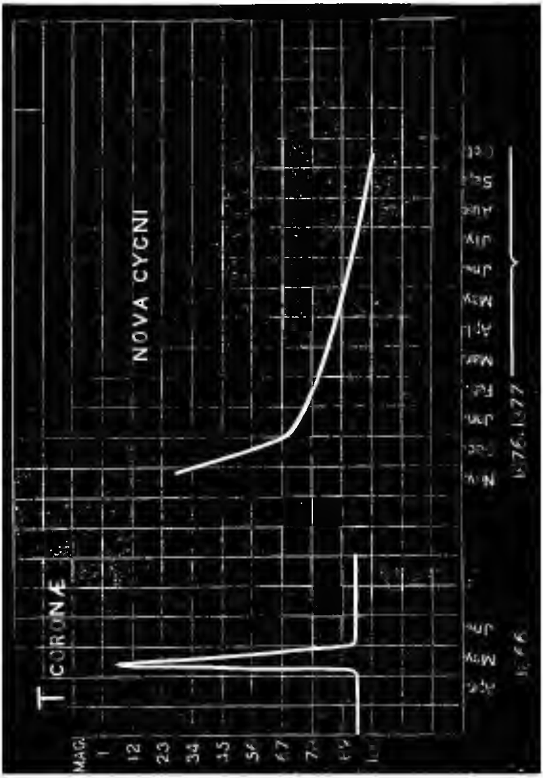


FIG. 5.—Light-curves of T Coronæ and Nova Cygni.

Scorpio (numbered 80 in Messier's Catalogue) on the 21st of May, 1860. A supposed "new star" seen near the star Chi (χ) Orionis, December 13, 1885, proves to be a variable of the "Mira" type, since it reached a second maximum after 364 days, December 12, 1886. In neither

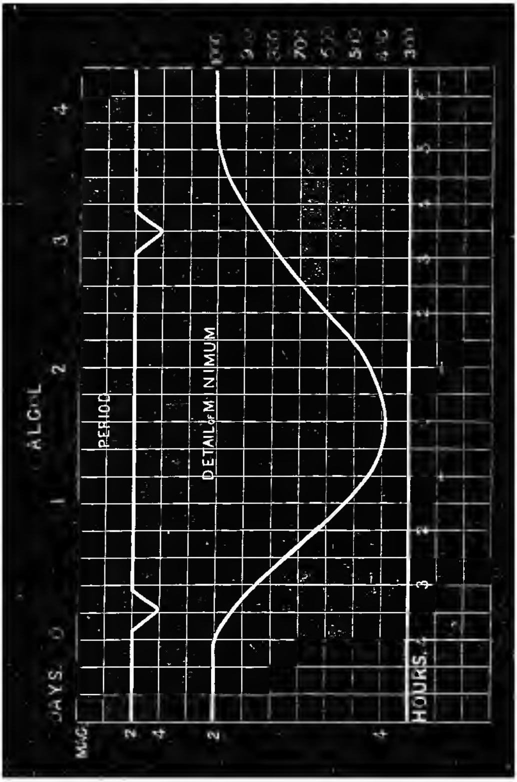


Fig. 6.—Light-curve of Algol.

of these two most recent cases was there the same evidence of gaseous incandescence as in the stars of 1866 and 1876.

57. The question of variable stars is one of the most interesting in the whole domain of astronomy. Prof. Pickering divides them into five classes, viz. 1. Temporary stars. 2. Stars markedly variable in long periods, such as Mira and Chi (χ) Cygni. 3. Stars exhibiting slight fluctuations according to laws not yet recognised. Alpha Orionis and Alpha Cassiopeiæ are among the better known examples, but in Dr. Gould's opinion, there are few stars which do not partake more or less of this character. 4. Stars continuously and regularly variable in periods of a few days. A good specimen of this class is Beta (β) Lyræ, of which the "light-curve" is traced in Fig. 4. The period of this remarkable star is thirteen days, during which it descends to two unequal minima, and twice resumes its original brightness of nearly third magnitude. 5. Stars discontinuously variable in very short periods. That is to say, they shine quite steadily except during one regularly recurrent interval of a few hours, during which they rapidly lose, and as rapidly regain, a large proportion of their light. To this class belong eight known stars, of which (β) Persei, or Algol, is the most conspicuous.

58. There are various different causes at work to produce these various effects. Such outbursts as those of T Coronæ and Nova Cygni are occasioned by the vivid incandescence not of a sunlike body, since such a body would take not a few weeks or months, but some millions of years to cool down again to its primitive state of comparative obscurity, while the extreme rapidity of their observed decline will be seen by a glance at Fig. 5. Effects of this kind are produced by an encounter between two meteor-swarms.

59. Recent investigations have shown that most of the variable stars are uncondensed meteorite-swarms, although the swarms are not so sparse as in nebulæ. In the variables of regular period the variations are due to cometic swarms of meteorites moving around a bright or

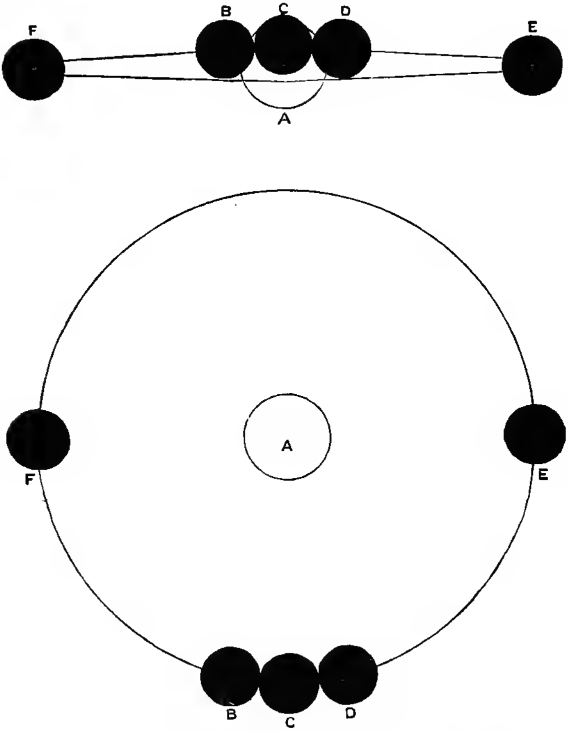


FIG. 7.—Plan and section of the orbit of the companion of Algol.

dark body, the maximum occurring at periastron, that is, when the swarm is nearest to the centre of the uncondensed or condensed mass. In that case, the velocity is greater and the collisions more violent, so that there is more light given out.

As regards the Algol class of variables, Prof. Pickering's investigations strongly countenance the hypothesis of partial eclipses at each revolution by a large dark satellite. In Fig. 6 the changes observed in the light of Algol are graphically represented; in Fig. 7 the orbit of the obscure companion the interposition of which produces those changes, first as seen from the earth, then projected in its own plane. In the case of another member of the same class, U Cephei (included in our list of variables), Pickering has shown that there must be a total eclipse by a partially luminous body, whereas the companion of Algol is altogether dark. This view is borne out by the reddening of the light of U Cephei at minima, as if by transmission through the absorbing atmosphere of another sunlike mass.

LESSON IV.—*Coloured Stars. Apparent Size. The Structure of the Stars. Clusters of Stars.*

60. The stars shine out with variously coloured lights; thus we have **scarlet stars, red stars, blue** and **green stars,** and indeed stars so diversified in hue that observers attempt in vain to define them, so completely do they shade into one another. Among large stars, Aldebaran, Antares, and Betelgeuse are unmistakably tinged with red; Sirius, Vega and Spica are of a bluish white; Arcturus, Capella, Procyon, and Dubhe in the Great Bear, show a yellow hue like that of our Sun.

61. In double and multiple stars, however, we meet with the most striking colours and contrasts; *Iota* (ι) *Cancri*, and *Gamma* (γ) *Andromedæ*, may be instanced. In *Eta* (η) *Cassiopeiæ* we find a large white star with a rich ruddy purple companion. Some stars occur of a red colour, almost as deep as that of blood. What wondrous colouring must be met with in the planets lit up by these glorious suns, especially in those belonging to the compound systems, one sun setting, say in clearest green, another rising in purple or yellow or crimson; at times two suns at once mingling their variously coloured beams! A remarkable group in the Southern Cross produced on Sir John Herschel "the effect of a superb piece of fancy jewellery." It is composed of over 100 stars, seven of which only exceed the tenth magnitude; among these, two are red, two green, three pale green, and one greenish blue.

62. The colours of the stars also change. The ancients called Sirius a red star, but then the habit was to observe it near the horizon. There are some striking differences between Sir William Herschel's observations on the colours of double stars and those of more recent observers.

63. In some variable stars the changes of colours observed are very striking. In the new star of 1572, Tycho Brahe observed changes from white to yellow, and then to red; and we may add that generally when the brightness decreases the star becomes redder.

64. The size or diameter of the stars cannot be determined by our most powerful instruments; but we know that, as seen from the Earth, they are, in consequence of their distance, mere points of light, so small as to be beyond all our most delicate measurements. The Moon, which travels very slowly across the sky, sometimes (as we shall see by and by) gets before, or *eclipses*, or *occults*, some of them; but they vanish in a moment—which they would not do if they were not as small as we have stated.

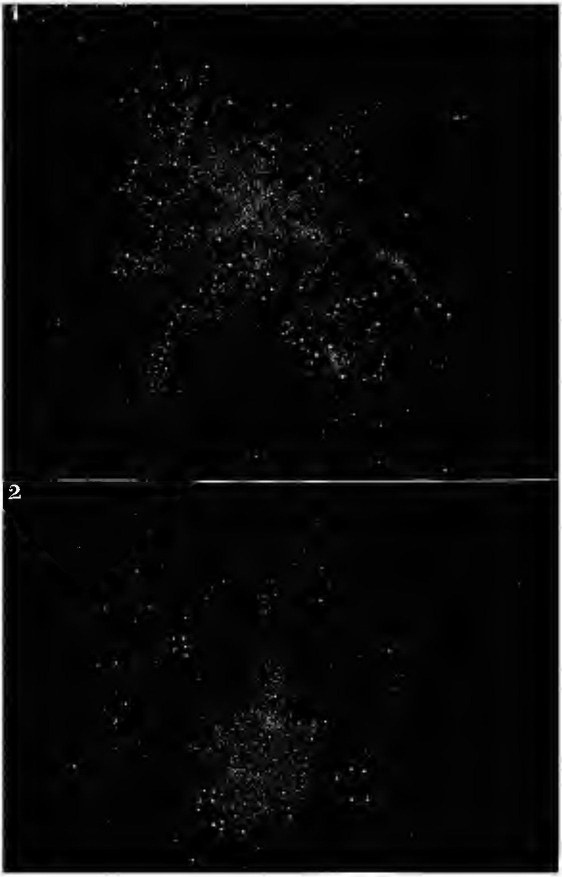
65. We will now pass on to what is known of the physical constitution of the stars. Recent researches have led to the conclusion that stars, and all other self-luminous bodies in the universe, consist of swarms of meteorites in various stages of condensation. The luminosity is due to the heat produced by collisions.

Some of the meteor-swarms are sparse, and consequently the number of collisions will be small, and very little light will be given out. As the swarm contracts the number of collisions will increase, and more light will be given out. After further contraction, the temperature of the swarm will be so high that the meteorites will become a mass of vapour, similar to that composing the sun. The highest stage of temperature is represented by such stars as Vega (*a* Lyræ). The subsequent cooling of such a mass of vapour will produce bodies of a different order—instead of meteorites scattered through a mass of vapour, there will be a densely gaseous, liquid, or solid nucleus, surrounded by an absorbing atmosphere, the composition of which will vary with the degree of cooling. There will be a considerable difference between an uncondensed swarm, and a condensed one at an equal mean temperature. The temperature of the former will be increasing, whilst that of the latter will be decreasing.

66. The vapours in a swarm will depend upon the temperature. Thus, while magnesium and manganese are driven off at the temperature of the Bunsen burner, the iron is only driven off at a very high temperature. While ice melts at 0° C., iron only melts at 2000° C. : the heat required to produce iron-vapour is not known.

67. The temperatures of the various celestial bodies can only be estimated by careful consideration of their spectra, and even then, in many cases, we have to be content with relative temperatures. While some of them are no hotter than a Bunsen burner, others are at temperatures far beyond our powers of measurement. The various orders of celestial bodies have been arranged in groups, such that the members of each group are at nearly equal temperatures and in similar states of condensation. (See Art. 504*a*).

Plate I.



STAR-CLUSTERS.

1. The Cluster of Hercules. 2. The Crab Cluster.

68. The colour of a celestial body will depend upon the state of condensation of the meteor-swarm of which it is composed. In the sparse swarms the colour is almost entirely dependent upon radiation. In closer swarms, absorption will affect the colour ; light from the meteorites will be absorbed by the vapours surrounding them. A green glass is green because it absorbs all other light but the green ; and so on with glasses, solids, vapours, or liquids of other colours. Our Sun at setting seems sometimes blood-red, in consequence of the absorption of *our* atmosphere ; if the absorption were in his own atmosphere, he would be blood-red at noonday. The white stars are the hottest, the yellow ones are cooler, and the red ones are not much botter than a Bunsen burner.

69. The elements already recognised in celestial bodies are those which are known to exist in meteorites. Those seen in the coolest bodies are those constituents of meteorites which are volatilised at lowest temperatures.

70. Having now dealt with the peculiarities of individual stars,—that is to say, their distance, arrangement, colour, variability, and structure,—we next come to the various assemblages or companies of stars observed in various parts of the heavens.

71. In the double and multiple systems (Art. 47) we saw the first beginnings of the tendency of the stars to group themselves together. In some parts of our system this tendency is exhibited in a very remarkable manner, the beautiful group of the **Pleiades** affording a familiar instance. The six or seven stars visible to the naked eye become 60 or 70 when viewed with a telescope of moderate power, while no less than 1,421 have recently been photographed. The **Hyades**, in the constellation Taurus, and the **Præsepe**, or "Beehive," in Cancer, may also be mentioned. In other cases the groups consist of an innumerable number of suns apparently closely packed together. That in the constellation Perseus is among the most beautiful objects in the heavens ; but many others, scarcely less stupendous, though much fainter by reason of their greater distance, are revealed by the telescope.

72. Assemblages of stars are divided into :—

1. **Irregular groups**, generally more or less visible to the naked eye.
2. **Star-clusters**, invisible to the naked eye, but which, in the most powerful telescopes, are seen to consist of separate stars. These are subdivided into ordinary clusters and globular clusters.

73. Clusters and nebulæ are designated by their number in the catalogues which have been made of them by different astronomers. The most important of these catalogues have been made by Messier, Sir William Herschel, and Sir John Herschel. A catalogue published by the latter in 1864 contains 5,079 objects, and the number was brought up to 6,251 by Dr. Dreyer in 1877.

74. We have already given some examples of star groups. The magnificent star-clusters, in the constellations Hercules, Libra, and Aquarius, may be instanced as among those which are best seen in moderate telescopes ; but some of the clusters which lie out of our universe, and which we must regard as other universes, are at such immeasurable distances, and are therefore so faint, that in the most powerful telescopes the real shape and boundary are not seen, and there is a gradual fading away at the edge, the last traces of which appear either as a luminous mist, or as cloud-like filaments, which become finer till they cease altogether to be seen. The Dumb-Bell cluster, in Vulpecula, and the Crab cluster, in Taurus, both of which have been resolved into stars, are instances of this.

75. In some of these star-clusters the increase of brightness from the edge to the centre is so rapid that it would appear that the stars are actually nearer together at the centre than they are near the edge of the cluster; in fact, that there is a real condensation towards the centre.

LESSON V.—*Nebulæ. Classification and Description.*

76. We now come to the **Nebulæ.** "Nebula" is a Latin word signifying a cloud, and for this reason the name has been given to everything which appeared cloud-like to the naked eye or in a telescope. The group in Perseus, for instance, appears like a nebula to the naked eye; in the smallest telescope, however, it is separated into stars.

77. Every time a telescope larger than any formerly used has been made use of, however, numbers of what were till then called nebulæ, and about which as nebulæ nothing was known, have been found to be nothing but star-clusters, some of them of very remarkable forms, so distant that even in telescopes of great power they could not be resolved,—that is to say, could not be separated into distinct stars.

78. Now, this is what has happened ever since the discovery of telescopes. Hence it was thought by some that all the so-called nebulæ were, in reality, nothing but distant star-clusters.

79. One of the most important discoveries of modern times, however, has furnished evidence of a fact,—long ago conjectured by some astronomers,—namely, that some of the nebulæ are something different from masses of stars, and that the cloud-like appearance is due to something else besides their distance and the still comparatively small optical means one can at present bring to bear upon them.

80. This discovery, however, has not yet led to an exhaustive re-arrangement of nebulæ according to their intrinsic nature. Thus their classification is still based upon telescopic appearance, real nebulæ being as yet imperfectly sorted out from those which, by reason of their great distance, appear like nebulæ.

81. By nebulæ, then, we understand all objects formerly classed as such, which up to this time have not been *resolved* into stars. They may be divided into the following classes:—

1.—Irregular nebulæ.
2.—Ring nebulæ and Elliptical nebulæ.
3.—Spiral, or Whirlpool nebulæ.
4.—Planetary nebulæ.
5.—Nebulæ surrounding stars.

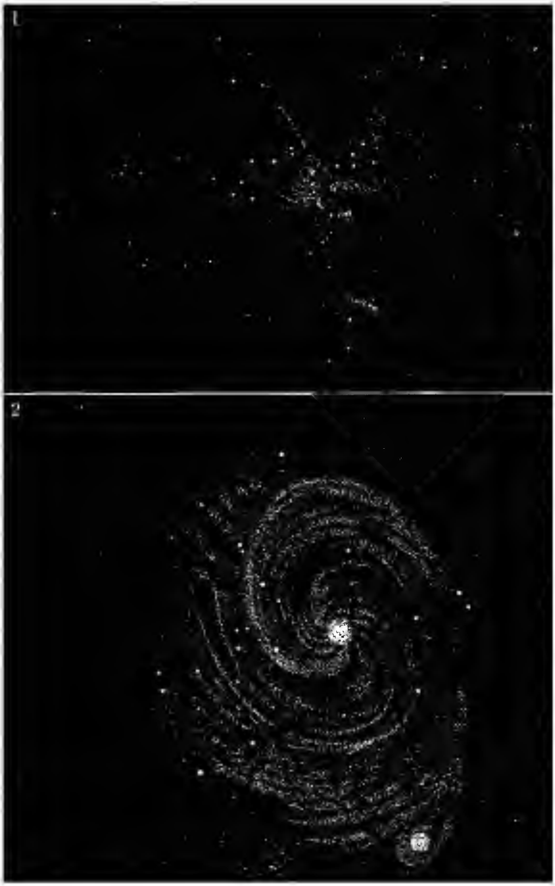
82. Some of the irregular nebulæ—those in the constellations Orion and Andromeda, for example—are visible to the naked eye on a dark night.

83. The great nebula of Orion is situated in the part of the constellation occupied by the sword-handle and surrounding the multiple-star Theta (θ). The nebulosity near the stars is flocculent, and of a greenish white tinge. There seems no doubt that the shape of this nebula and the position of its brightest portions are changing. One part of it appears, in a powerful telescope, startlingly like the head of a fish. On this account it has been termed the Fish-mouth nebula.

84. Two other fine irregular nebulæ are visible in the Southern hemisphere: one is in the constellation Dorado, the other surrounds Eta (η) Argûs. The latter occupies a space equal to about five times the apparent area of the Moon.

85. We have classed the ring-nebulæ and elliptical nebulæ together because probably the latter are, in several instances, ring-nebulæ looked at sideways. The finest

Plate II.



NEBULÆ.

1. The Nebula in Orion. 2. Spiral Nebula in Canes Venatici.

ring nebula is the 57th in Messier's catalogue (written 57 M. for short). It is in the constellation Lyra. The finest elliptical nebula is the one in Andromeda to which we have before referred. This nebula, the 31st of Messier's catalogue (31 M.) when viewed in large instruments, shows several curious black streaks running in the direction in which the nebula is longest.

86. The spiral or whirlpool nebulæ are represented by that in the constellation of Canes Venatici (51 M.). In an ordinary telescope this presents the appearance of two globular clusters, one of them surrounded by a ring at a considerable distance, the ring varying in brightness, and being divided into two in a part of its length. But in a larger instrument the appearance is entirely changed. The ring turns into a spiral coil of nebulous matter, and the outlying mass is seen connected with the main mass by a curved band. 33 M. Piscium, and 99 M. Virginis, are other examples of this strange phenomenon, which indicate to us the action of stupendous forces of a kind unknown in our own universe.

87. The fourth class, or planetary nebulæ, were so named by Sir William Herschel, as they shine with a planetary and often bluish light, and are circular or slightly elliptical in form. 97 M. Ursæ Majoris and 46 M. Argûs may be taken as specimens.

88. We come lastly to the nebulæ surrounding stars, or nebulous stars. The stars thus surrounded are apparently like all other stars, save in the fact of the presence of the appendage ; nor does the nebulosity give any signs of being resolvable with our present telescopes. Iota (ι) Orionis, Epsilon (ϵ) Orionis, 8 Canum Venaticorum, and 79 M. Ursæ Majoris, belong to this class.

Lesson VI.—*Nebulæ* (continued). *Their Faintness. Variable Nebulæ. Distribution in Space. Their Structure. Nebular Hypothesis.*

89. Having stated and described the several classes into which nebulæ may be divided, their general features and structure have next to be considered.

90. Like the stars, they are of different brightnesses, but as yet they have not been divided into magnitudes. This, however, has been done in a manner by determining what is termed the space-penetrating power or light-grasping power of the telescope powerful enough to render them visible. Thus supposing nebulæ to consist of masses of stars, it has been estimated that Lord Rosse's great Reflector, the most powerful instrument as yet used in such inquiries, penetrates 500 times further into space than the naked eye can; that is, can detect a nebula or cluster 500 times further off than a star of the sixth magnitude.

91. Now, if we suppose that a sixth magnitude star is 12 times further off than a star of the first magnitude—and this is within the mark—and that, as we have seen in Art. 27, light requires 120 years to reach us from such a star, the telescope we have referred to penetrates so profoundly into space that no star can escape its scrutiny "unless at a remoteness that would occupy light in over spanning it sixty thousand years."

92. An idea of the extreme faintness of the more distant nebulæ may be gathered from the fact, that the light of some of those visible in a moderately-large instrument has been estimated to vary from $\frac{1}{1500}$ to $\frac{1}{20000}$ of the light of a single sperm candle consuming 158 grains of material per hour, viewed at the distance of a quarter of a mile; that is, such a candle a quarter of a mile off is 20,000 times more brilliant than the nebula![1]

93. The phenomenon of variable, lost, new, and temporary stars has its equivalent in the case of the nebulæ, the light of which, it has been lately discovered, is in some cases subject to great variations.

94. In 1861 it was found that a small nebula, discovered in 1852 in Taurus, near a star of the tenth magnitude, had disappeared, the star also becoming dimmer. In the next year the nebula increased in brightness again; but was completely invisible 1877—1880. There is, besides, strong evidence of the periodical variability of two nebulæ—one situated in Cetus, the other in Virgo.

95. In Art. 30 the marked character of the distribution of the stars of our universe, giving rise to the appearance of the Milky Way, was pointed out. The distribution of the nebulæ, however, is very different; in general they lie out of the Milky Way, so that they are either less condensed there, or the visible universe (as distinguished from our own stellar one) is less extended in that direction. They are most numerous in a zone which crosses the Milky Way at right angles, the constellation Virgo being so rich in them that a portion of it is termed the nebulous region of Virgo. In fact, not only is the Milky Way the poorest in nebulæ, but the parts of the heavens furthest away from it are richest.

96. We now come to the question, What is a Nebula? The answer is—A true nebula consists of a sparse swarm of meteorites, the luminosity of which is due to the heat produced by collisions. The interspaces are partly filled with hydrogen and magnesium and other vapours, which are volatilised out of the meteorites. Amongst true nebulæ, are the great nebula in Orion, that surrounding Eta (η) Argûs; the ring nebula in Lyra, and all

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[1] Huggins.

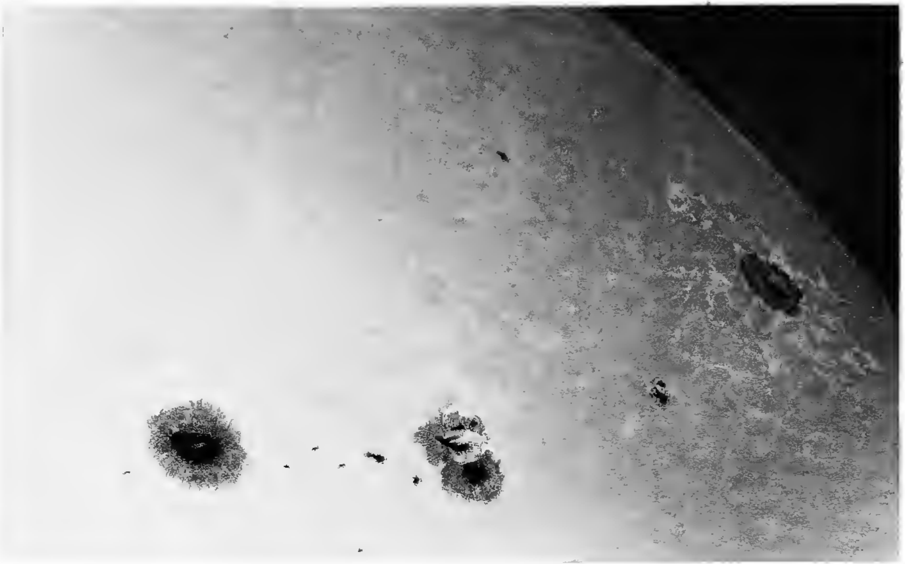
planetary nebulæ. The Andromeda nebula, on the other hand, seems to be of a stellar nature.

97. When, therefore, we see, in what we know to be a true nebula, closely associated points of light, we must not regard the appearance as an indication of resolvability into true stars. These luminous points, in some nebulæ at least, must be looked upon as probably denser aggregations of the meteorites composing the nebulæ.

98. The **nebular hypothesis** supposed that all the countless bodies which are distributed through space once existed in the condition of gaseous matter, but recent researches have shown that all of them have their origin in meteorites. According to this view, a nebula is to be regarded as a future star, for, by the gradual contraction of the mass which will be produced by gravitation, the collisions between the meteorites will become more numerous and violent, and the nebula will get hotter and brighter, first forming a star of Group II., then of Group III., and, if hot enough, of Group IV. During the subsequent cooling, it will become a star of Group V., then of Group VI., and finally it will become a cold body like a planet. (See Arts. 65 and 504*a*.) It may take long years to prove, or disprove, this hypothesis; but the tendency of recent observations assuredly is to show its correctness.

Plate. III

SUN SPOTS AND FACULÆ.



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A PHOTOGRAPH

Taken by M^{r} Warren De La Rue. *Sep^{t} 20, 1861.*

CHAPTER II.

THE SUN.

LESSON VII.—*Its relative Brightness, its Size, Distance, and Weight.*

99. We will now consider the star nearest to us—**the Sun,** which dazzles the whole family of planets by its brightness, supports their inhabitants by its heat, and keeps them in bounds by its weight.

100. The relative brilliancy of the centre of our system, compared to that of the stars, is, as we saw in Art. 23, so great that it is difficult at first to look upon it as in any way related to those feeble twinklers. This difficulty, however, is soon dispelled when we consider how near it is to us. Thus, to give another instance, though we receive 20,000,000,000 times more light from the Sun than we do from *Alpha* (α) *Lyræ*, that star is more than a million times further from us. There is reason to believe, indeed, that our Sun is, after all, by no means a large star compared with others ; for if we assume that the light given out by Sirius, for instance, is no more brilliant than is our sunshine, that star would be equal in bulk to nearly 600 suns.

101. Astronomers now know the **distance** of the Sun from the Earth. It is about 93,000,000 miles : and it is easy, therefore, as we shall see by and by (Chap. VIII.), to determine its size : and here again, as in the case of the distances of the stars, we arrive at figures which convey scarcely any ideas to the mind. The distance from one side of the Sun to the other, through its centre—or, in other words, the *diameter* of the Sun,—is 867,000 miles. Were there a railway round our earth, a train, going at the rate of 30 miles an hour, would accomplish the journey in a month: a railway journey round the Sun, going at the same rate, would require more than ten years. In this way we may also obtain the best idea of the Sun's distance from us—a distance travelled over by light in eight and a third minutes. A train going at the speed we have named, and starting on the 1st of January, 1887, would not arrive at the Sun till past the middle of the year 2,240!

102. Such then are the distance and size of the centre of our system. If we represent the Sun by a globe about two feet in diameter, a pea at the distance of 215 feet will represent the Earth; and let us add, the nearest fixed star would be represented by a similar globe placed at the distance of 11,000 miles.

103. More than 1,300,000 Earths, as commonly stated, would be required to make one Sun. This is expressed by saying that the **volume** of the Sun is 1,300,000 times greater than that of the Earth: but the statement takes into account only the globe bounded by the photosphere. The atmosphere of the Sun, however, extends to fully half a million of miles from its surface; and this space may well be included in our estimate of its volume. We find then on this view, that the Sun is more than thirteen million times as large as the Earth, while it only weighs 330,000 times as much. That is, bulk for bulk, thirteen million, but by mass or weight 330,000 Earths would go to make up the Sun. The matter composing the Sun and its immediate appendages is then, *on the average*, only $\frac{1}{40}$ as dense as the matter composing the Earth, or less than one seventh as dense as water. So that we are fully justified in asserting the Sun to be a mainly gaseous body; though the enormous compression must produce, below the photosphere, a consistence very different from what we ordinarily associate with a gas.

104. The Sun, like the Earth or a top when spinning, turns round, or rotates, on an axis; this **rotation** was discovered by observing the spots on its surface, about which we shall have much to say in the next Lesson. It is found that the spots always make their first appearance on the same side of the Sun; that they travel across it in about fourteen days; and that they then disappear on the other side. This is not all: if they be observed in June, they go *straight* across the sun's face or disc with a dip downwards; if in September, they then cross in a curve; while in December they go straight across again, with a dip upwards; and in March their paths are again curved, this time with the curve in the opposite direction.

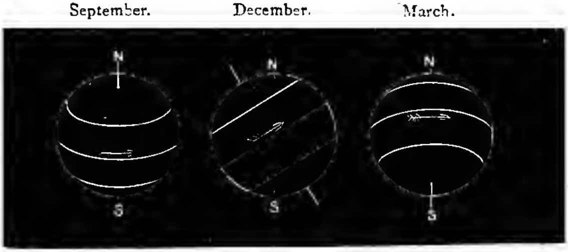


Fig. 8.—Position of the Sun's axis, and apparent paths of the spots across the disc, as seen from the Earth at different times of the year. The arrows show the direction in which the Sun turns round. The inclination of the Sun's axis is exaggerated, so that the effect it produces may be more clearly seen.

105. Now it is important that we make this perfectly clear. We know that the Earth goes round the Sun once a year. It has been found also that its path is so level—that is to say, the Earth in its journey does not go up or down, but always straight on—that we might almost imagine the earth floating round the Sun on a boundless ocean, both Sun and Earth being half immersed in it. We shall see further on that this level—this plane—called the

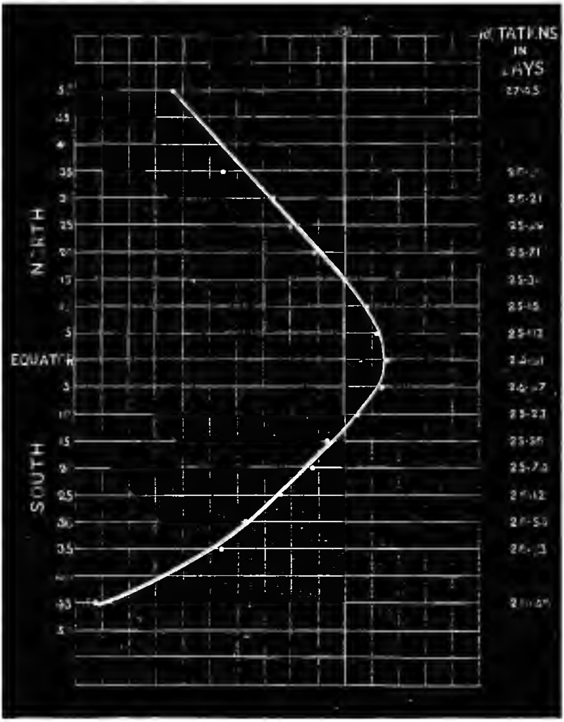


FIG. 9.—Curve showing the period of rotation of the photosphere in different latitudes north and south from Carrington's observations; 851′ of solar longitude per diem = rate of rotation in lat. 15° N. The vertical lines represent differences of 10′ of longitude + to the right, - to the left, of the line cutting the curve in lat. 15° N.

plane of the Ecliptic—is used by Astronomers in precisely the same way as we commonly use the sea level. We say, for instance, that such a mountain is so high above the level of the sea. Astronomers say that such a star is so high above the plane of the ecliptic.

106. Well then, we have imagined the Earth and Sun to be floating in an ocean up to the middle—which is the meaning of half immersed. Now, if the Sun were quite upright, the spots would always seem at the same distance above the level of our ocean. But this we have not found to be the case. From two opposite points of the Earth's path (the points it occupies in June and December) the spots are seen to describe straight lines across the disc, while midway between these points (September and March) their paths are observed to be sharply curved, in one case

FIG. 10.—Copy of part of a photograph taken at Dehra Dun in 1884, showing a sun-spot passing over the Sun's edge.

with the convex side downwards, in the other with the convex side upwards. A moment's thought will show that these appearances can only arise from a dipping down of the Sun's axis of rotation. Now this we find to be the case. The Sun's axis inclines towards the point occupied by the Earth in September. When we come to deal with the Earth and the other planets, we shall find that their axes also incline in different directions.

107. It has been found that the spots, besides having an apparent motion, caused by their being carried round by the Sun in its rotation, have a motion of their own. This **proper motion**, as distinguished from their apparent motion, has recently been investigated in the most complete manner by Mr. Carrington. What he has discovered shows that there need be no wonder that different observers have varied so greatly in the time they have assigned to the Sun's rotation. As we have already shown (Art. 104), this rotation has been deduced from the time taken by the spots to cross the disc; but it now seems that all sun-spots have a movement of their own, and that the rapidity of this movement varies regularly with their distance from the solar equator,—that is, the region half-way between the two poles of rotation. In fact, the spots near the equator travel faster than those away from it (Fig. 9), so that if we take an equatorial spot we shall say that the Sun rotates in about twenty-five days; and if we take one situated half-way between the equator and the poles, in either hemisphere, we shall say that it rotates in twenty-seven and a half days.

108. We have now considered the distance and size of the Sun; we have found that it, like our Earth, rotates on its axis, and we have determined the direction in which the axis points. We must next try to learn something of its appearance and of its nature, or, as it is called, its physical constitution. Here we confess at once that our knowledge on this subject is not yet complete. This, however, is little to be wondered at. We have done so much, and gleaned so many facts, at distances the very statement of which is almost meaningless to us, so stupendous are they, that we forget that our mighty Sun, in spite of its brilliant shining and fostering heat, is still some 93,000,000 miles removed ;—that its diameter is 100 times that of our Earth ; and that the chasm we call a sun-spot is yet large enough to swallow us up, and half a dozen of our sister planets besides ; while, if we employ the finest telescope, we can only observe the various phenomena as we should do with the naked eye at a distance of 180,000 miles.

To look at the Sun through a telescope, without proper appliances, is a very dangerous affair. Several astronomers have lost their eyesight by so doing, and our readers should not use even the smallest telescope without proper guidance.

Lesson VIII.—Telescopic Appearance of the Sun-spots. Penumbra, Umbra, Nucleus, Faculæ, Granules. Red Flames.

109. We have already said that the first things which strike us on the Sun's surface, when we look at it with a powerful telescope, are the spots. In Plate IV. we give drawings of a very fine one, visible on the Sun in 1865. We shall often refer to them in the following description. The spots are not scattered all over the Sun's disc, but are generally limited to those parts of it a little above and below the Sun's equator, which is represented by the middle lines in Fig. 8. The arrows show the direction in which the spots, carried round by the Sun's rotation, appear to travel across the disc.

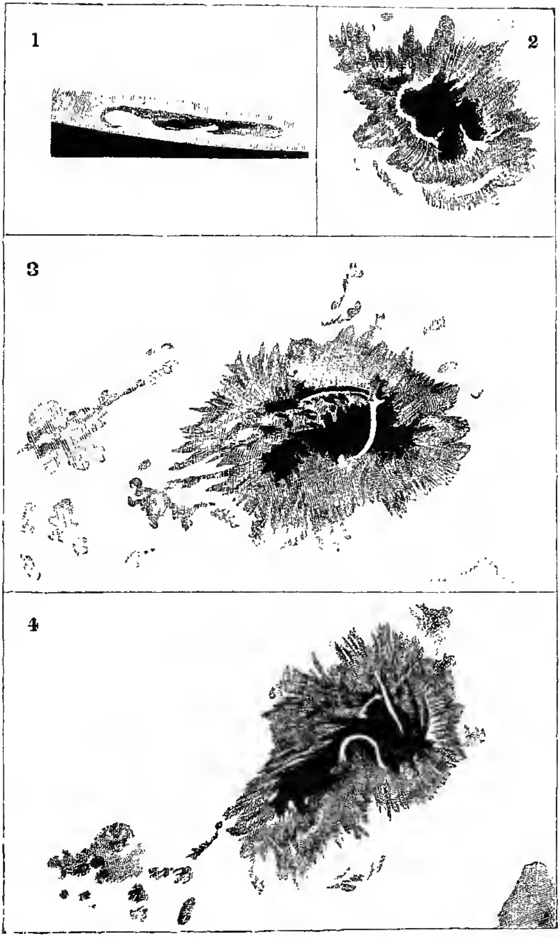
110. The spots float, as it were, in what, as we have already seen in the case of the stars, is called the **photosphere ;** the half-shade shown in the spot is called the **penumbra** (that is, half shade) ; inside the penumbra is a still darker shade, called the **umbra,** and inside this again is the **nucleus.** Diagrams 3 and 4 of Plate IV. will render this perfectly clear. The white surface represents the photosphere; the half tones the penumbra; the dark, irregular central portions the umbra; and the blackest parts in the centre of these dark portions, the nucleus.

111. Sun-spots are cavities, or hollows, eaten into the photosphere, and these different shades represent different depths. Their occasional appearance as notches on the Sun's limb, or edge (as shown in Fig. 4), renders this absolutely certain.

112. Diligent observation of the umbra and penumbra, with powerful instruments, reveals to us the fact that *change* is going on incessantly in the region of the spots. Sometimes changes are noticed, after the lapse of an hour even: here a portion of the penumbra is seen setting sail across the umbra; here a portion of the umbra is melting from sight; here, again, an evident change of position and direction in masses which retain their form. The enormous changes, extending ever tens of thousands of square miles of the Sun's surface, which took place in the great sun-spot of 1865, are shown in Plate IV.

113. Near the edge of the solar disc, and especially about spots approaching the edge, it is quite easy, even with a small telescope, to discern certain very bright streaks of diversified form, quite distinct in outline, and either entirely separate or uniting in various ways into ridges and network. These appearances, which have been termed **faculæ,** are the most brilliant parts of the Sun. Where, near the edge, the spots become invisible, undulated shining ridges still indicate their place—being more remarkable thereabout than elsewhere, though everywhere traceable in good observing weather. Faculæ may be of all magnitudes, from hardly visible, softly-gleaming, narrow tracts 1,000 miles long, to continuous complicated and heapy ridges 40,000 miles and more in length, and 1,000 to 4,000 miles broad. Ridges of this kind

Plate IV.



SUN-SPOTS (the great Sun-spot of 1865).

1. The spot entering the Sun's disk Oct. 7th (foreshortened view). 2. Oct. 10th. 3. Oct. 14th; central view, showing the formation of a bridge, and the nucleus. 4. Oct. 16th.

often surround a spot, and hence appear the more conspicuous; such a ridge is shown in Fig. 1, Plate IV.; but sometimes there appears a very broad white platform round the spot, and from this the white crumpled ridges pass in various directions.

114. So much for the more salient phenomena of the Sun's surface, which we can study with our telescopes. There is much more, however, to be inquired into; and here we may remark that the Sun himself has bestowed a great boon upon observational Astronomy; and, whether brightly shining or hid in dim eclipse, now tells his own story, and prints his image in all parts of the world on a retina which never forgets, and is withal so sensitive as to receive, in a small fraction of a second, impressions of more exact detail than could be made out by hours of scrutiny with a powerful telescope.

115. We may begin by saying, that the whole surface of the Sun, except those portions occupied by the spots, is more or less finely *mottled*; as, indeed, may be seen with no very large amount of optical power. The general arrangement of this mottling comes out very plainly in some photographs of the Sun lately taken by Dr. Janssen at the Meudon Observatory near Paris. They show blurred patches circumscribed by what seem like currents of fine, distinct granulation. This curious appearance is known as the "photospheric network." The luminous masses between the dusky marblings present an irregularly rounded form: they have been variously called "nodules," "floccules," "rice grains," "granules or granulations," and so on.

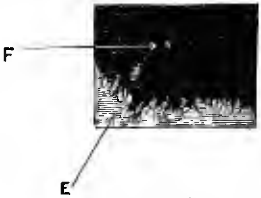


FIG. 11.—Part of a Sun-spot. "Willow-leaves" detaching themselves from the penumbra. A very faint one at F.

116. The word "willow-leaf" very well paints the appearance of the minute details *sometimes* observed in the penumbræ of spots, which occasionally are made up apparently of elongated masses of unequal brightness, so arranged that for the most part they point like so many arrows to the centre of the nucleus, giving to the penumbra a radiated appearance. At other times and occasionally in the same spot, the jagged edge of the penumbra projecting over the nucleus has caused the interior edge of the penumbra to be likened to coarse thatching with straw.

117. There are darker or shaded portions between the granules, often pretty thickly covered with dark dots, like stippling with a soft lead-pencil; these are what were called "pores," or "incipient openings," by Sir William Herschel. They are sometimes almost black, and are like excessively small spots.

118. When the Sun is totally eclipsed,—that is, as will be explained by and by, when the Moon comes exactly between the Earth and the Sun,—other appearances are unfolded to us, which the extreme brightness of the Sun prevents our observing under ordinary circumstances: the Sun's atmosphere is seen to contain red masses of fantastic shapes, some of them quite disconnected from the Sun; to these the names of "**red-flames**" and "**prominences**" have been given. These are the higher waves of the more vivid portions of a solar envelope, from 5,000 to 10,000 miles in height, called the CHROMOSPHERE, which overlies the photosphere, and is composed chiefly of hydrogen, and an unknown gas named "helium." Outside the chromosphere lies the **coronal atmosphere** of the Sun, extending to an undetermined, and perhaps variable distance. On these appearances we shall say a word or two further on when we come to deal with Eclipses.

LESSON IX.—*Explanation of the Appearances on the Sun's Surface. The Sun's Light and Heat. Sun-force. The Past and Future of the Sun.*

119. We are now familiar with the appearances presented to us on the Sun's surface in a powerful telescope. Let us see if we can account for them. As the spots break out and close up with great rapidity, as changes both on a large and small scale are always going on on the surface, we can only infer that the photosphere of the Sun, and therefore of the stars, is of a cloudy nature; but while our clouds are made up of particles of water, the clouds on the Sun must be composed of particles of various metals and other substances in a state of intense heat—how hot we shall see by and by. The photosphere is surrounded by an atmosphere composed of the vapours of the bodies which are incandescent in the photosphere. It seems also, that not only is the visible surface of the Sun entirely of a cloudy nature, but that the atmosphere is a highly absorptive one. Moreover its absorption chiefly affects the blue, or more refrangible end of the spectrum, so that, if it were removed, sunlight would be very much bluer than it actually is.

119 a. Faculæ reach high up into this atmosphere, and consequently escape some of its absorption. This accounts for their brilliancy, and also for their increased conspicuousness (as shown in Plate IV.) near the edge of the Sun, where they are thrown into relief by a greater depth of atmosphere. Faculæ really consist of the bright granules, or "domes" of the Sun's mottled surface, heaped up together, or arranged in certain directions. Though by no means confined to the vicinity of spots, they are closely associated with them. Their development, however, is always *subsequent* to that of spots, and they appear predominantly on their *left-hand* borders. They exist on a vast scale. It is quite common to see reaches of them tens of thousands of miles long, lasting for days or even weeks. The more minute features of the solar surface—the granules—are most probably the dome-like tops of the smaller masses of the clouds, bright for the same reason that the faculæ are bright, but to a less degree; and the fact that these granules lengthen out as they approach a spot and descend the slope of the penumbra, may possibly be accounted for by supposing them to be elongated by the current which causes their downrush into a spot, as the

FIG. 12.—Sun-spot showing details of the penumbra. The dark portion in the centre is the umbra, the surrounding half-tone is the penumbra. A, a bridge, or tongue or facula being carried over the umbra; B, clouds forming at the end; C, part of the penumbra being driven over the spot (the domes are drawn out); D, domes on photosphere; F, "thatch" on penumbra.

clouds in our own sky are lengthened out when they are drawn into a current.

120. Some spots cover millions of square miles, and last for months; others are only visible in powerful instruments, and are of very short duration. There is a great difference in the number of spots visible from time to time; indeed, there is a minimum period, when none are seen for weeks together, and a maximum period, when more are seen than at any other time. The interval between two maximum periods, or two minimum periods, is about eleven years.

121. Now, as the Sun is more energetic when he is covered with spots than when there are none, we may look upon him as a **variable star**, with a period of eleven years. This period most probably depends upon changes in the circulation of the Sun's atmosphere, and Mr. Balfour Stewart has suggested that it may be in some way modified by the action of the planets. It is also known that the magnetic needle has a period of the same length, its greatest oscillations occurring when there are most sun-spots. Auroræ, and the currents of electricity which traverse the Earth's surface, are affected by a similar period.

122. The detailed spectroscopic examination of the Sun's surface and of his spots has afforded evidence of their being due to the absorption of the Sun's light by atmospheric layers of greater pressures than are at work in the other regions. A spot, we know, is a saucer-like depression in the photosphere. It is dark, because the depression is filled with comparatively cool, dense vapours which powerfully absorb light. These vapours have fallen from the upper regions of the Sun's atmosphere, so that each spot is the seat of a downrush, the answering uprush to which we see in faculæ and a certain kind of flames or prominences. Each "pore," too, is the visible effect of a descending current on a smaller scale.

123. We have before seen (Art. 67) what substances exist in a state of incandescence in some of the stars. In the case of the Sun we are acquainted with a greater number. Here are tables based on the researches of Kirchhoff, Ångström, Thalèn, and Lockyer, of the different substances, which, so far, have been traced in the Sun's atmosphere by means of their spectral lines.

TABLE A.—*Elements present in the Sun according to Kirchhoff, Ångström, and Thalèn.*

Kirchhoff.	Ångström and Thalèn.
Sodium	Sodium
Iron	Iron
Calcium	Calcium
Magnesium	Magnesium
Nickel	Nickel
Barium	—
Copper	—
Zinc	—
	Chromium
	Cobalt
	Hydrogen
	Manganese
	Titanium

Table B gives the substances which were added to the preceding list by taking a special consideration into account. Some time after the first work on the chemical composition of the solar atmosphere was accomplished, a method was introduced by which it was easy to determine the existence of a small quantity of any particular vapour in a mixture of vapours, so that the substances indicated in the second table are those substances which possibly exist in the sun's atmosphere in a small quantity only.

TABLE B.—*Elements the Longest Lines of which coincide with Fraunhofer Lines.*

Certainly coincident.	Probably coincident.
Aluminium	Indium
Strontium	Lithium
Lead	Rubidium
Cadmium	Cæsium
Cerium	Bismuth
Uranium	Tin
Potassium	Silver
Vanadium	Glucinum
Palladium	Lanthanum
Molybdenum	Yttrium or Erbium

It is, however, by no means certain that these vapours exist in the Sun just as we know them in the laboratory. There is, on the contrary, very strong evidence that, at the level of the photosphere, the heat is so tremendous as to drive them asunder into finer constituent particles than we have any terrestrial experience of. In this fact of "dissociation" is not unlikely to be found the key to many of the riddles of the solar constitution.

124. Now let us inquire into some of the benign influences spread broadcast by the Sun. We all know that our Earth is lit up by its beams, and that we are warmed by its heat; but this by no means exhausts its benefits, which we share in common with the other planets which gather round its hearth.

125. And first, as to its **light**. We have already compared its light with that which we receive from the stars, but that is merely its *relative* brightness; we want now to know its actual, or, as it is otherwise called, its *intrinsic* brightness. Now it is clear, at once, that no number of candles can rival this brightness; let us therefore compare it with one of the brightest lights that we know of—the lime-light. The lime-light proceeds from a ball of lime made intensely hot by a flame composed of a mixture of hydrogen and oxygen playing on it. It is so bright that we cannot look on it any more than we can look on the Sun; but if we place it in front of the Sun, and look at both through a dark glass, the lime-light, though so intensely bright, looks like a black spot. In fact, Sir John Herschel has found that the Sun gives out as much light as 146 lime-lights would do if each ball of lime were as large as the Sun and gave out light from all parts of its surface.

126. Then, as to the Sun's **heat.** The heat thrown out from *every square yard* of the Sun's surface is as great as that which would be produced by burning six tons of coal on it each hour. Now, we may take the surface of the Sun roughly at 2,284,000,000,000 square miles, and there are 3,097,600 square yards in each square mile. How many tons of coal must be burnt, therefore, in an hour, to represent the Sun's heat?

127. But the Sun sends out, or *radiates*, its light and heat in all directions; it is clear, therefore, that as our Earth is so small compared with the Sun, and is so far away from it, the light and heat the Earth can intercept is but a very small portion of the whole amount; in fact, we only grasp the $\frac{1}{227000000}$th part of it. That is to say, if we suppose the Sun's light and heat to be divided into two hundred and twenty-seven million parts, we only receive one of them.

128. But this is not all. There is something else besides light and heat in the Sun's rays, and to this something we owe the fact that the Earth is clad with verdure; that in the tropics, where the Sun shines always in its might, vegetable life is most luxuriant, and that with us the spring time, when the Sun regains its power, is marked by a new birth of flowers. There comes from the Sun, besides its light and heat, another force, **chemical force,** which separates carbon from oxygen, and turns the gas which, were it to accumulate, would kill all men and animals, into the life of plants. Thus, then, does the Sun build up the vegetable world.

129. Now, let us think a little. The enormous engines which do the heavy work of the world; the locomotives which take us so smoothly and rapidly across a whole continent; the mail-packets which take us so safely across the broad ocean; owe all their power to steam, and steam is produced by heating water by coal. We all know that coal is the remains of an ancient vegetation; we have just seen that vegetation is the direct effect of the Sun's action. Hence, without the Sun's action in former times we should have had no coal. The heavy work of the world, therefore, is indirectly done by the Sun.

130. Now for the light work. Let us take man. To work a man must eat. Does he eat beef? On what was the animal which supplied the beef fed? On grass. Does he eat bread? What is bread? Corn. In both these, and in all cases, we come back to vegetation, which is, as we have already seen, the direct effect of the Sun's action. Here again, then, we must confess that to the Sun is due man's power of work. All the world's work, therefore, with one trifling exception (tide-work, of which more presently,) is done by the Sun, and man himself, prince or peasant, is but a little engine, which *directs* merely the energy supplied by the Sun.

131. Will the Sun, then, keep up for ever a supply of this force? It cannot, if it be not replenished, any more than a fire can be kept in unless we put on fuel; any more than a man can work without food. At present, philosophers are ignorant of any means by which it is replenished. As, probably, there was a time when the Sun existed as matter diffused through infinite space, the coming together of which matter has stored up its heat, so, probably, there will come a time when the Sun, with all its planets welded into its mass, will roll, a cold, black ball, through infinite space.*

132. Such, then, is our Sun—the nearest star. Although some of the stars appear not to contain those elements which on the earth are most abundant, still we see that, on the whole, the stars differ from each other, and from our Sun, only by the lower order of differences of special modification, and not by the more important differences of distinct plans of structure. There is, therefore, a probability that they fulfil an analogous purpose; and are, like our Sun, surrounded with planets, which by their attraction they uphold, and by their radiation illuminate and energise. As has been previously pointed out, the elements most widely diffused through the host of stars are some of those most closely connected with the constitution of the living organisms of our globe, including hydrogen, sodium, magnesium, and iron.

The probable past and future of the Sun are, therefore, the probable past and future of every star in the firmament of heaven.

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* Sir W. Thomson.

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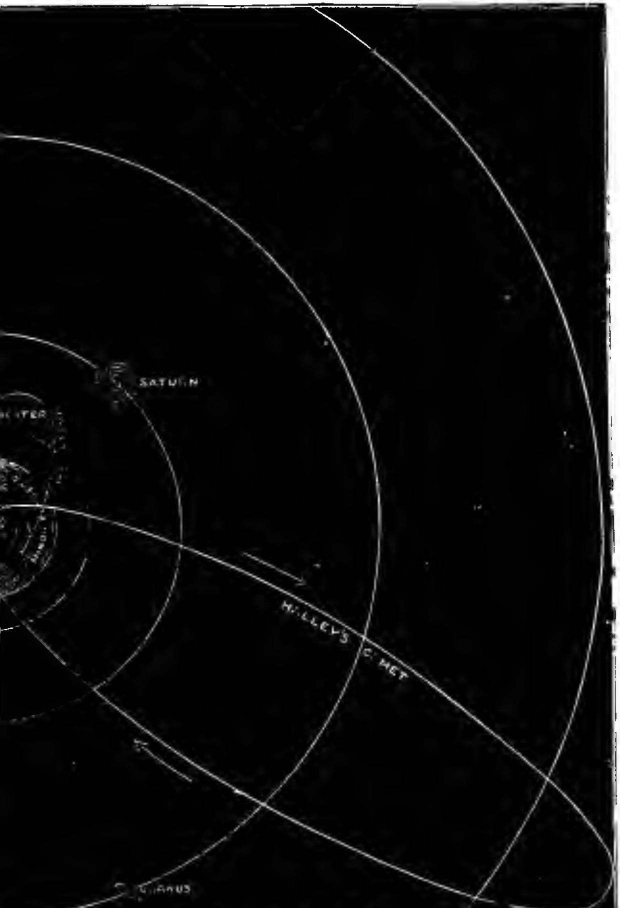

ar System.

CHAPTER III.

THE SOLAR SYSTEM.

LESSON X.—*General Description. Distances of the Planets from the Sun. Sizes of the Planets. The Satellites. Volume, Mass, and Density of the Planets.*

133. From the Sun we now pass to the system of bodies which revolve round it: and here, as elsewhere in the heavens, we come upon the greatest variety. We find **planets**—of which the Earth is one—differing greatly in size, and situated at various distances from the Sun. We find again a ring of little planets clustering in one part of the system ; these are called **asteroids,** or minor **planets.** We next come to systems of bodies like the **comets,** and **meteors,** or **shooting-stars,** or **bolides,** which a recent discovery has established to be connected phenomena. These bodies travel round the sun in orbits of all degrees of eccentricity. The systems of meteors are met by the Earth in her annual round, while some of the comets break in from all parts of space ; and then, passing round our Sun, rush back again. Besides these there is, according to some, although the point is a doubtful one, another ring which is rendered visible to us by the appearance called the **Zodiacal Light,** others holding that this light is located in the Earth's atmosphere.

134. The Solar System, then, consists of the following:—

Eight large Planets, as follow, in the order of distance from the Sun:*—

1. Mercury.	5. Jupiter.
2. Venus.	6. Saturn.
3. EARTH.	7. Uranus.
4. Mars.	8. Neptune.

Two hundred and seventy-two small Planets revolving round the Sun between the orbits of Mars and Jupiter. Their names are given in the Appendix.

Comets and Meteoric bodies, which at times approach near the Earth's orbit, the latter occasionally reaching the Earth's surface.

The Zodiacal Light. A ring of apparently nebulous matter, the exact nature and position of which in the system are not yet determined.

135. Let us begin by getting some general notions of this system. In the first place, all the planets travel round the Sun in the same direction, and that direction, looking down upon the system from the northern side of it, is in the opposite direction to that in which the hands of a clock or a watch move. Secondly, the forms of the paths of all the planets and of many of the comets are elliptical, but some are very much more elliptical than others.

136. Next let the reader turn back to Article 105, in which we have attempted to give an idea of the *plane of the Ecliptic.* Now, the larger planets keep very nearly to this level, which is represented in the following figure.

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* A ninth planet, named Vulcan, has been suspected to revolve within the orbit of Mercury, but proof of its existence is still wanting.

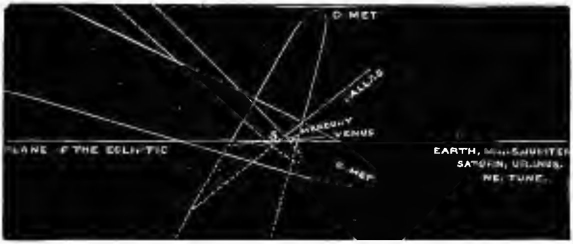

FIG. 13.—Section, or side view, of the plane of the Ecliptic, showing that the orbits of the large planets are nearly in the plane; that the orbit of Pallas has the greatest dip or inclination to it; and that the orbits of the comets are inclined to it in all directions.

The straight line we suppose to represent the Earth's orbit looked at edgeways, as we can look at a hoop edgeways. The others represent the orbits of some of the planets and of some of the comets seen edgeways in the same manner. The orbits of Mars, Jupiter, Saturn, Uranus, and Neptune lie so nearly in the plane of the ecliptic, that in our figure, the scale of which is very small, they may be supposed to lie in that plane. With some of the smaller planets and comets we see the case is very different. The latter especially plunge as it were down into the surface of our ideal sea, or *plane of the ecliptic*, in all directions, instead of floating on, or revolving in it.

137. Again, as we thus find planets travelling round the Sun, so also do we find other bodies travelling round some of the planets. These bodies are called **Moons,** or **Satellites.** The Earth, we know, has one Moon; Mars has two; Jupiter four, Saturn eight, Uranus four, and Neptune, according to our present knowledge, one.

138. As we have before stated, all the planets revolve round the Sun in one direction, *i.e.* from west to east. They rotate, or turn on their axes and their satellites revolve in the same direction, with two exceptions, occurring at the outskirts of the system. The satellites both of Uranus and Neptune move from east to west, and in planes widely different from that of the ecliptic.

139. Let us next inquire into the various **distances** of the planets from the Sun, bearing in mind, that as the orbits are elliptical, the planets are sometimes nearer to the Sun than at other times. This will be explained by and by; in the meantime we may say, that the average or mean distances are as follow; the **times of revolution** are also given :—

	Distance in Miles.	Period of revolution round the Sun.		
		D.	H.	M.
Mercury	35,987,000	87	23	15
Venus	67,245,000	224	16	48
EARTH	92,965,000	365	6	9
Mars	141,650,000	686	23	31
Jupiter	483,678,000	4332	14	2
Saturn	886,779,000	10759	5	16
Uranus	1,783,383,000	30688	7	12
Neptune	2,794,000,000	60180	20	38

140. Let us next see what are the **sizes** of the different planets. Their diameters are as follow :—

	Diameter in Miles.
Mercury	2,992
Venus	7,660
EARTH	7,916
Mars	4,211
Jupiter	86,000
Saturn	70,500
Uranus	31,700
Neptune	34,500

141. We have before attempted to give an idea of the **comparative sizes** of the Earth and Sun, and of the distance between them; let us now complete the picture. Still taking a globe about two feet in diameter to represent the Sun, Mercury will be represented by a grain of mustard-seed, revolving in a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle of 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; the asteriods, grains of sand, in orbits of from 1,000 to 1,200 feet; Jupiter, a moderate-sized orange, on a circle nearly half a mile across; Saturn, a small orange, on a circle of four-fifths of a mile; Uranus, a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half; and Neptune, a good-sized plum, on a circle about two miles and a half in diameter.*

142. As the planets revolve round the Sun at vastly different distances, so do the satellites revolve round their primaries. Our solitary Moon courses round the Earth at a distance of 238,000 miles, and its journey is performed in a month. The first satellite of the planet Saturn is at only just half this distance, and its journey is performed in less than a day. The first satellite of Uranus is about equally near, and requires about two days and a half. The first satellite of Jupiter is about the same distance from that planet as our Moon is from us, and its revolution is accomplished in one and three-quarters of our days. The only satellite which takes a longer time to revolve round its primary than our Moon, is Japetus, the eighth satellite of Saturn. On the other hand, the inner satellite of Mars finishes its circuit in seven hours and thirty-nine minutes, revolving at a distance less than one-fortieth that of our Moon. We have seen above (Art. 140), that the diameter of the smallest planet—leaving the asteroids out of the question—is 2,992 miles. We find that among the satellites we have three bodies—the third and fourth satellites of Jupiter, and the sixth moon of Saturn—of greater dimensions than one of the

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* Sir John Herschel.

large planets, Mercury, and nearly as large as another, Mars.

It is not necessary in this place to give more details concerning the distances and sizes of the planets and satellites. A complete statement of them will be found in Tables II. and III. of the Appendix.

143. The *relative* distances of the planets from the Sun were known long before their *absolute* distances—in the same way as we might know that one place was twice or three times as far away as another without knowing the exact distance of either. When once the distance of the Earth from the Sun was known, astronomers could easily find the distance of all the rest from the Sun, and therefore from the Earth. Their sizes were next determined, for we need only to know the distance of a body and its *apparent size*, or the angle under which we see it, to determine its real dimensions.

144. In the case of a planet accompanied by satellites we can at once determine its weight, or **mass,** for a reason we shall state by and by (Chap. IX.); and when we have got its weight, having already obtained its size or **volume,** we can compare the **density** of the materials of which the planet is composed with those we are familiar with here; having first also obtained experimentally the density of our own Earth.

145. Let us see what this word density means. To do this, let us compare platinum, the heaviest metal, with hydrogen, the lightest gas. The gas is, to speak roughly, a quarter of a million times lighter than the metal; the gas is therefore the same number of times less dense: and if we had two planets of exactly the same size, one composed of platinum and the other of hydrogen, the latter would be a quarter of a million times less dense than the former. Now, if it seems absurd to talk of a hydrogen planet, we must remember that if the materials of which our system, including the Sun, is composed, once existed as a great nebulous mass extending far beyond the orbit of Neptune, as there is reason to believe, the mass must have been more than 200,000,000 times *less dense than hydrogen!*

146. Philosophers have found that the mean density of the Earth is a little more than five and a half times that of water, that is to say, our Earth is five and a half times heavier than it would be if it were made up of water. If we now compare the density of the other planets with it, we find that they almost regularly increase in density as we approach the Sun ; Mercury being the most dense ; Venus, the Earth, and Mars, having densities nearly alike, but less than that of Mercury ; while Saturn and Neptune are the least dense.

147. Here is a Table showing the *volumes, masses,* and *densities,* of the planets ; those of the Earth being taken as 100 :—

	Volume.	Mass.	Density.
Mercury	6	7	121
Venus	90	77	85
EARTH	100	100	100
Mars	15	11	74
Jupiter	129,945	31,187	24
Saturn	71,795	9,333	13
Uranus	6,287	1,446	23
Neptune	8,430	1,686	20

148. To sum up, then, our first general survey of the Solar System, we find it composed of planets, satellites, comets, and several rings or masses of meteoric bodies ; the planets, both large and small, revolving round the Sun in the same direction, the satellites revolving in a similar manner round the planets. We have learned the mean distances of the planets from the Sun, and we have compared the distances and times of revolution of some of the satellites. We have also seen that the volumes, masses, and densities of the various planets have been determined. There is still much more to be learnt, both about the system generally, and the planets particularly; but it will be best, before we proceed with our general examination, to inquire somewhat minutely into the movements and structure of the Earth on which we dwell.

LESSON XI.—*The Earth. Its Shape. Poles. Equator. Latitude and Longitude. Diameter.*

149. As we took the Sun as a specimen of the stars, because it was the nearest star to us, and we could therefore study it best, so now let us take our Earth, with which we should be familiar, as a specimen of the planets.

150. In the first place, we have learned that it is round. Had we no proof, we might have guessed this, because both Sun and Moon, and the planets observable in our telescopes, are round. But we have proof. The Moon, when eclipsed, enters the shadow thrown by the Earth; and it is easy to see on such occasions, when the edge of the shadow is thrown on the bright Moon, that the shadow is circular.

151. Moreover, if we watch the ships putting out to sea, we lose first the hull, then the lower sails, until at last the highest parts of the masts disappear. Similarly, the sailor, when he sights land, first catches the tops of mountains, or other high objects, before he sees the beach or port. If the surface of the Earth were an extended plain, this would not happen; we should see the nearest things and the biggest things best: but as it is, every point of the Earth's surface is the top, as it were, of a flattened dome; such a dome therefore is interposed between us and every distant object. The inequalities of the land render this fact much less obvious on *terra firma* than on the surface of the sea.

152. On all sides of us we see a circle of land, or sea, or both, on which the sky seems to rest: this is called the **sensible horizon.** If we observe it from a little boat on the sea, or from a plain, this circle is small; but if we look out from the top of a ship's mast or from a hill, we find it largely increased—in fact, the higher we go the more is the horizon extended, always however retaining its circular form. Now, the sphere is the only figure which, looked at from any external point, is bounded by a circle; and as the horizons of all places are circular, the Earth is a sphere, or at all events nearly so.

153. The Earth is not only round, but it rotates, or turns round on an axis, as a top does when it is spinning; and the names of **north pole** and **south pole** are given to those points on the Earth where the axis would come to the surface if it were a great iron rod instead of a mathematical line. Half-way between these two poles, there is an imaginary line running round the Earth, called the **equator** or **equinoctial line.** The line through the Earth's centre from pole to pole is called the **polar diameter**; the line through the Earth's centre, from any point in the equator to the opposite point, is called the **equatorial diameter,** and one of these, as we shall see, is longer than the other.

154. We owe to the ingenuity of a French philosopher, M. Léon Foucault, two experiments which render the Earth's rotation visible to the eye. For although, as we shall presently see, it is made evident by the apparent motion of the heavenly bodies and the consequent succession of day and night, we must not forget that these effects might be, and for long ages were thought to be, produced by a real motion of the Sun and stars round the Earth. The first method consists in allowing a heavy weight, suspended by a fine wire, to swing backwards and forwards like the pendulum of a clock. Now, if we move the beam or other object to which such a pendulum is suspended, we shall not alter the direction in which the pendulum swings, as it is more easy for the thread or wire, which supports the weight, to twist than for the heavy weight itself to alter its course or swing when once in motion in any particular direction. Therefore, in the experiment, if the Earth were at rest, the swing of the pendulum would always be in the same direction with regard to the support and the surrounding objects, but would vary if the earth were in motion.

155. M. Foucault's pendulum was suspended from the dome of the Panthéon in Paris, and a fine point at the bottom of the weight was made to leave a mark in sand at each swing. The marks successively made in the sand showed that the plane of oscillation varied with regard to the building. Here, then, was a proof that the building, and therefore the Earth, moved.

156. Such a pendulum swinging at either pole would make a complete revolution in 24 hours, and would serve the purpose of a clock were a dial placed below it with the hours marked. As the Earth rotates at the north pole from west to east, the dial would appear to a spectator, carried like it round by the Earth, to move under the pendulum from west to east, while at the south pole the Earth and dial would travel from east to west; midway between the poles, that is, at the equator, this effect, of course, is not noticed, as there the two motions in opposite directions meet.

157. The second method is based upon the fact, that when a body turns on a perfectly true and symmetrical axis, and is left to itself in such a manner that gravity is not brought into play, the axis maintains an invariable position; so that if it be made to point to a star, which is a thing outside the Earth and not supposed to move, it will continue to point to it. A **gyroscope** is an instrument so made that a heavy wheel set into very rapid motion shall be able to rotate for a long period, and that all disturbing influences, the action of gravity among them, are prevented.

158. Now, if the Earth were at rest, there would be no apparent change in the position of the axis, however long the wheel might continue to turn; but if the Earth moves and the axis remains at rest, there should be some difference. Experiment proves that there is a difference, and just such a difference as is accounted for by the Earth's rotation. In fact, if we so arrange the gyroscope that the axis of its rotation points to a star, it will remain at rest with regard to the star, while it varies with regard to the Earth. This is proof positive that it is the Earth which rotates on its axis, and not the stars which revolve round it; for if this were the case the axis of the gyroscope would remain invariable with regard to the Earth, and change its direction with regard to the star.

159. If we look at a terrestrial globe, we find that the equator is not the only line marked upon it. There are other lines parallel to the equator,—that is, lines which are at the same distance from the equator all round,—and other lines passing through both poles, and dividing the equator into so many equal parts. These lines are for the purpose of determining the exact position of a place upon the globe, and they are based upon the fact, that all circles are divided into 360 degrees (marked °), each degree into 60 minutes (′), and each minute into 60 seconds (″).

160. We have first the equator midway between the poles, so that from any part of the equator to either pole is one quarter round the Earth, or 90 degrees. On either side of the equator there are circles parallel to it; that is to say, at the same distance from it all round, dividing the distance to the poles into equal parts. Now, it is necessary to give this distance from the equator some name. The term **latitude** has been chosen: north latitude from the equator towards the north pole; south latitude from the equator towards the south pole.

161. This, however, is not sufficient to define the exact position of a place, it only defines the distance from the equator. This difficulty has been got over by fixing upon Greenwich, our principal astronomical observatory, and supposing a circle passing through the two poles and that place, and then reckoning east and west from the circle as we reckon north and south from the equator. To this east and west reckoning the term **longitude** has been applied.

162. On the terrestrial globe we find what are termed **parallels** of latitude, and **meridians** of longitude, at every 10° or 15°. Besides these, at 23½° on either side of the equator, are the Tropics: the north one the **tropic of Cancer**, the southern one the **tropic of Capricorn**; and at the same distance from either pole, we find the **arctic** and **antarctic circles.** These lines divide the Earth's surface into five zones—one **torrid**, two **temperate**, and two **frigid zones.**

163. The distance along the axis of rotation, from pole to pole, through the Earth's centre, is shorter than the distance through the Earth's centre, from any one point in the equator to the opposite one. In other words, the diameter from pole to pole (the polar diameter) is shorter than the one in the plane of the equator (the equatorial diameter), and their lengths are as follows :—

	Feet.
Equatorial diameter	41,852,404
Polar diameter	41,709,790

Now turn these feet into miles: the difference after all is small; still it proves that the Earth is not a *sphere*, but what is called an **oblate spheroid.**

LESSON XII..—*The Earth's Movements. Rotation. Movement round the Sun. Succession of Day and Night.*

164. The Earth turns on its axis, or polar diameter, in 23h. 56m. In this time we get the succession of **day** and **night**, which succession is due therefore to the Earth's rotation. Before we discuss this further we must return to another of the Earth's movements. We know also that it goes round the Sun, and the time in which that revolution is effected we call a year.

165. Let us now inquire into this movement round the Sun. We stated (Art. 135) that the planets travelled round the centre of the system in *ellipses*. We will here state the meaning of this. If the orbits were circular, the planet would always be at the same distance from the Sun, as all the diameters of a circle are equal; but an ellipse is a kind of flattened circle, and some parts of it are nearer the centre than others.

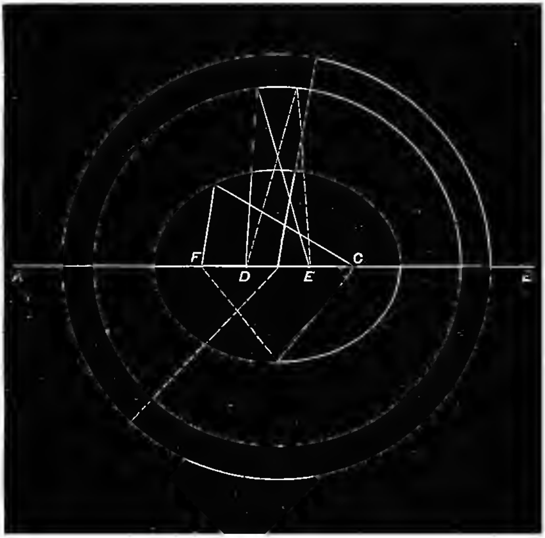

FIG. 14.—Showing the difference between a circle and ellipses of different eccentricities, and how they are constructed.

166. In Fig. 14 the outermost ring is a circle, which can be easily constructed with a pair of compasses, or by sticking a pin into paper, throwing a loop over it, keeping the loop tight by means of a pencil, and letting the pencil travel round. The two inner rings are ellipses. It is seen at once that one is very like the circle, and the other unlike it. The points D E and F G are called the foci of the two ellipses, and the shape of the ellipse depends upon the distance these points are apart. We can see this for ourselves if we stick two pins in a piece of paper, pass a loop of cotton over them, tighten the cotton by means of a pencil, and, still keeping the cotton tight, let the pencil mark the paper, as in the case of the circle. The pencil will draw an ellipse, the shape of which we may vary at pleasure (using the same loop) by altering the distance between the *foci.*

167. Now the Sun does not occupy the centre of the ellipse described by the Earth, but one of the foci. It results from this, that the Earth is nearer the Sun at one time than another. When these two bodies are nearest together, we say the Earth is **in perihelion.**[*] When they are furthest apart, we say it is **in aphelion.**[†] Let us now make a sketch of the orbit of the Earth as we should see it if we could get a bird's-eye view of it, and determine the points the Earth occupies at different times of the year, and how it is presented to the Sun.

168. Now refer back to Art. 106, in which we spoke of the position of the Sun's axis. We found that the Sun was not floating uprightly in our sea, the plane of the ecliptic; it was dipped down in a particular direction. So it is with our Earth. The Earth's axis is inclined in the same manner, but to a much greater extent. The direction of the inclination, as in the case of the Sun, is, roughly speaking, *always the same.*

169. We have then two completely distinct motions—one round the axis of rotation, which, roughly speaking, remains parallel to itself, performed in a day;—one

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[*] *περί*, at or near to; *ἥλιος*, the Sun.

[†] *ἀπό*, from, and *ἥλιος*.

round the Sun, performed in a year. To the former motion we owe the succession of **day** and **night**; to the latter, combined with the inclination of the Earth's axis, we owe the **seasons.**

170. In Fig. 15 is given a bird's-eye view of the system. It shows the orbit of the Earth, and how the axis of the Earth is inclined—the direction of the dip being such that on the 21st of June the axis is directed towards the Sun, the inclination being $23\frac{1}{2}^\circ$. Now, if we bear in mind that the Earth is spinning round once in twenty-four hours, we shall immediately see how it is we get day and night. *The Sun can only light up that half of*

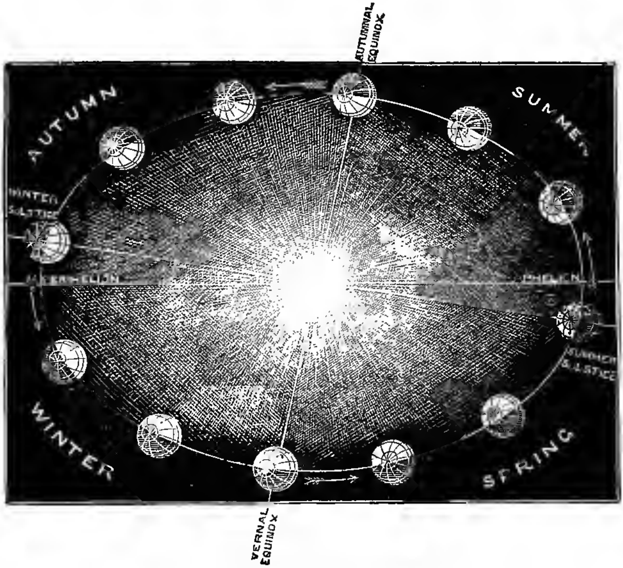

FIG. 15.—The Earth's path round the Sun.

the Earth turned towards it; consequently, at any moment, one half of our planet is in sunshine, the other in shade; the rotation of the Earth bringing each part in succession from sunshine to shade.

171. But it will be asked, "How is it that the days and nights are not always equal?" For a simple reason. In the first place, the days and nights are equal all over the world on the 22nd of March and the 22nd of September, which dates are called the **vernal** and **autumnal equinoxes** for that very reason—equinox being the Latin for equal night. But to make this clearer let us look at the small circle we have marked on the Earth—it is the **arctic circle.** Now let us suppose ourselves living in Greenland, just within that circle. What will happen? At the **spring equinox** (it will be most convenient to follow the order of the year) we find that circle half in light and half in shade. One half of the twenty-four hours (the time of one rotation), therefore, will be spent in sunshine, the other in shade; in other words, the day and night will be equal, as we before stated. Gradually, however, as we approach the **summer solstice** (going from left to right), we find the circle coming more and more into the light, in consequence of the inclination of the axis, until, when we arrive at the solstice, in spite of the Earth's rotation, *we cannot get out of the light.* At this time we see the **midnight sun** due north! The Sun, in fact, does not set. The solstice passed, we approach the autumnal equinox, when again we shall find the day and night equal, as we did at the vernal equinox. But when we come to the winter solstice, we get no more midnight suns; as shown in the figure, all the circle is situated in the shaded portion; hence, again in spite of the Earth's rotation, *we cannot get out of the darkness,* and we do not see the Sun even at noonday.

172. Now, these facts must be well thought of. If this be done there will be no difficulty in understanding how it is that at the poles (both north and south) the years consist of one day of six months' duration, and one night of equal length. To comprehend our long summer days and short nights in England, we have only to take a part about half-way between the arctic circle and the equator, as marked on the plate, and reason in the same way as we did for Greenland. At the equator we shall find the day and night always equal.

173. Here is a Table showing the length of the longest days in different latitudes, from the equator to the poles. We see that the Earth's surface on either side the equator may be divided into two zones, in one of which the days and nights are measured by hours, and in the other by months :—

°	′	Hours.	°	′	Hours.
0	0 (Equator)	12	65	48	22
16	44	13	66	21	23
30	48	14	66	32	24
41	24	15			Months.
49	2	16	67	23	1
54	31	17	69	51	2
58	27	18	73	40	3
61	19	19	78	11	4
63	23	20	84	5	5
64	50	21	90	0 (Pole)	6

174. What we have said about the northern hemisphere applies equally to the southern one, but the diagram will not hold good, as the northern winter is the southern summer, and so on ; and moreover, if we could look upon our Earth's orbit from the other side, the direction of the motions would be reversed. The reader should construct a diagram for the southern hemisphere for himself.

LESSON XIII.—*The Seasons.*

175. So much, then, for the succession of day and night. The **seasons** next demand our attention. Now, the changes to which we inhabitants of the temperate zones are accustomed, the heat of summer, the cold of winter, the medium temperatures of spring and autumn, depend simply upon the height to which the Sun attains at midday. The proof of this lies in the facts that on the equator the Sun is never far from the zenith, and we have perpetual summer: near the poles,—that is, in the frigid zones,—the Sun never gets very high, and we have perpetual winter. How, then, are the changing seasons in the temperate zones caused?

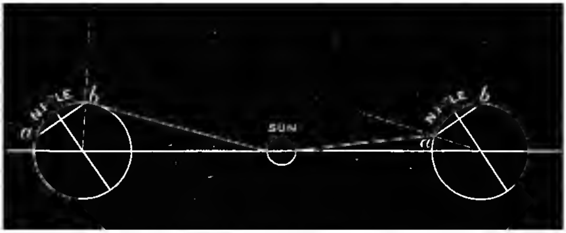

FIG. 16.—Explanation of the apparent altitude of the Sun, as seen from London, in summer and winter.

176. In Fig. 15 we were supposed to be looking down upon our system. We will now take a section from solstice to solstice through the Sun, in order that we may have a side view of it. Here, then, in Fig. 16, we have the Earth in two positions, and the Sun in the middle. On the left we have the winter solstice, where the axis of rotation is inclined *away* from the Sun to the greatest possible extent. On the right we have the summer solstice, when the axis of rotation is inclined *towards* the Sun to the greatest possible extent. The line *ab* in both represents the parallel of latitude passing through London. The dotted line from the centre through *b* shows the direction of the zenith—the direction in which our body points when we stand upright. We see that this line forms a larger angle with the line leading to the Sun, or the two lines open out wider, at the winter solstice, than they do at the summer one. Hence we see the Sun in winter at noon, low down, far from the zenith, while in summer we are glad to seek protection from his beams nearly overhead. The reader should now make a similar diagram to represent the position of the Sun at

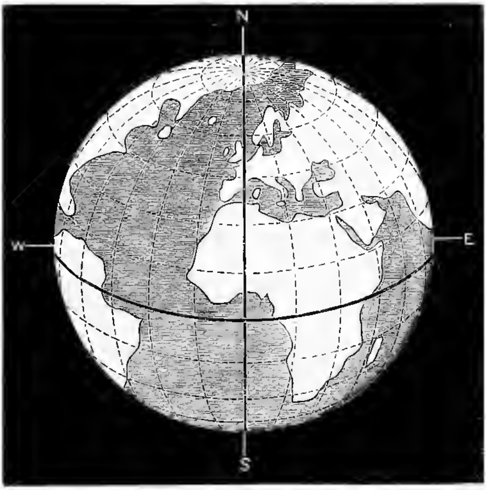

FIG. 17.—The Earth, as seen from the Sun at the Summer Solstice (noon at London).

the equinoxes; he will find that the axis is not then inclined either to or from the Sun, but sideways, the result being that the Sun itself is seen at the same distance from the point overhead in spring and autumn, and hence the temperature is nearly the same, though Nature apparently works very differently at these two seasons; in one we have the sowing-time, in the other the fall of the leaf.

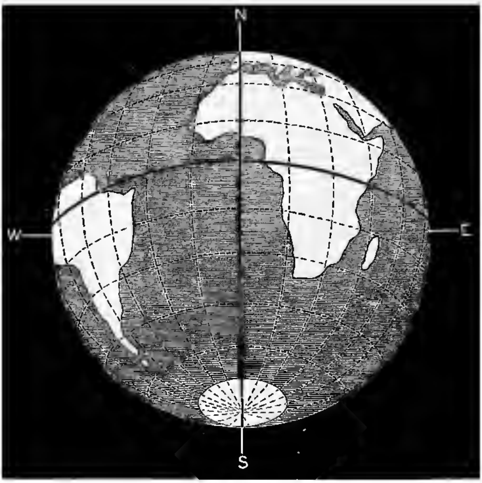

FIG. 18.—The Earth, as seen from the Sun at the Winter Solstice (noon at London).

177. Perhaps the Sun's action on the Earth, in giving rise to the seasons, will be rendered more clear by inquiring how the Earth is presented to the Sun at the four seasons—that is, how the Earth would be seen by an observer situated in the Sun. First, then, for summer and winter. Figs. 17 and 18 represent the Earth as it would be seen from the Sun at noon in London, at the summer and winter solstices. In the former, England is seen well down towards the centre of the disk, where the Sun is vertical, or overhead ; its rays are therefore most felt, and we enjoy our summer. In the latter, England is so near the northern edge of the disk that it cannot be properly represented in the figure. It is therefore furthest from the region where the Sun is overhead ; the Sun's rays are consequently feeble, and we have winter.

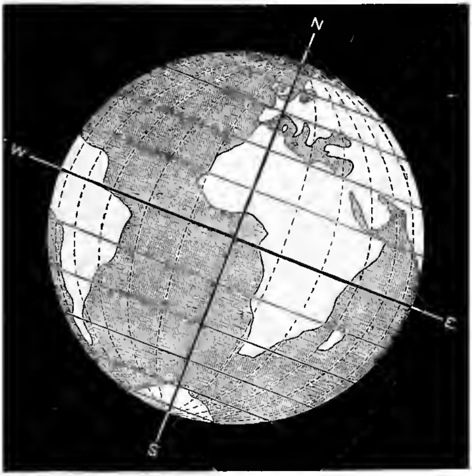

FIG. 19.—The Earth, as seen from the Sun at the Vernal Equinox (noon at London).

178. In Figs. 19 and 20, representing the Earth at the two equinoxes, we see that the position of England, with regard to the centre of the disk, is the same—the only difference being that in the two figures the Earth's axis is inclined in different directions. Hence there is no difference in temperature at these periods.

179. These figures should be well studied in connexion with Fig. 15, and also with Art. 170, in which the cause of the succession of day and night is explained. All these drawings represent London on the meridian which passes through the centre of the illuminated side of the Earth. It must therefore be noon at that place, as noon is half-way between sunrise and sunset. All the places represented on the western border have the Sun rising upon them; all the places on the eastern border have the Sun setting. As, therefore, at the same moment of absolute time we have the Sun rising at some places, overhead at others, and setting at others, we cannot have the same time, as measured by the Sun, at all places alike.

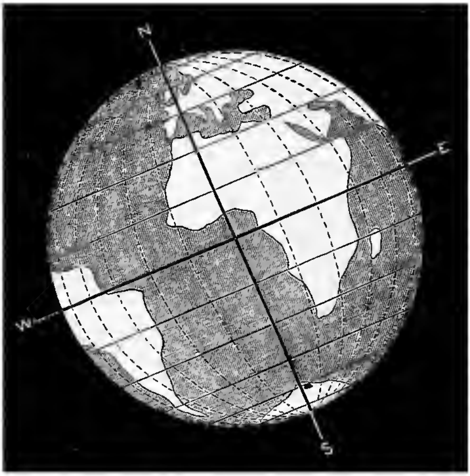

FIG. 20.—The Earth, as seen from the Sun at the Autumnal Equinox. (noon at London).

180. In fact, as the Earth, whose circumference is divided into 360° (Art. 159), turns round once in twenty-four hours, the Sun appears to travel 15° in one hour from east to west. One degree of longitude, therefore, makes a difference of four minutes of time, and *vice versâ.*

LESSON XIV.—*Structure of the Earth. The Earth's Crust. Interior Heat of the Earth. Cause of its Polar Compression. The Earth once a Star.*

181. Having said so much of the motions of our Earth —we shall return to them in a subsequent Lesson—let us now turn to its **structure,** or physical constitution.

We all of us are acquainted with the present appearance of our globe, how that its surface is here land, there water; and that the land is, for the most part, covered with soil which permits of vegetation, the vegetation varying according to the climate; while in some places meadows and wood-clad slopes give way to rugged mountains, which rear their bare or ice-clad peaks to heaven.

182. Taking the Earth as it is, then, the first question that arises is, Was it always as it is at present? The answer given by **Geology** and **Physical Geography,** two of the kindred sciences of Astronomy, is that the Earth was not always as we now see it, and that for millions of years changes have been going on, and are going on still.

183. It has been found, that what is called the **Earth's crust**—that is, the outside of the Earth, as the peel is the outside of an orange—is composed of various rocks of different kinds and of different ages, all of them, however, belonging to two great classes:—

CLASS I. Rocks that have been deposited by water these are called **stratified** or **sedimentary rocks.**

CLASS II. Rocks that once were molten: these are called **igneous rocks.**

184. Now, the sedimentary rocks have not always existed, for when we come to examine them closely it is found that they are piled one over the other in successive layers: the newer rocks reposing upon the older ones. The order in which these rocks have been deposited by the sea is as follows:—

List of Stratified Rocks.

Cainozoic, or Tertiary	Upper	Alluvium. Drift. Crag.
	Lower	Eocene.
Mesozoic, or Secondary	Upper	Cretaceous.
	Lower	Oolite. Lias. Trias.
Palæozoic, or Primary	Upper	Permian. Carboniferous. Devonian.
	Lower	Silurian. Cambrian. Archæan.

185. That these beds have been deposited by water, and principally by the sea, is proved by the facts—first, that in their formation they resemble the beds being deposited by water at the present time; and, secondly, that they nearly all contain the remains of fishes, reptiles, and shell-fish in great abundance — indeed, some of the beds are composed almost entirely of the remains of animal life.

186. It must not be supposed that the stratified beds of which we have spoken are everywhere met with as they are shown in the table; each bed could only have been deposited on those parts of the Earth's crust which were under water at the time; and since the earliest period of the Earth's history, earthquakes and changes of level have been at work, as they are at work now—but much more effectively, either because the changes were more decided and sudden, or because they were at work over immense periods of time.

187. It is found, indeed, that the sedimentary rocks have been upheaved and worn away again, bent, contorted, or twisted to an enormous extent; instead of being horizontal, as they must have been when they were originally formed at the bottom of the sea, they are now seen in some cases upright, in others dome-shaped, over large areas.

188. Had this not been the case, the mineral riches of the Earth would for ever have been out of our reach, and the surface of the Earth would have been a monotonous plain. As it is, although it has been estimated that the thickness of the series of *sedimentary* rocks, if found complete in any one locality, would be 14 miles, each member of the series is found at the surface at some place or other.

189. The whole series of the sedimentary rocks, from the most ancient to the most modern, have been disturbed by eruptions of volcanic materials, similar to those thrown up by Vesuvius, and other volcanoes active in our own time, and by intrusions of rocks of igneous origin proceeding from below; of which igneous rocks, granite, which in consequence of its great hardness is so largely used for paving and macadamizing our streets, may here be taken as one example out of many. These rocks are extremely easy to distinguish from the stratified ones, as they have no appearance of stratification, contain no fossils, and their constituents are different, and are irregularly distributed throughout the mass.

190. If we strip the Earth, then, in imagination, of the sedimentary rocks, we come to a kernel of rock, the constituents of which it is impossible to determine, but which may be imagined to be analogous to the older rocks of the granitic series, and to have been part of the original molten sphere, which must have been both hot and luminous, in the same way that molten iron is both hot and luminous. Doubtless there was a time when the surface of our earth was as hot and luminous as the surfaces of the sun and stars are still.

191. Now, suppose we have a red-hot cannon-ball; what happens? The ball gradually parts with, or radiates away, its heat, and gets cool, and as it cools it ceases to give out light; but its centre remains hot long after the surface in contact with the air has cooled down.

192. So precisely has it been with our earth; indeed, we have numerous proofs that the interior of the earth is at a high temperature at present, although its surface has cooled down. Our deepest mines are so hot that, without a perpetual current of cold fresh air, it would be impossible for the miners to live down them. There are hot springs coming from great depths, and the water which issues from them is, in some cases, at the boiling temperature—that is, 100° of the Centigrade thermometer. In the hot lava emitted from volcanoes we have evidence again of this interior heat, and how it is independent of that at the surface; for among the most active volcanoes with which we are acquainted are Hecla in Iceland, and Mount Erebus in the midst of the icy deserts which surround the south pole.

193. It has been calculated that the temperature of the earth increases as we descend at the rate of 1° (Centigrade) in about thirty yards. We shall therefore have a temperature of—

Centigrade.		Miles.
100°, or the temperature of boiling water . . .	at a depth of .	2

Centigrade.		Miles.
400°, or the temperature of red-hot iron . . .	at a depth of . . .	7½
1,000°, or the temperature of melted glass . . .	"	18
1,500°, or the temperature at which everything with which we are acquainted would be in a state of fusion	"	28

194. If this be so, then the Earth's crust cannot exceed 28 miles in thickness—that is to say, the $\frac{1}{141}$th part of the radius (or of half the diameter), so that it is comparable to the shell of an egg. But this question is one on which there is much difference of opinion, some philosophers holding that the liquid matter is not continuous to the centre, but that, owing to the great pressure, the centre itself is solid. Evidence also has recently been brought forward to show that the Earth may be a solid or nearly solid globe from surface to centre.

195. The density of the Earth's crust is only about half of the mean density of the Earth taken as a whole. This has been accounted for by supposing that the materials of which it is composed are made denser at great depths than at the surface, by the enormous pressure of the overlying mass; but there are strong reasons for believing that the central portions are made up of much denser bodies, such as metals and their compounds, than are common at the surface.

196. It was prior to the solidification of its crust, and while the surface was in a soft or fluid condition, that the Earth put on its present flattened shape, the flattening being due to a bulging out at the equator, caused by the Earth's rotation. If we arrange a hoop, as shown in Fig. 21, and make it revolve very rapidly, we shall see that that part of the hoop furthest from the fixed points, and in which the motion is most rapid, bulges out as the Earth does at the equator.

197. The form of the Earth, moreover, is exactly that which any fluid mass would take under the same circumstances. M. Plateau has proved this by placing a mass of oil in a transparent liquid exactly of the same density as the oil. As long as the oil was at rest it took the form of a perfect sphere floating in the middle of the fluid, exactly as the Earth floats in space; but the moment a slow motion of rotation was given to the oil by means of a piece of wire forced through it, the spherical form was changed into a spheroidal one, like that of the Earth.

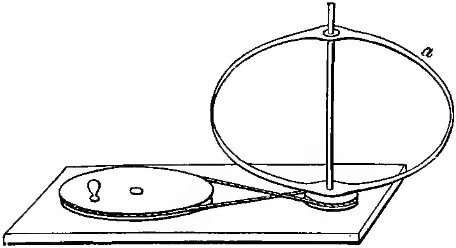

FIG. 21.—Explanation of the spheroidal form of the Earth.

198. The tales told by geology, the still heated state of the Earth, and the shape of the Earth itself, all show that long ago the sphere was intensely heated, and fluid.

LESSON XV.—*The Earth (continued). The Atmosphere. Belts of Winds and Calms. The Action of Solar and Terrestrial Radiation. Clouds. Chemistry of the Earth. The Earth's Past and Future.*

199. Having said so much of the Earth's crust, we must now, in order to fully consider our Earth as a planet, pass on to the atmosphere, which may be likened to a great ocean, covering the Earth to a height which has not yet been exactly determined. This height is generally supposed to be 45 or 50 miles, but there is evidence to show that we have an atmosphere of some kind at a height of 400 or 500 miles.

200. The atmosphere, as we know, is the home of the winds and clouds, and it is with these especially that we have to do, in order to try to understand the appearances presented by the atmospheres of other planets. Although in any one place there seems no order in the production of winds and clouds, on the Earth treated as a whole we find the greatest regularity; and we find, too, that the Sun's beat and the Earth's rotation are, in the main, the causes of all atmospheric disturbances.

201. If we examine a map showing the principal movements and conditions of the atmosphere, we shall find, belting the Earth along the equator, **a belt of equatorial calms and rains.** North of this we get a broad region, a belt of **trade-winds,** where the winds hlow from the north-east; to the south we find a similar belt, where the prevailing winds are south-east. Polewards from these belts to the north and south respectively lie the **calms of Cancer** and the **calms of Capricorn.** Still further towards the poles, we find the **counter-trades,** in regions where the winds blow from the equator to the poles: *i.e.* in the northern hemisphere they blow south and west, and in the southern hemisphere north and west; and at the poles themselves we find a region of **polar calms.**

202. Now if the Earth did not rotate on its axis we should still get the trade-winds, but both systems would blow from the pole to the equator; but as the Earth does rotate, the nearer the winds get to the equator the more rapidly is the Earth's surface whirled round underneath them; the Earth, as it were, slips from under them in an easterly direction, and so the northern trade-winds appear to come from the north-east, and the southern ones from the south-east. Similarly, the counter-trades, which blow towards the poles, appear to come, the northern ones from the south-west and the southern ones from the north-west. The nearer they approach the poles the slower is the motion of the Earth under them, compared with the regions nearer the equator ; consequently, they are travelling to the eastward faster than the parallels at which they successively arrive, and they appear to come from the westward.

203. Now, how are these winds set in motion? The tropics are the part of the Earth which is most heated, and, as a consequence, the air there has a tendency to ascend, and a surface-wind sets in towards the equator on both sides, to fill up the gap, as it were ; when it gets there it also is heated ; the two streams join and ascend, and flow as upper-currents towards either pole. Where the two streams meet in the region of equatorial calms some 4° or 5° broad, we have a cloud-belt, and daily rains. The counter-trades are the upper-currents referred to above, which in the regions beyond the calms of Cancer and Capricorn descend to the Earth's surface, and form surface-currents.

204. We see, therefore, that it is the Sun which sets all this atmospheric machinery in motion, by heating the equatorial regions of the Earth ; and as the Sun changes its position with regard to the equator, oscillating up and down in the course of the year, so do the calm-belts and trade-winds. The belt of equatorial calms follows the Sun northwards from January to July, when it reaches 25° N. lat. and then retreats, till at the next January it is in 25° S. lat.

205. So much for the Sun's direct action, and one of its effects on our rotating planet—the prevailing wind-currents, which are set in motion by the $\frac{1}{227000000}$ part of the Sun's radiation into space, which represents an amount of heat that would daily raise 7,513 cubic miles of water from the freezing to the boiling point.

206. To the radiation from the Earth, combined with the existence of the vapour of water in the air, must be ascribed all the other atmospheric phenomena. Aqueous vapour is the great mother of clouds. When it is chilled by a cold wind or a mountain-top, it parts with its heat, is condensed, and forms a cloud; and then mist, rain, snow, or hail, is formed: when it is heated by the direct action of the Sun, or by a current of warm air, it absorbs all the heat and expands, and the clouds disappear.

207. We now come to the materials of which our planet, including the Earth's crust and atmosphere, is composed. These are about 70 in number; they are called the **chemical elements**,* and consist of:—

Non-Metallic elements; or Metalloids.	Nitrogen, oxygen, chlorine, bromine, iodine, fluorine, silicon, boron, carbon, sulphur, selenium, tellurium, phosphorus, arsenic.
Metallic elements.	*Gaseous metal*:—Hydrogen. *Metals of the alkalies*:—Potassium, sodium, cæsium, rubidium, lithium. *Metals of the alkaline earths*:—Calcium, strontium, barium. *Other metals*:—Aluminium, zinc, iron, tin, tungsten, lead, silver, gold, &c.

The elements which constitute the great mass of the Earth's crust are comparatively few—aluminium, calcium, carbon, chlorine, hydrogen, magnesium, oxygen, potassium, silicon, sodium, sulphur. Oxygen combines with many of these elements, and especially with the earthy and alkaline metals; indeed, one-half of the ponderable matter of the exterior parts of the globe is composed of oxygen in a state of combination. Thus sandstone, the most common sedimentary rock, is composed of silica, which is a compound of silicon and oxygen, and is half

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* See Roscoe's "Elementary Chemistry," a volume in this series.

made up of the latter; granite, a common igneous rock, composed of quartz, feldspar, and mica, is nearly half made up of oxygen in a state of combination in those substances.

208. The chemical composition, by weight, of 100 parts of the atmosphere at present is as follows :—

Nitrogen	77 parts.
Oxygen	23 „

Besides these two main constituents, we have—

Carbonic acid .	quantity variable with the locality.
Aqueous vapour .	quantity variable with the temperature and humidity.
Ammonia . . .	a trace.

We said *at present*, because, when the Earth was molten, the atmosphere must have been very different. We had, let us imagine, close to the still glowing crust—composed perhaps of acid silicates—a dense vapour, made up of compounds of the materials of the crust which were volatile only at a high temperature; the vapour of chloride of sodium, or common salt, would be in large quantity; above this, a zone of carbonic acid gas; above this again, a zone of aqueous vapour, in the form of steam; and lastly, the nitrogen and oxygen.*

As the cooling went on, the lowest zone, composed of the vapour of salt, and other chlorides, would be condensed on the crust, covering it with a layer of these substances in a solid state. Then it would be the turn of the steam to condense too, and form water; it would fall on the layer of salt, which it would dissolve, and in time the oceans and seas would be formed, which would consequently be salt from the first moment of their appearance. Then, in addition to the oxygen and nitrogen which still remain, we should have the carbonic acid, which, in the

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* David Forbes, in the *Geological Magazine*, vol. iv. p. 429.

course of long ages, was used up by its carbon going to form the luxuriant vegetation, the pressed remains of which is the coal which warms us, and does nearly all our work.

209. Now it is the presence of vapour in our lower atmosphere which renders life possible. When the surface of the Earth was hot enough to prevent the formation of the seas, as the water would be turned into steam again the instant it touched the surface, there could be no life. Again, if ever the surface of the Earth be cold enough to freeze all the water and all the gaseous vapour in the atmosphere, life—as we have it—would be equally impossible. If this be true, all the Earth's history with which we are acquainted, from the dawn of life indicated in what geologists call the oldest rocks, down to our own time, and perhaps onwards for tens of thousands of years, is only the history of the Earth between the time at which its surface had got cold enough to allow steam to turn into water, and that at which its whole mass will be so cold that all the water on the surface, and all the vapour of water in the atmosphere, will be turned into ice.

210. The nebular hypothesis comes in here and shows us how, prior to the Earth being in a fluid state, it existed dissolved in a vast nebula, the parent of the Solar System; how this nebula gradually contracted and condensed, throwing off the planets one by one; and how the central portion of the nebula, condensed perhaps to the fluid state, exists at present as the glorious heat-giving Sun.

Although, therefore, we know that stars give out light because they are white-hot bodies, and that planets are not self-luminous because they are comparatively cold bodies, we must not suppose that planets were always cold bodies, or that stars will always be white-hot bodies. Indeed, as we have shown, there is good reason for supposing that all the planets were once white-hot, and gave out light as the Sun does now.

LESSON XVI.—*The Moon: its Size, Orbit, and Motions: its Physical Constitution.*

211. The Moon, as we have already seen, is one of the satellites, or secondary bodies; and although it appears to us at night to be so infinitely larger than the fixed stars and planets, it is a little body of 2,160 miles in diameter; so small is it, that 49 moons would be required to make one earth, 1,300,000 earths being required, as we have seen, to make one sun!

212. Its apparent size, then, must be due to its nearness. This we find to be the case. The Moon revolves round the Earth in an elliptic orbit, as the Earth revolves round the Sun, at an average distance of only 238,793 miles, which is equal to about 10 times round our planet. As the Moon's orbit is elliptical, she is sometimes nearer to us than at others. Her greatest and least distances are 251,947, and 225,719 miles: the difference is 26,228. When nearest us, of course she appears larger than at other times, and is said to be in perigee (περί near, and γῆ the Earth); when most distant, she is said to be in apogee (ἀπό from, and γῆ).

213. The Moon travels round the Earth in a period of 27d. 7h. 43m. 11½s. As we shall see presently, she requires more time to complete a revolution with respect to the Sun, which is called a **lunar month,** lunation, or synodic period.

214. The Moon, like the planets and the Sun, rotates on an axis; but there is this peculiarity in the case of the Moon, namely, that her rotation and her revolution round the Earth are performed in equal times, that is, in 27d. 7h. 43m. Hence we only see one side of our satellite. But as the Moon's axis is inclined 1° 32′ to the plane of its orbit, we sometimes see the region round one pole, and sometimes the region round the other. This is termed the **libration in latitude.** There are also a **libration in longitude**, arising from the fact, that though its rotation is uniform, its rate of motion round the Earth varies, so that we sometimes see more of the western edge and sometimes more of the eastern one ; and a **daily libration,** due to the Earth's rotation carrying the observer to the right and left of a line joining the centres of the Earth and Moon. When on the right of this line, we see more of the right edge of the Moon ; when on the left, we see more of the left edge.

215. The plane in which the Moon performs her journey round the Earth is inclined 5° to the plane of the ecliptic, or the plane in which the Earth performs her journey round the Sun (Art. 105). The two points in which the Moon's orbit, or the orbit of any other celestial body, intersects the Earth's orbit, are called the **nodes.** The line joining these two points is called the **line of nodes.** The node at which the body passes to the north of the ecliptic is called the **ascending node,** the other the **descending node.**

216. The motions of the Moon, as we shall see by and by, are very complicated. We may get an idea of its path round the Sun if we imagine a wheel going along a road to have a pencil fixed to one of its spokes, so as to leave a trace on a wall : such a trace would consist of a series of curves with their concave sides downwards, and such is the Moon's path with regard to the Sun.

217. Besides the bright portion lit up by the Sun, we sometimes see, in the phases which immediately precede and follow the New Moon, that the obscure part is faintly visible. This appearance is called the "*Earth shine*" (*Lumen incinerosum*, Lat. ; *Lumière cendrée*, Fr.), and is due to that portion of the Moon reflecting to us the light it receives from the Earth. When this faint light is visible—when the "Old Moon" is seen in the "New Moon's arms"—the portion lit up by the Sun seems to belong to a larger moon than the other. This is an effect of what is called irradiation, and is explained by the fact that a bright object makes a stronger impression on the eye than a dim one, and appears larger the brighter it is.

218. The average of four estimations gives the Moon's light as $\frac{1}{547513}$ of that of the Sun, so we should want 547,513 full moons to give as much light as the Sun does; and as there would not be room to place such a large number in the one-half of the sky which is visible to us, since the Moon covers $\frac{1}{240000}$ of it, it follows that the light from a sky full of moons would not be so bright as sunshine.

219. At rising or setting, the Moon sometimes appears to be larger than it does when high up in the sky. This is a delusion, and the reverse of the fact; for, as the Earth is a sphere, we are really nearer the Moon by half the Earth's diameter when the part of the Earth on which we stand is underneath it; as at moonrise or moonset we are situated, as it were, on the side of the Earth, half-way between the two points nearest to and most distant from the Moon. Let the reader draw a diagram, and reason this out.

220. Now a powerful telescope will magnify an object 1,000 times; that is to say, it will enable us to see it as if it were a thousand times nearer than it is: if the Moon were 1,000 times nearer, it would be 240 miles off, consequently astronomers can see the Moon as if it were situated at a little less than that distance, since it is measured from centre to centre, and we look from surface to surface. In consequence of this comparative nearness, the whole of the surface of our satellite turned towards us has been studied and mapped with considerable accuracy.

221. With the naked eye we see that some parts of the Moon are much brighter than others; there are dark patches, which, before large telescopes were in use, were thought to be, and were named, *Oceans*, *Gulfs*, and so on. The telescope shows us that these dark markings are smooth plains, and that the bright ones are ranges of mountains and hill country broken up in the most tremendous manner by volcanoes of all sizes. A further study convinces us that the smooth plains are nothing but old *sea-bottoms*. In fact, once upon a time the surface of the Moon, like our Earth, was partly covered with water, and the land was broken up into hills and fertile valleys; as on the Earth we have volcanoes, so did it once happen in the Moon, with the difference that there the size of the volcanoes and the number and activity of them were far beyond anything we can imagine: Etna, the largest volcanic mountain in Europe, is a mere dwarf compared with many on the Moon.

222. The best way of seeing how the surface of our satellite is broken up in this manner, is to observe the terminator—the name given to the boundary between the lit-up and shaded portions: along this line the mountain peaks are lit up, while the depressions are in shade, and the shadows of the mountains are thrown the greatest distance on the illuminated portion. The heights of the mountains and depths of the craters have been measured by observing the shadows in this manner.

223. Besides the **mountain-ranges** and **crater-mountains**, there are also **walled plains**, isolated **peaks**, and curious markings, called **rilles**. The principal ranges, craters, and walled plains have been named after distinguished philosophers, astronomers, and travellers.

224. The diameter of the walled plain Schickard, near the south-east limb or edge of the Moon, is 133 miles. Clavius and Grimaldi have diameters of 142 and 138 miles respectively. Here is a table of the height of some of the peaks, with that of some of our terrestrial ones, for comparison:

		Feet.
Dörfel		26,691
Ramparts of Newton	measured from the floor of the crater	23,853
Eratosthenes (central cone)		15,750
Mont Blanc		15,870
Snowdon		3,500

Beer and Mädler have measured thirty-nine mountains higher than Mont Blanc. It must be recollected also that as the Moon is so much smaller than the Earth, the proportion of the height of a mountain to the diameter is much greater in the former.

225. As far as we know, with one or two very doubtful exceptions, the volcanoes are now all extinct; the oceans have disappeared; the valleys are no longer fertile; nay, the very atmosphere has apparently left our satellite, and that little celestial body which probably was once the scene of various forms of life now no longer supports them.

This may be accounted for by supposing (see Art. 191) that, on account of the small mass of the Moon, its original heat has all been radiated into space (as a bullet will take less time to get cold than a cannon-ball).

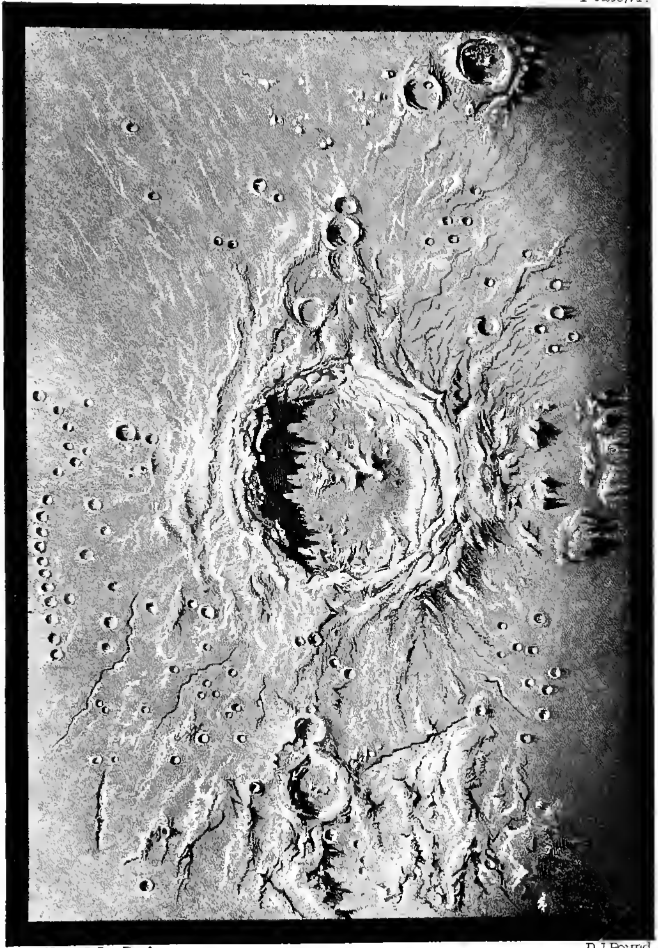
226. The rilles, of which nearly 1,000 are now known, are trenches with raised sides more or less steep. Besides the rilles, at full Moon, bright **rays** are seen, which seem to start from the more prominent mountains. Some of these rays are visible under all illuminations; one, which, emanating from Tycho, crosses a crater on the north-east of Fracastorius, is not only distinctly visible when the terminator grazes the west edge of Fracastorius, but is even brighter as the terminator approaches it. Those emanating from Tycho are different in their character from those emanating from Copernicus, while those from Proclus form a third class.

Mr. Nasmyth has been able to produce somewhat similar appearances on a glass globe by filling it with cold water, closing it up, and plunging it into warm water. This causes the inclosed cold water to expand very slowly, and the globe eventually bursts, its weakest point giving way, forming a centre of radiating cracks in a similar manner to the fissures, if they be fissures, in the Moon.

227. We say that the Moon has apparently no atmosphere: (1) because we never see any clouds there, and (2) because, when the Moon's motion causes it to travel

LUNAR CRATERS
COPERNICUS

Plate, VI.



James Nasmyth Esq. Pinx^t

D.J. Pound

Scale of 10 5 0 10 20 30 40 Miles

over a star, or to occult it, as it is called, the star disappears at once, and does not seem to linger on the edge, as it would do if there were an atmosphere.

228. As the Moon rotates on her axis, as we do, only more slowly, the changes of day and night occur there as here; but instead of being accomplished in 24 hours, the Moon's day is 29½ of our days long, so that each portion of the surface is in turn exposed to, and shielded from, the Sun for a fortnight. Now it has been pointed out that if the Moon be absolutely devoid of atmosphere, its surface, undefended from the intense cold of space, could never, even under a vertical sun, rise above – 50° Fahrenheit; in other words, would be always below the freezing-point of mercury. Some recent experiments, however, of a very delicate nature, seem to show that the temperature of the illuminated side of the Moon is not so excessively low, leading to the inference that a very thin lunar atmosphere does really exist.

In Plate VI. we give a view of the crater Copernicus, one of the most prominent objects in the Moon. The details of the crater itself, and of its immediate neighbourhood, represented in the drawing, reveal to us unmistakable evidences of volcanic action. The floor of the crater is seen to be strewn over with rugged masses, while outside the crater-wall (which on the left-hand side casts a shadow on the floor, as the drawing was taken soon after sunrise at Copernicus, and the Sun is to the left) many smaller craters, those near the edge forming a regular line, are distinctly visible. Enormous unclosed cracks and chasms are also distinguishable. The depth of the crater floor, from the top of the wall, is 11,300 feet; and the height of the wall above the general surface of the Moon is 2,650 feet. The irregularities in the top of the wall are well shown in the shadow. The scale of miles attached to the drawing shows the enormous proportions of the crater.

LESSON XVII.—*Phases of the Moon. Eclipses: how Caused. Eclipses of the Moon.*

229. Let us now explain what are called the **phases** of the Moon,—that is, the different shapes the Moon puts on. We stated very early in this little book (Art. 12) that the Moon, like the Earth, got all her light from the Sun. Now, in the first place, it is clear that the Sun can only light up that half of the Moon which is turned towards it; it is clear also that, if we could get on the same side of the Moon as the Sun is, we should see the lit-up half; if we got on the other side, we should see just nothing at all of the Moon. But this is exactly what happens, and to explain this let us suppose the plane of the Moon's motion to be in the plane of the ecliptic. In Fig. 22, we suppose the Sun to lie to the right; the Earth and its orbit are shown, the half turned towards the Sun being of course lit up. We also represent the Moon's orbit. Let us first take the Moon at A. We represent it with the side turned to the Sun lit up. Now it is clear that, as we are on the side opposite to the Sun, we cannot see the lit-up portion—this is the position occupied by the **New Moon**—and practically we do not see the New Moon. Now let us take the Moon at B; it is equally clear that at this point we face the lit-up portion and see all of it. Now this occurs at **Full Moon,** when the Moon arrives at such a position in her orbit that the Sun, Earth, and herself are in the same line, the Moon lying outside, and not in the middle as at New Moon.

230. At C and D our satellite is represented midway between these two positions. Again, it is evident that at C we shall see one-half of the lit-up Moon—that half lying to the right, as seen from the Earth; at D we shall see the lit-up portion lying to the left, looking from the Earth. These positions are those occupied by the Moon at the **First Quarter** and **Last Quarter** respectively.

When the Moon is at E and F we shall see but a small part of the lit-up portion, and we shall get a **crescent Moon**, the crescent in both cases being turned to the Sun. At G and H the Moon will be **gibbous**.

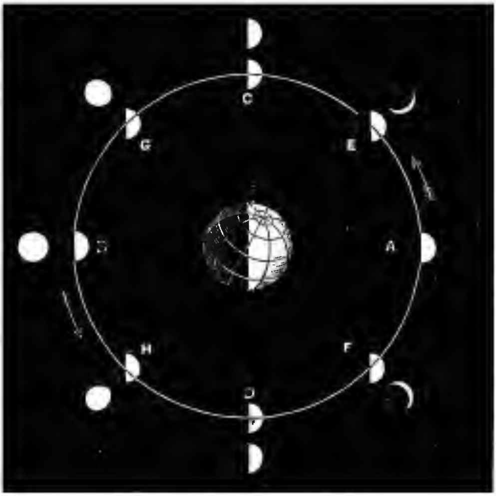


FIG. 22.—Phases of the Moon.

231. So that the history of the phases is as follows :—

New Moon.	The Moon is invisible to us, because the Sun is lighting up one side and we are on the other.
Crescent Moon.	We just begin to see a little of the illuminated portion, but the Moon is still so nearly in a line with the Sun, that we only catch, as it were, a glimpse of the side turned towards the Sun, and see the Moon herself for a short time after sunset.

First Quarter.	As seen from the Moon, the Earth and Sun are at right angles to each other. When the Sun sets in the west, the Moon is south. Hence, as the illumination is sideways, the right-hand side of the Moon is lit up.
Gibbous Moon.	The Moon is now more than half lighted up on the right-hand side.
Full Moon.	The Earth is now between the Sun and Moon, and therefore the entire half of the Moon which is illuminated is visible.

232. From Full Moon we return through the Second Quarter and other similar phases to the New Moon, when the cycle recommences. So that, from New Moon the illuminated portion of our satellite waxes, or increases in size, till Full Moon, and then wanes, or diminishes, to the next New Moon; the illuminated portion, except at Full Moon, being separated from the dark one by a semi-ellipse, called, as we have seen (Art. 222), the terminator.

233. In Fig. 22 we supposed that the Moon's motion was performed in the plane of the ecliptic. Our readers now know (Art 215) that this is not the case: if it were so, every New Moon would put out the Sun; and as the Earth, and every body through which light cannot pass, both on the Earth and off it, casts a shadow, every Full Moon would be hidden in that shadow. These appearances are called **eclipses,** and they do happen sometimes. Let us see if we can show under what circumstances they do happen. One-half of the Moon's journey is performed above the plane of the ecliptic, one-half below it; hence at certain times—twice in each revolution—the Moon is in that plane, at those parts of it called the **nodes.** Now, if the Moon at that time happens to be new or full—that is, in line with the Earth and Sun—in one case we shall have an eclipse of the Sun, in the other we shall have an eclipse of the Moon. This will be rendered clear by the accompanying figure. We have the Sun at bottom, the Earth at top, and the Moon in two positions marked A and B, the level of the page representing the level, or plane, of the ecliptic. We suppose therefore in both cases that the Moon is at a node,—that is, on that level, neither above nor below it.

234. At A, therefore, the Moon stops the Sun's light, its shadow falls on a part of the Earth; and the people, therefore, who live on that particular part of it where the shadow falls cannot see the Sun, because the Moon is in the way. Hence we shall have what is called an **eclipse of the Sun.**

235. At B the Moon is in the shadow of the Earth cast by the Sun; therefore the Moon cannot receive any light from the Sun, because the Earth is in the way. Hence we shall have what is called an **eclipse of the Moon.**

236. It will easily be seen from the figure, that whereas the eclipse of the Moon by the shadow of the much larger Earth will be more or less visible to the whole side of the Earth turned away from the Sun, the shadow cast by the small Moon in a solar eclipse is, on the contrary, so limited, that the eclipse is only seen over a small area.

FIG. 23.—Eclipses of the Sun and Moon.

237. In the figure two kinds of shadows are shown, one much darker than the other; the former is called the

umbra, the latter the **penumbra.** If the Sun were a point of light merely, the shadow would be all umbra; but it is so large, that round the umbra, where no part of the Sun is visible, there is a belt where a portion of it can be seen; hence we get a partial shadow, which is the meaning of penumbra. This will be made quite clear if we get two candles to represent any two opposite edges of the Sun, place them rather near together, at equal distances from a wall, and observe the shadow they cast on the wall from any object; on either side the shadow thrown by both candles will be a shadow thrown only by one.

238. In a total eclipse of the Moon, as the Moon travels from west to east, we first see the eastern side of the Moon slightly dim as she enters the penumbra; this is the first contact with the penumbra, spoken of in almanacs. At length, when the real umbra is reached, the eastern edge becomes almost invisible; we have the first contact with the dark shadow; the circular shape of the Earth's shadow is distinctly seen, and at last she enters it entirely. When the Moon passes, however, into the shadow of the Earth, it is scarcely ever quite obscured; the Sun's light is bent by the Earth's atmosphere towards the Moon, and sometimes tinges it with a ruddy colour. The eclipses, however, which occurred in 1642, 1761, 1816, and on the 4th of October, 1884, were remarkable for the total disappearance of the Moon.

A total eclipse of the Moon may last about $1\frac{3}{4}$ hours. When the Moon again leaves the umbra we have the last contact with the dark shadow; and after the last contact with the penumbra, the eclipse is over.

239. If the Moon is not exactly at a node, we shall only get a **partial eclipse of the Moon,** the degree of eclipse depending upon the distance from the node. For instance, if the Moon is to the north of the node, the lower limb may enter the upper edge of the penumbra or of the umbra; if to the south of the node, the upper portion will be obscured.

LESSON XVIII.—*Eclipses (continued). Eclipses of the Sun. Total Eclipses and their Phenomena. Corona. Red-flames.*

240. In a total eclipse of the Sun, the diameter of the shadow which falls on the Earth is never large, averaging about 150 miles; the Moon, which obscures the Sun, revolves from west to east in a month, and the Earth's surface, on which the shadow falls, also rotates from west to east in a day, and the shadow sweeps across it from west to east with great rapidity. The longest time an eclipse of the Sun can be total at any place is seven minutes, and of course it is only visible at those places swept by the shadow. Hence, in any one place, total eclipses of the Sun are of very rare occurrence; in London, for instance, there has been no total eclipse of the Sun since 1715.

241. In eclipses of the Sun there are no visible effects of umbra and penumbra seen on the Sun itself; we have the real (though invisible) Moon eating into the real and visible Sun, the western edge of the Sun in the case of total eclipses being first obscured. The obscuration increases until the Moon covers all the Sun, and soon afterwards the western edge of the Sun reappears.

242. As in the case of the Moon, there are other eclipses besides total ones. To explain this we must give a few figures. As both Sun and Moon are round, or nearly so, the shadow from the latter is round; and as the Sun is larger than the Moon, the shadow ends in a point. The shape of the shadow is, in fact, that of a **cone**—hence the term "cone of shadow." Now, the length of this cone varies with the Moon's distance from the Sun: when nearest, the Moon will of course throw the shortest shadow. The lengths are about as follow:—

	Miles.
When the Moon and Sun are nearest together .	230,000
„ „ „ furthest apart . .	238,000

But in Art. 212 we saw that the distance between the Earth and Moon varied as follows :—

	Miles.
When the Moon and Earth are nearest together	225,719
" " " furthest apart	251,947

Hence, when the Moon is furthest from the Earth, or in apogee, the shadow thrown by the Moon is not long enough to reach the Earth ; at such times the Moon looks smaller than the Sun ; and if she be at a node, we shall have an **annular eclipse**—that is, there will be a ring (*annulus*, Lat. ring) of the Sun visible round the Moon when the eclipse would otherwise have been total.

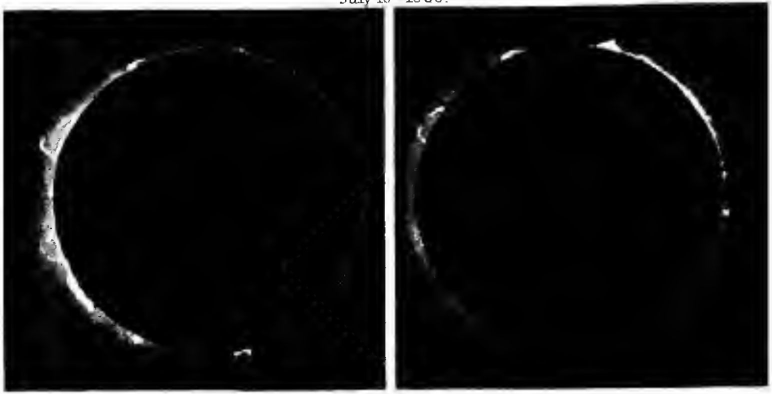
243. There may be **partial eclipses of the Sun**, for the same reason as we have partial eclipses of the Moon ; only as the Moon is not exactly at the node in one case, she does not get totally eclipsed, because she does not pass quite into the shadow of the Earth ; and in the other, the Sun does not get totally eclipsed, because the Moon does not pass exactly between us and the Sun.

244. The nodes of the Moon are not stationary, but move backwards upon the Moon's orbit, a complete revolution taking place with regard to the Moon in 18 years 219 days, nearly. The Moon in her orbit, therefore, meets the same node again before she arrives at the same place with regard to the Sun again, one period being 27d. 5h. 6m., called the **nodical revolution of the Moon** ; and the other, 29d. 12h. 44m., called the **synodical revolution of the Moon,** in which it regains the same position with regard to the Sun. The node is in the same position with regard to the Sun after an interval of 346d. 14h. 52m. This is called a **synodic revolution of the node.** Now it so happens that nineteen synodic revolutions of the node, after which period the Sun and node would be alike situated, are equal to 223 synodic revolutions of the Moon, after which period the Sun and Moon would be alike situated ; so that, if we have an eclipse at the beginning of the period, we shall have one at the end of it, the Sun, Moon,

TOTAL ECLIPSE OF THE SUN

July 18^{th} 1860.

Plate VII.



APPEARANCE OF THE LUMINOUS PROMINENCES AT RIVABELLOSA, SPAIN

AT $3^{h}\ 0^{min}\ 40^{sec}$ AND AT $3^{h}\ 3^{min}\ 50^{sec}$ G.M.T.

Photographed by Warren De La Rue, F.R.S.

Engraved by S Russell

and node having got back to their original positions. This period of 18 years 10 days is a cycle of the Moon, known to the ancient Chaldeans and Greeks under the name of **Saros,** and by its means eclipses were roughly predicted before astronomy had made much progress.

245. A total eclipse of the Sun is at once one of the most awe-inspiring and grandest sights it is possible for man to witness. As the eclipse advances, but before the totality is complete, the sky grows of a dusky livid, or purple, or yellowish crimson colour, which gradually gets darker and darker, and the colour appears to run over large portions of the sky, irrespective of the clouds. The sea turns lurid red. This singular colouring and darkening of the landscape is quite unlike the approach of night, and gives rise to strange feelings of sadness. The Moon's shadow is seen to sweep across the surface of the Earth, and is even seen in the air ; the rapidity of its motion and its intenseness produce a feeling that something material is sweeping over the Earth at a speed perfectly frightful. All sense of distance is lost, the faces of men assume a livid hue, fowls hasten to roost, flowers close, cocks crow, and the whole animal world seems frightened out of its usual propriety.

246. A few seconds before the commencement of the totality the stars burst out ; and surrounding the dark Moon on all sides is seen a glorious halo, generally of a silver-white light ; this is called the **corona.** It reveals to us for the most part the exterior portion of the Sun's atmosphere, which is not seen when the Sun itself is visible, owing to the overpowering light of the latter. It is slightly radiated in structure, and extends sometimes beyond the Moon to a distance equal to our satellite's diameter. Besides this, rays of light, called aigrettes, diverge from the Moon's edge, and appear to be shining through the light of the corona. In some eclipses some parts of the corona have reached to a much greater distance from the Moon's edge than in others.

247. During the total eclipse observed in America on July 29, 1878, equatorial streamers were seen proceeding from the Sun to a distance of fully 10,000,000 miles, and something of the same extraordinary appearance had also been noticed in 1867. Now, it is remarkable that both these years were epochs of sun-spot minimum, so that the shape of the corona has been assumed to be in some way

FIG. 24.—Corona of 1878, as seen behind a screen.

connected with the phases of the Sun's activity. The view has, however, lately been put forward that these apparent coronal extensions may really indicate a permanent solar appendage in a ring of cooled material revolving partly within the limits of the solar atmosphere. The fall of matter from this ring upon the Sun's surface, resulting from inevitable disturbances, would produce spots and prominences, and account for many of the best-marked features of the sun-spot period. It would also explain the acceleration of spots near the equator.

247a. The spectroscope tells us that the corona is in part made up of two kinds of gas—hydrogen, and an unknown gas emitting green light exclusively; in part of solid or liquid particles reflecting sunlight.

248. When totality has commenced, apparently close to the edge of the Moon, and therefore within the corona, are observed fantastically-shaped masses, full lake-red, fading into rose-pink, variously called **red flames** and **red prominences.** Two of the most remarkable of these hitherto noticed were observed in the eclipse of 1851. They have thus been described by the Rev. W. R. Dawes :—

"A bluntly triangular pink body [was seen] *suspended*, as it were, in the corona. This was separated from the Moon's edge when first seen, and the separation increased as the Moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening soft and ill-defined substance. . . To the north of this appeared the most wonderful phenomenon of the whole: a red protuberance, of vivid brightness and very deep tint, arose to a height of perhaps 1½′ when first seen, and increased in length to 2′ or more, as the Moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish cimeter*, the northern edge being convex, and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. . . . To my great astonishment, this marvellous object continued visible for about five seconds, as nearly as I could judge, after the Sun began to reappear."

249. It has been definitely established that these prominences belong to the Sun, as those at first visible on the eastern side are gradually obscured by the Moon, while those on the western are becoming more visible, owing to the Moon's motion from west to east over the Sun. The height of some of them above the Sun's surface is upwards of 90,000 miles, and occasional uprushes have been watched, to elevations of more than 200,000 miles.

250. These red prominences are composed of incandescent hydrogen gas and metallic vapours lying outside the photosphere; and their spectroscopic examination indicates that the pressure in the high prominences is small. It indicates also that the matter composing them is in exceedingly rapid motion, upward movements up to 250 *miles a second*, having been detected by this means. (See Art. 504*b*.)

LESSON XIX.—*The other Planets compared with the Earth. Physical Description of Mars.*

251. We are now in a position to examine the other planets of our system, and to bring the facts taught us by our own to bear upon them. In the case of all the planets we have been able to ascertain the facts necessary to determine the elements of their revolution round the Sun; that is to say, the time in which the complete circuit round the common luminary is accomplished, and the shape and position of their orbits with regard to our own. Now, the shape of the orbit depends upon the degree of its ellipticity —for all are elliptical—and its position upon the distance of the planet from the Sun, and the degree in which the plane of each orbit departs from that of our own. When we have, in addition to these particulars, the position of the *nodes*—the points in which the orbit intersects the plane of our orbit—and the position of the perihelion points, we have all the materials necessary for calculation or for making a diagram of the planet's path.

252. Still, however satisfactory our examination of the planets has been with regard to their revolution round the Sun, we are compelled to state that when we wish to inquire into their rotations on their axes, the length of their days, their seasons, and their physical constitutions, the knowledge as yet acquired by means of the telescope is far from complete. Thus, of the planets Mercury and Venus we have nothing quite certain to tell on these matters; they are both so lost in the Sun's rays, and so refulgent in consequence of their nearness to that body, that our observation of them, of Mercury especially, has been to a great extent baffled. Nevertheless, the observations made in the beginning of this century by a German astronomer named Schröter have been so far confirmed in recent years, that we may pretty safely admit a period of about 25 hours for Mercury's rotation on his axis. That is, his day is an hour or so longer than ours. And the period assigned to Venus of 23h. 21m. is probably still more nearly exact. This has been confirmed by the measurement of photographs taken during the transit of Venus in 1882, which show that the *figure* of the planet is nearly identical with that of the Earth. It is *bulged* just to the same extent (see Art. 196); consequently it rotates at just about the same rate.

252a. The same class of facts in the case of Uranus and Neptune are equally hard to get at, but for a different reason. At our nearest approach to Uranus we are nearly 1,700,000,000 miles away from that planet; at our nearest approach to Neptune we are about 2,700,000,000 miles away, and we cannot be surprised that our telescopes almost fail us in delicate observations at such distances. Still, on the small disk of Uranus some delicate cloud-markings have lately been detected, evidently connected with his rotation ; and the reappearances of a bright spot seem to give for that rotation a period of about 10 hours.

253. With regard however to Mars, Jupiter, and Saturn, the planets whose orbits are nearest to our own, our information is comparatively full and complete. For instance, we can for these planets give the following information in addition to that stated in Arts. 139 and 140, and Table II. of the Appendix :—

	Length of Day.			Inclination of Axis.		
	H.	M.	S.			
Mars . . .	24	37	22 . . .	24°	52′	0″
Jupiter . .	9	55	21 . .	3	4	0
Saturn . .	10	14	23 . . .	28	10	0

The first column requires no explanation. We see, however, at once that the day in Mars is nearly equal to our own, while in the large planets, Jupiter and Saturn, it is not half so long. Now the revolutions of these planets round the Sun are accomplished as follows :—

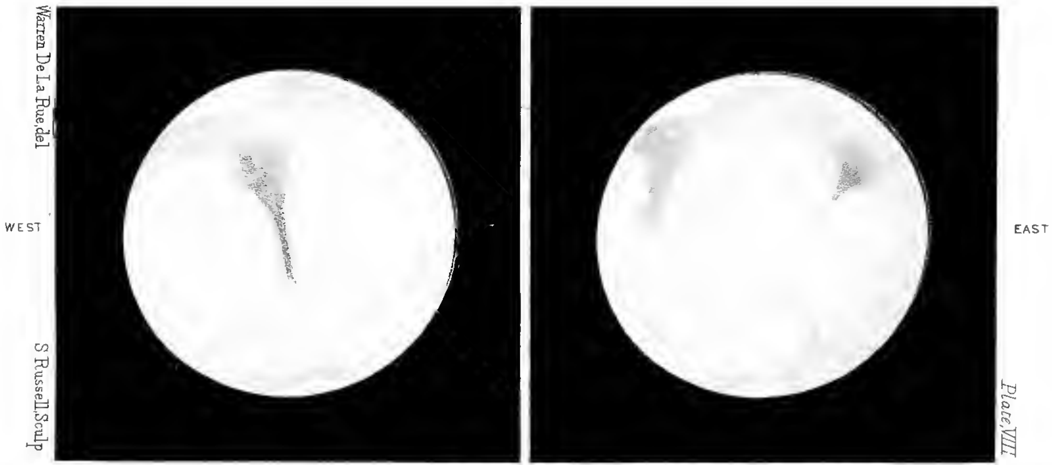
Mars in	686	of our days.
Jupiter in	4,333	„
Saturn in	10,759	„

We can therefore easily find the number of days according to the period of rotation of each planet, which go to make each planetary year : thus in Saturn's year there are 24,584 Saturnian days, or 67 times more days than in our own.

254. In the second column the inclination of the planets' axes of rotation is given. It will be recollected that the inclination of our own is 23½°, and that it is on this inclination that our seasons depend. It will be seen at once therefore that Mars and Saturn are much like the Earth in this respect, and that Jupiter is a planet almost without seasons, for the inclination of its axis is only 3°, while that of Venus is 53°. The axis of rotation

MARS.

APRIL 20th 1856.



Warren De La Rue, del

S Russell, Sculp

Plate, VIII

9$^{\text{hour}}$ 40$^{\text{min}}$ G.M.T.

11$^{\text{hour}}$ 45$^{\text{min}}$ G.M.T.

AS SEEN WITH A NEWTONIAN EQUATOREAL OF THIRTEEN INCHES APERTURE

Scale 0$^{\text{in}}$125 = One Second of Arc

of Uranus is, so far as can be judged, tilted by about the same amount.

255. As in the case of the Earth, we find in many instances the axis of rotation, or polar diameter, of the other planets shorter than the equatorial diameter. The amount of **polar compression**,—that is, the amount of flattening, by which the polar diameter is less than the equatorial one,—measured in fractions of the latter, is as follows:—

Mercury .	$\frac{1}{29}$	Jupiter .	$\frac{1}{17}$
Venus .	$\frac{1}{303}$	Saturn .	$\frac{1}{9}$
Earth . .	$\frac{1}{299}$	Uranus .	?
Mars . .	?	Neptune	?

From this table we learn that if the equatorial diameter of Mercury be taken as 29, the polar one is only 28: in the cases of Jupiter and Saturn, the diameters are as 17 to 16 and 9 to 8, respectively. In these two last the rotation is very rapid (Art. 253); and this great flattening is what we should expect from the reasoning in Art. 196.

256. We now come to what we can glean of the physical structure of the planets as seen in the telescope when they are nearest the Earth. Let us begin with **Mars.** We give in Plate IX. two sketches, taken in the year 1862. Here at once we see that we have something singularly like the Earth. The shaded portions represent water, the lighter ones land, and the bright spot at the top of the drawings is probably snow lying round the south pole of the planet, which was then visible.

257. The two drawings represent the planet as seen in an astronomical telescope, which inverts objects so that the south pole of the planet is shown at top. The upper drawing was made on the 25th of September, the lower one on the 23rd. In the upper one a sea is seen on the left, stretching down northwards; while, joined on to it, as the Mediterranean is joined on to the Atlantic, is a long narrow sea, which widens at its termination.

In the lower drawing this narrow sea is represented on the left. The coast-line on the right strangely reminds one of the Scandinavian peninsula, and the included Baltic Sea.

258. It will now be easy to understand how we have been able to determine the length of the day and the inclination of the axis. We have only to watch how long it takes one of the spots near the equator of each planet to pass from one side to the other, and the direction it takes, to get at both these facts.

259. Mars not only has land and water and snow like us, but it has clouds and mists, and these have been watched at different times. The land is generally reddish when the planet's atmosphere is clear; this is due to the absorption of the atmosphere, as is the colour of the setting Sun with us. The water appears of a greenish tinge.

259a. A very curious feature of the surface of Mars was detected in 1877, when the planet made one of its nearest approaches to the Earth. The so-called "continents" were then seen to be divided into innumerable islands by a net-work of "canals," or long and narrow arms of the seas, sometimes running almost in a straight line for 3,000 or 4,000 miles. It was on the same occasion that the moons of Mars were discovered by Professor Hall at Washington. These two little bodies are quite the smallest of known satellites. They have been called *Deimos* and *Phobos*, from a passage in the *Iliad*, in which Pain and Fear are represented as the attendants of Mars.

260. Now, if we are right in supposing that the bright portion surrounding the pole is ice and snow, we ought to see it rapidly decrease in the planet's summer. This is actually found to be the case, and the rate at which the thaw takes place is one of the most interesting facts to be gathered from a close study of the planet. In 1862 this decrease was very visible. The summer solstice of Mars

Plate IX.

MARS in 1862.

occurred on the 30th of August, and the snow-zone was observed to be smallest on the 11th of October, or forty-two of our days after the highest position of the Sun. This very rapid melting may be ascribed to the inclination of the axis, which is greater than with us; to the greater eccentricity of the planet's orbit; and to the fact that the summer-time of the southern hemisphere occurs when the planet is near perihelion.

261. For a reason that will be easily understood when we come to deal with the effect of the Earth's revolution round the Sun on the apparent positions and aspects of the planets, we sometimes see the north pole, and sometimes the south pole of Mars, and sometimes both: when either pole only is visible, the features, which appear to pass across the planet's disk in about 12 hours—that is, half the period of the planet's rotation—describe curves with the concave side towards the visible pole. When both poles are visible they describe straight lines, exactly as in the case of the Sun (Art. 106). These changes enable all the surface to be seen at different times, and maps of Mars have been constructed, the exact position of the features of the planet being determined by their latitude and longitude, as in the case of the Earth.

262. But although we see in Mars so many things that remind us of our planet, and show us that the extreme temperatures of the two planets are not far from equal, a distinction must be drawn between them. In consequence of the great eccentricity of the orbit of Mars, the lengths of the various seasons are not so equal as with us, and, owing to the longer year, they are of much greater extent. In the northern hemisphere of the planet they are as under:—

	Days.	Hrs.
Spring lasts . .	191	8
Summer ,,	181	0
Autumn ,, . .	149	8
Winter ,, . .	147	0

As we must reverse the seasons for the southern hemisphere, spring and summer, taken together, are 76 days longer in the northern hemisphere than in the southern.

LESSON XX.—*The other Planets compared with the Earth (continued). Jupiter: his Belts and Moons. Saturn: General Sketch of his System.**

263. Let us now pass on to **Jupiter**, by far the largest planet in the system, and bright enough sometimes, in spite of its great distance, to cast a shadow like Venus. The first glance at the drawing (Plate X. Fig. 1) will show us that we have here something very unlike Mars; and such is the fact. The planet Jupiter is surrounded by an atmosphere so densely laden with clouds, that of the actual planet itself we know nothing.

What are generally known as the **belts** of Jupiter are dusky streaks which cross a brighter background in directions generally parallel to the planet's equator. And for the most part, the largest belts are situated on either side of it, in exactly the same way as the two belts of Trade-Winds on the Earth lie on either side of the belt of Equatorial Calms and rains. Outside these, again, we get representatives of the Calms of Cancer and Capricorn, although these are not so regularly seen, the portion of the planet's surface polewards of the two belts being liable to great changes of appearance, sometimes in a very short time. The portions of the atmosphere representing the terrestrial calm-belts sometimes exhibit a beautiful rosy tint, the equatorial one especially.

264. The variations of this cloudy atmosphere lend great variety to the appearance of the planet at different times; the belts are sometimes seen in large numbers, and extend almost to the poles. Besides the belts, some-

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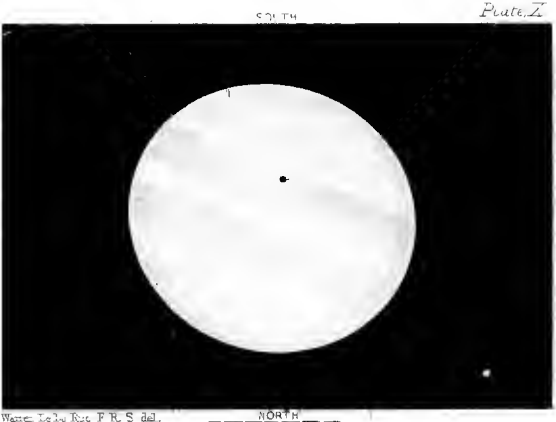
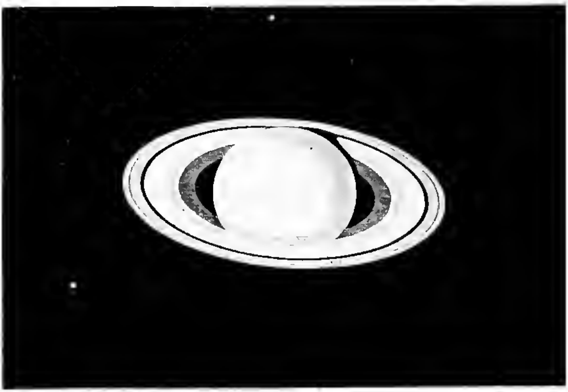
* Proctor's "Saturn and his System," from which some of the statements concerning Saturn are taken, may be consulted by the teacher.



Warren De la Rue, F.R.S. del.

JUPITER



Warren De la Rue, F.R.S. del.

SATURN

times bright spots, sometimes dark ones, are seen, which have enabled us to determine the period of the planet's rotation, which, as we have seen, is very rapid—so rapid that on the equator an observer would be carried round at the rate of 467 miles a minute, instead of 17 as on the Earth. It is remarkable that spots near the equator travel faster than those remote from it, just as they do on the Sun, differences of as much as 7½ minutes having been observed in the periods of rotation derived from differently situated spots. An enormous red spot, for instance, 30,000 miles long by nearly 7,000 wide, which appeared in 1878, and is still faintly visible, took about 5½ minutes longer to complete a rotation than a brilliant white spot conspicuous at the same time. This sun-like mode of rotation, and other facts, favour the opinion that the internal temperature of Jupiter is still very high; and the same conclusion probably holds good for Saturn, Uranus, and Neptune.

265. Although all astronomers do not agree that the surface of the planet is never seen, there are many strong reasons why it should not be seen. In the first place, Mars and the Earth, whose atmospheres are nearly alike, have nearly the same densities (Art. 145), while in the case of Jupiter and Saturn—the belts of which latter planet, as far as we can observe them, resemble Jupiter's —the density, as calculated on the idea that what we see is all planet, is only about one-fifth that of the Earth; and as the density of the Earth is 5½ times that of water, it follows that the densities of the two planets in question are not far off that of water.

266. Now, if we suppose that the apparent volume of Jupiter (and similarly of Saturn) is made up of a large shell of cloudy atmosphere and a kernel of planet, there is no reason why the density of the real Jupiter (and of the real Saturn) should vary very much from that of the Earth or Mars, and this would save us from the water-planet hypothesis. Moreover, a large shell of cloudy atmosphere is precisely what our own planet was most probably enveloped in, in one of the early stages of its history (Art. 208).

267. In addition to the changing features of Jupiter itself, the telescope reveals to us four **moons,** which as they course along rapidly in their orbits, and as these orbits lie nearly in the plane of the planet's orbit, lend a great additional interest to the picture. In the various positions in their orbits the satellites sometimes appear at a great distance from the primary; sometimes they come between us and the planet, appearing now as bright and now as dark spots on its surface. At other times they pass between the planet and the Sun, throwing their shadows on the planet's disk, and causing, in fact, eclipses of the Sun. They also enter into the shadow cast by the planet, and are therefore eclipsed themselves; and sometimes they pass behind the planet and are said to be occulted. Of these appearances we shall have more to say by and by (Lesson XXXVI.).


FIG. 25.—Jupiter and his Moons (general view).

268. Referring to the sizes of these moons and their distances from the planet, in Table III. of the Appendix, it may be here added that, like our Moon, they rotate on their axes in the same time as they revolve round Jupiter. This has been inferred from the fact that their light varies, and that they are always brightest and dullest in the same positions with regard to Jupiter and the Sun.

269. In Plate X. the black spot is the shadow of a satellite, and the satellite itself is seen to the left; the passage of either a satellite or shadow is called a **transit.** In a solar eclipse, could we observe it from Venus, we should see a similar spot sweeping over the Earth's surface.

270. We now come to **Saturn**; and here again, as in the case of Jupiter, we come upon another departure from Mars and the Earth. The planet itself, which is belted like Jupiter, is surrounded not only by eight moons, but by a series of rings, one of which. the inner one, is transparent! The belts have been before referred to (Art. 265), they need not, therefore, detain us here; and we may dismiss the satellites—as their distances from Saturn, &c., are given in Table III. of the Appendix—with the remark, that as the equator of Saturn, unlike that of Jupiter, is greatly inclined to the ecliptic, transits, eclipses, and occultations of the satellites, the orbits of which for the most part lie in the plane of Saturn's equator, happen but rarely.

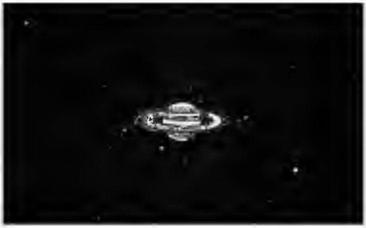


FIG. 26.—Saturn and his Moons (general view).

271. It is to the **rings** that most of the interest of this planet attaches. We may well imagine how sorely puzzled the earlier observers, with their very imperfect telescopes, were, by these strange appendages. The planet at first was supposed to resemble a vase; hence the name *Ansæ*, or handles, given to the rings in certain positions of the planet. It was next supposed to consist of three bodies, the largest one in the middle. The true nature of the rings was discovered by Huyghens in 1655, who announced it in this curious form:—

"aaaaaaa ccccc d eeeee g h iiiiiii llll mm
nnnnnnnnn oooo pp q rr s ttttt uuuuu,"

which letters, transposed, read:—

"*annulo cingitur, tenui plano, nusquam cohaerente. ad eclipticam inclinato.*"

There is nothing more encouraging in the history of astronomy than the way in which eye and mind have bridged over the tremendous gap which separates us from this planet. By degrees the fact that the appearance was due to a ring was determined; then a separation was noticed dividing the ring into two; further observations suggested to the French astronomers Du Séjour and Lalande that the number of rings should be multiplied many-fold; the extreme thinness of the ring came out next, when Sir William Herschel observed the satellites "like pearls strung on a silver thread." The making out of the transparent ring by Dawes and Bond followed in 1850; then the transparent ring was discovered to be divided as the whole system had once been thought to be; last of all comes evidence that the smaller divisions in the various rings are subject to change, and that the ring-system itself is probably increasing in breadth, and approaching the planet.

LESSON XXI.—*The other Planets compared with the Earth (continued). Dimensions of Saturn and his Rings. Probable Nature of the Rings. Effects produced by the Rings on the Planet. Uranus. Neptune: its Discovery.*

The lower figure of Plate X. will give an idea of the appearance presented by the planet and its strange and beautiful appendage. It will be shown in the sequel (Chap. IV.) how we see, sometimes one surface, and sometimes another, of the ring, and how at other times the edge of it is alone visible.

272. The ring-system is situated in the plane of the planet's equator, and its dimensions are as follow:—

	Miles.
Outside diameter of outer ring . . .	166,920
Inside „ „ . . .	147,670
Distance from outer to inner ring . . .	1,680
Outside diameter of inner ring	144,310
Inside „ „	109,100
Inside „ dark ring	91,780
Distance from dark ring to planet . . .	9,760
Equatorial diameter of planet	72,250

so that the breadths of the three principal rings, and of the entire system, are as follow :—

	Miles.
Outer bright ring	9,625
Inner bright ring . . .	17,605
Dark ring	8,660
Entire system	37,570

and the distance between the two bright rings is 1,680 miles.

In spite of this enormous breadth, the thickness of the rings is not supposed to exceed 100 miles.

273. Of what, then, are these rings composed? There is great reason for believing that they are neither solid nor liquid; and the idea now generally accepted is that they are composed of myriads of satellites, or little bodies, moving independently, each in its own orbit, round the planet; giving rise to the appearance of a bright ring when they are closely packed together, and a very dim one when they are most scattered. In this way we may account for the varying brightness of the different parts, and for the haziness on both sides of the ring near the planet (shown in Fig. 26), which is supposed to be due to the bodies being drawn out of the ring by the attraction of the planet.

274. Although Saturn appears to resemble Jupiter in its atmospheric conditions, unlike that planet, and like our own Earth, its year, owing to the great inclination of its axis, is sharply divided into seasons, which however are here indicated by something else than a change of temperature; we refer to the effects produced by the presence of the strange ring appendage. To understand these effects, its appearance from the body of the planet must first be considered. As the plane of the ring lies in the plane of the planet's equator, an observer at the equator will only see its thickness, and the ring therefore will put on the appearance of a band of light passing through the east and west points and the zenith. As the observer, however, increases his latitude either north or south, the surface of the ring-system will begin to be seen, and it will gradually widen, as in fact the observer will be able to look down upon it; but as it increases in width it will also increase its distance from the zenith, until in lat. 63° it is lost below the horizon, and between this latitude and the poles it is altogether invisible.

275. Now the plane of the ring always remains parallel to itself, and twice in Saturn's year—that is, in two opposite points of the planet's orbit—it passes through the Sun. It follows, therefore, that during one half of the revolution of the planet one surface of the rings is lit up, and during the remaining period the other surface. At night, therefore, in one case, the ring-system will be seen as an illuminated arch, with the shadow of the planet passing over it, like the hour-hand over a dial; and in the other, if it be not lit up by the light reflected from the planet, its position will only be indicated by the entire absence of stars.

276. But if the rings eclipse the stars at night, they can also eclipse the Sun by day. In latitude 40° there occur in Saturn morning and evening eclipses for more than a year, gradually extending until the Sun is eclipsed during the whole day—that is, when its apparent path lies entirely in the region covered by the ring; and these total eclipses continue for nearly seven years: eclipses of one kind or another taking place for 8 years 292 days. This will give us an idea how largely the apparent phenomena of the heavens, and the actual conditions as to climates and seasons, are influenced by the presence of the ring.

As the year of Saturn is as long as thirty of ours, it follows that each surface of the rings is in turn deprived of the light of the Sun for fifteen years.

277. We have now finished with the planets known to the ancients; the remaining ones, **Uranus** and **Neptune,** have been discovered in modern times—the former in 1781, by Sir Wm. Herschel, and the latter in 1846, independently, by Professor Adams and M. Leverrier.

278. Both these planets are situated at such enormous distances from the Sun, and therefore from us, that Uranus is scarcely, and Neptune not at all, visible to the naked eye. Owing to this remoteness, nothing is known of their physical peculiarities. We have already stated, however, that the motion of the satellites of Uranus, as well as of the solitary moon of Neptune, is in the opposite direction to that of all the other planetary members of the system.

279. The discovery of the planet Neptune is one of the most astonishing facts in the history of Astronomy. As we shall see in the sequel, every body in our system affects the motions of every other body; and after Uranus had been discovered some time, it was found, that, on taking all the known causes into account, there was still something affecting its motion; it was suggested that this something was another planet, more distant from the Sun than Uranus itself. And the question was, where was this planet, if it existed?

When we come to consider the problem in all its grandeur, we need not be surprised that two minds, who felt themselves competent to solve it, should have independently undertaken it. As far back as July 1841, we find Mr. Adams determined to investigate the irregularities of Uranus: early in September 1846, the new planet had fairly been grappled. We find Sir John Herschel remarking, "We see it as Columbus saw America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis with a certainty hardly inferior to ocular demonstration."

On the 29th July, 1846, the large telescope of the Cambridge Observatory was first employed to search for the planet in the place assigned to it by Professor Adams's calculations. M. Leverrier, in September, wrote to the Berlin observers, stating the place where his calculation led him to believe it would be found: his theoretical place and Professor Adams's being not a degree apart. At Berlin, thanks to their star-maps, which had not yet been published, Dr. Galle found the planet the same evening, very near the position assigned to it by both Astronomers.

LESSON XXII.—*The Asteroids, or Minor Planets. Bode's Law. Size of the Minor Planets: their Orbits: how they are observed.*

280. If we write down—

0 3 6 12 24 48 96

and add 4 to each, we get

4 7 10 16 28 52 100

and this series of numbers represents very nearly the distances of the ancient planets from the Sun, as follows:—

Mercury, Venus, Earth, Mars, —, Jupiter, Saturn.

This singular connexion was discovered by Titius, and is known by the name of **Bode's Law.** We see that the fifth term has apparently no representative among the planets. Although ignorant of the existence of any such relation between the distances of the planets, Kepler boldly attempted to bridge the gap between Mars and

Jupiter by inventing an unknown body to revolve there. Up to the time of the discovery of Uranus the undetected planet did not reveal itself: when it was found, however, that the actual position of Uranus was very well represented by the next term of the series, 196, it was determined to make an organized search for it, and for this purpose a society of astronomers was formed; the zodiac was divided into 24 zones, each zone being confided to a member of the society. On the first day of the present century a planet was discovered and named **Ceres,** which, curiously enough, filled up the gap. But the discovery of a second, third, and fourth, named respectively **Pallas, Juno,** and **Vesta,** soon followed, and up to the present time (February 1888) no less than 271 of these little bodies have been detected. A list of them, with their symbols, will be found in the Appendix, Table I.

281. None of these planets, except occasionally Ceres and Vesta, can be seen by the naked eye; and this brings us at once to their chief characteristic—the largest minor planet is but 320 miles in diameter, and many of the smaller ones are less than 20. In fact, the whole of the 268 now known rolled into one would form a planet scarcely $\frac{1}{4300}$ the size of our earth.

282. The orbits of those hitherto discovered, for the most part, lie nearer to Mars than Jupiter, and the orbits in some cases are so elliptical, that if we take the extreme distances into account, they occupy a zone 290,000,000 miles in width—the distance between Mars and Jupiter being 341,000,000. The planet nearest the Sun is (149) **Medusa,** whose journey round the Sun is performed in 3 years 43 days at a mean distance of 198,000,000 miles; the most distant one is (153) **Hilda,** whose year is nearly as long as 8 of ours, and whose mean distance is 367,400,000 miles.

283. Not only do some of the orbits approach those of comets in the degree of eccentricity, but they resemble them in another matter—their great inclination to the ecliptic. The orbit of ② **Pallas,** for instance, is inclined 34° to the plane of the ecliptic; while ⑳ **Massilia** is inclined but a few minutes of arc.

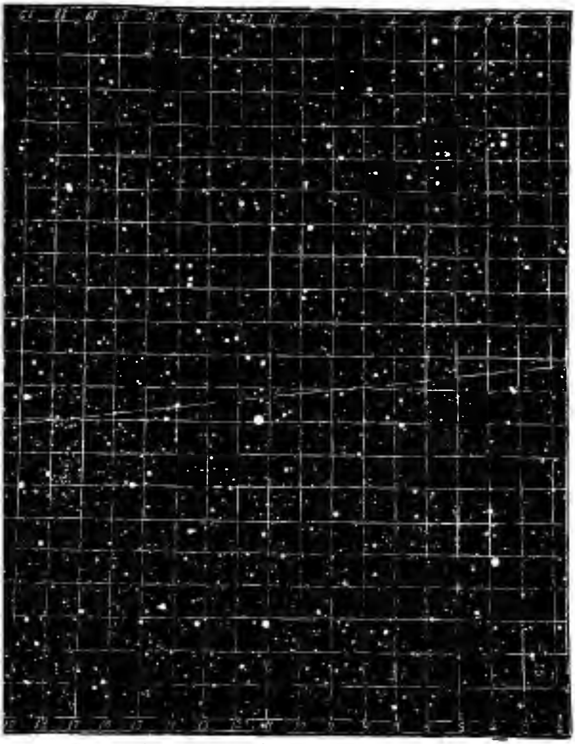


FIG. 27.—Star Map, showing the path of a Minor Planet.

284. The minor planets lately discovered shine as stars of the tenth or eleventh magnitude, and the only way in which they can be detected, therefore, is to compare the star-charts of different parts of the heavens with the heavens themselves, night after night. Should any point of light be observed not marked on the chart, it is immediately watched, and if any motion is detected, the amount and direction are determined. Some idea of the diligence and patience required for this branch of observation may be gathered from Fig. 27, which is the reduction of a part of one of M. Chacornac's ecliptic charts. The faint diagonal line shows the path of a minor planet across that portion of the heavens represented.

285. With regard to the cause for the existence of these little bodies, it was long ago suggested that they may be fragments of a larger planet destroyed by contact with some other celestial body. A closer investigation of the character and distribution of their orbits has, however, of late thrown much doubt on this view Yet the remark of D'Arrest should not be lost sight of: "One fact," he says, "appears, above all, to confirm the idea of an intimate relation between all the minor planets: it is, that if their orbits are figured under the form of material rings, these rings will be found so entangled that it would be possible, by means of one among them, taken at hazard, to lift up all the rest."

286. ② Pallas has been supposed, from its hazy appearance, to be surrounded by a dense atmosphere, and this may also be the case with the others, as their colours are not the same. There are also evidences that some among them rotate on their axes like the larger planets.

LESSON XXIII.—*Comets: their Orbits. Short-period Comets. Head, Tail, Coma, Nucleus, Jets, Envelopes. Their probable Number and Physical Constitution.*

287. We have seen that round the white-hot Sun cold or cooling solid bodies, called planets, revolve; that because they are cold they do not shine by their own light; that they perform their journeys in almost the same plane; that the shape of their orbit is oval or elliptical; and that they all move in one direction,—that is, from west to east.

But these are not the only bodies which revolve round the Sun. In addition to them there are bodies called **comets,** consisting of clouds of stones or meteorites, which do shine by their own light in consequence of collisions between the stones. These perform their journeys round the Sun in every plane, in orbits which in some cases are so elongated that they can scarcely be called elliptical, and—a further point of difference—while some revolve round the Sun in the same direction as the planets, others revolve from east to west.

288. The orbit of a comet is generally best represented by what is called a **parabola**; that is, an infinitely long ellipse, which latter, like a circle, is a closed curve—whereas the parabola may be regarded as an open one (Chap. IX.). In the case of a comet whose whole orbit has been watched, we know that the orbit is elliptical. In the case of those with parabolic orbits, we know not whence they come or whither they are going, and therefore we cannot say whether they will return or not. There are some comets whose return may be depended upon and calculated with certainty. Here is a list of some of them:—

Comet.	Time of Revolution.	Nearest Approach to the Sun.	Greatest Distance from the Sun.	Next Return.
	Years.			
Encke's	3¼	32,000,000	381,000,000	1888
Tempel's II ...	5¼	125,000,000	433,000,000	1889
Winnecke's ...	5½	72,500,000	511,000,000	1892
Brorsen's ...	5½	57,500,000	526,000,000	1890
Swift's	5½	99,500,000	478,000,000	1891
Tempel's I ...	6	164 000,000	448,000,000	1891
D'Arrest's ...	6½	109,000,000	532,000,000	1890
Faye's	7½	157,000,000	550,000,000	1888
Tuttle's	13¾	96,000,000	977,000,000	1899
Halley's... ...	76	54,500.000	3·251.000,000	1912

We may add the comet known as Biela's, with a period of 6½ years, but which, there is reason to believe, has ceased to exist *as a comet.* (See Art. 297).

289. These are called **short-period comets.** Of the **long-period comets** we may instance the comets of 1858, 1811, and 1844, the times of revolution of which have been estimated at 2,100, 3,000, and 100,000 years respectively.

290. From the table that we have given it will be seen how the distance of these erratic bodies from the Sun varies in different points of the orbit. Thus Encke's comet is ten times nearer the Sun in perihelion than at aphelion. Some comets, whose aphelia lie far beyond the orbit of Neptune, approach so close to the Sun as almost to graze its surface. Sir Isaac Newton estimated that the comet of 1680 approached so near the Sun that its temperature was 2,000 times that of red-hot iron: at the nearest approach it was but one-sixth part of the sun's diameter from the surface. The comets of 1843 and 1882 also approached very close to the Sun, and both were visible in broad daylight.

FIG. 28.—Donati's Comet (general view).

291. We next come to what a comet is like. In Fig. 28 we give a representation of **Donati's comet,** visible in 1858, which will make a general description clear. The brighter part of the comet is called the **head,** or **coma,** and sometimes the head contains a brighter portion still, called the **nucleus.** The **tail** is the dimmer part flowing from the head, and, as observed in different comets, it may be long or short, straight or curved, single, double, or multiple. The comet of 1744 had six tails, that of 1823 two. In some comets the tail is entirely absent. Both head and tail are so transparent that all but the faintest stars are easily seen through them. In 1858 the bright star Arcturus was seen through the tail of Donati's comet at a place where the tail was 90,000 miles in diameter.

292. In olden times, when less was known about comets, they caused great alarm—not merely superstitious terror, which connected their coming with the downfall of a king or the outbreak of a plague, but a real fear that they would dash this little planet to pieces should they come into contact with it. Modern science teaches us that in the great majority of instances the mass of the comet is so small that we need not be alarmed; indeed, there is good reason to believe that on June 30, 1861, we did actually pass through the tail of the glorious comet which then became so suddenly visible to us. There is another fact too which teaches us the same thing. In 1779 a comet approached so close to Jupiter that it may actually have got entangled among the satellites of that planet, but the satellites all the time pursued their courses as if the comet had never existed. This, however, was by no means the case with the comet; it was thrown entirely out of its course, and has changed its orbit from one bringing it back to the Sun every 5½ years to one in which it has never since been visible to terrestrial observers.

293. The number of comets recorded from the earliest times, beginning with the Chinese annals, to our own, is nearly 900, but the number observed at present is much greater than formerly, as many telescopic ones are now recorded, whereas the old chronicles tell us only of those in bygone times which were brilliant enough to attract general attention, and to give rise to the most gloomy forebodings. It is worthy of remark that in the year of the Norman invasion, 1066, a fine comet with three tails appeared, which in the Norman chronicle is given as evidence of William's divine right to invade this country.

It has been estimated that there may be many millions of comets belonging to our system, and perhaps passing between this and other systems. We see but few of them, because those only are visible to us which are well placed for observation when they pass the Earth in their journey to or from perihelion, while there may be thousands which at their nearest approach to the Sun are beyond the orbit of Neptune.

294. We have already stated that these bodies consist of clouds of meteorites. Now, when they are far away from the Sun, the collisions are few, and their light is dim, and we observe them in our telescopes as round misty bodies, moving very slowly, say a few yards in a second, in the depths of space. Gradually, as the comet approaches the Sun, and the collisions increase (for, as we shall see in Chap. IX., the nearer any body, be it planet or comet, gets to the Sun, the faster it travels), the Sun's action begins to be felt, the comet gets hotter and becomes visible to the naked eye. A violent action commences; **jets** of meteoric vapours burst forth from the coma towards the Sun, and are instantly driven back again. The jets rapidly change their position and direction, and a *tail* is formed consisting of the finer particles resulting from collisions, and rendered visible in part by Sunlight, in part by their own incandescence. The tail-forming materials are most likely driven from the Sun by electrical repulsion. The variety in the forms of these appendages is now thought to be caused by differences in chemical constitution. The lightest and smallest particles, because driven away the quickest, produce the straightest tails. The long rigid-looking rays which issued from Donati's comet, were, according to this view, made up of hydrogen particles, while its curved plume was composed of carbon. Other comets have thrown out short strangely-bent tails, possibly due to vapour of iron. These are the three types or classes, into which comets' tails have been divided by Bredichin.

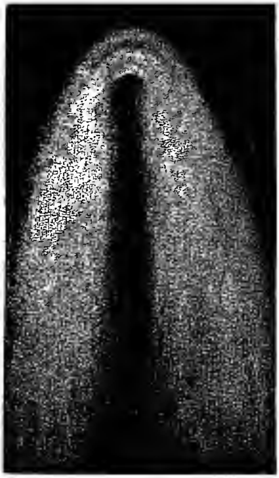


FIG. 29.—Donati's Comet (showing Head and Envelopes).

294a. The tail is always turned away from the Sun, whether the comet be approaching or receding from that body. As the comet still gets nearer the Sun and therefore the Earth, we begin to see in some instances that the *coma* or head contains a kernel or *nucleus*, which is brighter than the *coma* itself, the jets are distinctly visible, and sometimes the coma consists of a series of envelopes. In the beautiful comet of 1858 we saw what this meant: the nucleus was continually throwing off these envelopes or shells which surrounded it like the layers of an onion, and peeled off, and these layers expanded outwards, giving place to others. Seven distinct envelopes were thus seen: as they were driven off, they seemed expelled into the tail. Here we have a reason why the tails of comets should, as a rule, increase so rapidly as they approach the Sun, which gives rise to all this violent action:—the tail of the comet of 1861 was

20,000,000 miles in length, but this length has been exceeded in many cases, notably by the tail of the comet of 1843, which was 112,000,000 long, the diameter of the coma being 112,000 miles, that of the nucleus 400 miles.

We have said *as a rule*, because Halley's comet, as observed by Sir John Herschel, and Encke's comet, furnish us with exceptions. As these comets approached the Sun, both tail and coma decreased, and the whole comet appeared only like a star. Still for all that, in the majority of instances, comets increase in brilliancy, and their tails lengthen as they near the Sun, so much so that in some instances they have been visible in broad daylight. The enormous effect of a near approach to the Sun may be gathered from the fact that the comet of 1680 at its perihelion passage, while it was travelling at the rate of 1,200,000 miles an hour, in two days shot out a tail 20,000,000 leagues long.

295. Since the tail indicates the waste, so to speak, of the head, each return to the Sun must reduce the mass of the comet. A reduction of speed would, moreover, in time be enough to reduce the most refractory comet into a quiet member of the solar family, as the orbit would become less elliptical, or more circular, at each return to perihelion. This effect has, in fact, been observed in some of the short-period comets. Encke's comet, for instance, now performs its revolution round the Sun in three days less than it did eighty years ago. It has been affirmed that this effect is due to the friction offered by an ethereal medium increasing in density towards the Sun—an effect we do not perceive in the case of the planets, their mass being so much larger—as the resistance of the air stops the flight of a feather sooner than it does that of a stone. Sir Isaac Newton has calculated that a cubic inch of air at the Earth's surface—that is, as much as is contained in a good-sized pill-box—if reduced to the density of the air 4,000 miles above the surface, would be sufficient to fill a sphere the circumference of which would

FIG. 30.—Great Comet and Nucleus as observed at Palermo, September 29, 1882.

be as large as the orbit of Neptune. The tail of the largest comet, if it be gas, may therefore weigh but a few ounces or pounds; and the same argument may be applied to the comet itself, if it be not solid. We can understand, then, that with such a small supply there is not much room for waste, and with such a small mass the resistance offered to it may easily become noticeable. The hypothesis of resistance, however, has of late been rendered doubtful by the discovery that its effects are variable.

296. The spectroscopic study of comets proves that their light is partly original, partly that of the Sun reflected. The nucleus is a mass of red or white-hot stones; the coma and tail are largely composed of the glowing vapour of carbon, which is derived from compounds of carbon originally forming part of the stones. Sodium, in addition, blazed up in "Comet Wells" as it drew near the Sun in May and June 1881; and sodium and iron as well as carbon, showed themselves present in the great comet of September 1882.

297. There is an instance on record of a comet dividing itself into two portions, each separate portion afterwards pursuing distinct but similar orbits. This is Biela's comet, mentioned in Art. 288. It was first noticed as double December 29, 1845, and the twin comets returned together to perihelion in 1852, but have never since been seen. Yet they ought to have been easily visible when due back again at the Sun in the end of January 1866, as the practically identical track pursued by both intersects the orbit of the Earth at the place occupied by our planet on the 30th of November. The lost comet was, however, strangely replaced by the two brilliant meteoric showers which broke upon the Earth as it passed the node of the comet's orbit, November 27, 1872, and November 27, 1885. These were products of the disintegration of the vanished comet, and may be regarded as a positive proof of the meteoric constitution of comets.

297a. Biela's is probably not the only comet which has broken up into two or more distinct bodies of the same kind in the course of its travels round the Sun. A "double comet" was observed in Brazil in 1860; and several examples have lately occurred of comets revolving in the same orbit, yet certainly not simply returns of the same body. Thus "Tebbutt's comet," which passed the Sun June 16, 1881, at a distance of 68,000,000 miles, was found to move in the track of a comet observed in 1807, and not again due at perihelion until the year 3346 A.D. The irresistible conclusion is that one original comet split, like Biela's, into two, the fragments following each other along an identical path, while becoming separated (as must inevitably happen) by an ever-growing distance. Even more surprising was the discovery of a similar relation between *three* great comets—those which appeared in 1843, 1880, and 1882. All of them passed so exceedingly near the Sun as almost to graze its surface; and reliable calculations show them to retire to so vast a distance that 700 or 800 years must elapse before they again successively revisit the solar neighbourhood.

LESSON XXIV.—*Luminous Meteors. Shooting Stars. November Showers. Radiant Points.*

298. There are very few nights in the year in which, if we watch for some time, we shall not see one of those appearances which are called, according to their brilliancy, **meteors, bolides,** or **falling** or **shooting stars.** On some nights we may even see a *shower* of falling stars, and the shower in certain years is so dense that in some places the number seen at once equals the apparent number of the fixed stars seen at a glance;* indeed, it has been calculated that the average number of meteors which traverse the atmosphere daily, and which are large enough to be visible to the naked eye on a dark clear night, is no less than

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* Baxendell.

20,000,000; and if we include meteors which would be visible in a telescope, this number will have to be increased to 400,000,000! so that, in the mean, in each volume as large as the Earth, of the space which the Earth traverses in its orbit about the Sun, there are as many as 30,000 small bodies, each body such as would furnish a shooting star, visible under favourable circumstances to the naked eye. If telescopic meteors be counted, this number should be increased at least forty-fold.

299. It is now generally held that these little bodies are not scattered uniformly in the space comprised by the Solar System, but are collected into distinct swarms or groups, which travel as comets travel—indeed, as we have seen, in the closest connexion with comets—in elliptic orbits round the Sun; and that what we call a shower of meteors is due to the Earth breaking through one of these groups. Two of the best defined of them are encountered in August and November in each year. The exquisitely beautiful star-shower which was witnessed during the year 1866 has placed the truth of this explanation beyond all doubt. Let us consider how the appearances observed are connected with the theory, and what the theory actually is in its details.

300. Here again we must fall back upon our imaginary ocean (Art. 105) to represent the plane of the ecliptic. Let us further suppose that the Earth's path is marked out by buoys placed at every degree of longitude, beginning from the place occupied by the Earth at the autumnal equinox, and numbered from right to left from that point. Now if it were possible to buoy space in this way, we should see the November group of meteors rising from the plane at the point occupied by our Earth on Nov. 14th.

301. But why do we not have star-showers every November? Because the principal mass of the meteors occupies only a part of its orbit, the extent of the mass being so far restricted that it requires only two or three years to cross the plane of the ecliptic. To get a star-shower we must not only go through the orbit, but through that exact part of it where the mass is collected. Hence we do not go through the group every year, because the mass of little bodies performs its revolution like a comet, in 33¼ years.

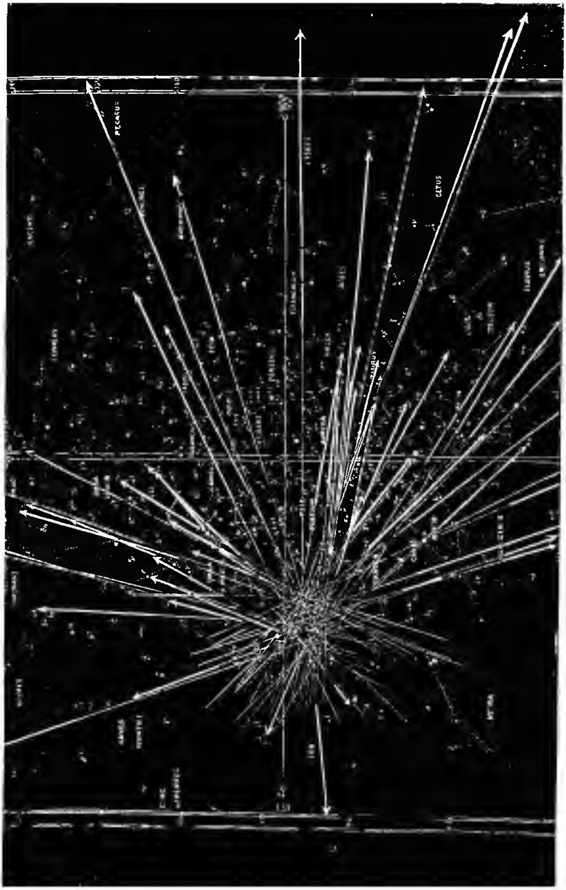
302. Now what will happen when the Earth, sailing along in its path, reaches the node and encounters the mass of meteoric dust, the particles of which travel, as is known (see Art. 308) in the opposite direction to that of the Earth?

303. Let us in imagination connect the Earth and Sun by a straight line: at any moment the direction of the Earth's motion will be very nearly at right angles to that line (or, as it is called, *a tangent to its orbit*): therefore, as longitudes are reckoned, as we have seen, from right to left, the motion will be directed to a point 90° of longitude behind, or to the right of the Sun. The Sun's longitude at noon on the 14th November, 1866, was 232° within a few minutes; 90° from this gives us 142°.

304. Since therefore the meteors, as we meet them in our journey, should seem to come from the point of space towards which the Earth is travelling, and not from any side street as it were, we ought to see them coming from a point situated in longitude 142°, or thereabouts. Now what was actually seen?

305. One of the most salient facts, noticed by those even who did not see the significance of it, was that all the meteors seen in the late display really did seem to come from one part of the sky. In fact, there was a region in which the meteors appeared trainless, and shone out for a moment like so many stars, *because they were directly approaching us.* Near this spot they were so numerous, and all so foreshortened, and for the most part faint, that the sky at times put on almost a phosphorescent appearance. As the eye travelled from this region, the trains became longer, those being longest as a rule which

Plate XI.



Radiant point of the November Meteors.

first made their appearance overhead, or which trended westward. Now, if the paths of all had been projected backwards, they would have all intersected in one region, and that region the one in which the most foreshortened ones were seen. So decidedly did this fact come out, that there were moments in which the meteors belted the sky like the meridians on a terrestrial globe, the pole of the globe being represented by a point in the constellation *Leo*. In fact, they all seemed to *radiate* from that point, and **radiant-point** is precisely the name given to it by astronomers. Now the longitude of this point is 142° or thereabout!

306. The apparent radiation from this point is an effect of perspective, and hence we gather that the paths of the meteors are parallel, or nearly so, and that the meteors themselves are all travelling in straight lines from that point.

307. Here, then, is proof positive enough that the meteoric hail was fairly directed against, and as fairly met by, the Earth. Now here another set of considerations comes in. Suppose, for instance, we were situated in the radiant point, and could see exactly the countries which occupied the hemisphere of our planet facing the meteors, at the moments our planet entered the shower, when it was in its midst, and when it emerged again. In consequence of the Earth's rotation, and as the shower can of course only fall on the hemisphere of the Earth most forward at the time, the places at which the shower is central, rising, and setting, so to speak, will be constantly varying. In fact, each spectator is carried round by the Earth's rotation, and enters about midnight the front hemisphere of the Earth—the one which is exposed to the meteoric hail. We know, therefore, again to take an instance from the last display, that as the shower did not last long into the morning, the time of maximum for the whole Earth was certainly not later than that observed at Greenwich; but we do not know that it was not considerably earlier. Had the actual number of meteors encountered by the Earth remained the same the apparent number would have increased from midnight to 6 A.M.; as at 6 we should have been nearly in the middle of the front side of the Earth on which they would be showering.

308. By careful observations of the radiant-point it has been determined that the orbit of each member of the November star-shower, and therefore of the whole mass, is an ellipse with its perihelion lying on the Earth's orbit, and its aphelion point lying just beyond the orbit of Uranus; that its inclination to the plane of the ecliptic is 17°; and that the direction of the motion of the meteors is retrograde.

309. Up to the present time several hundred such radiant-points, which possibly indicate several hundred other similar groups moving round the Sun in cometary or planetary orbits, have been determined. The meteors of particular showers vary in their distinctive characters, some being larger and brighter than others, some whiter, some more ruddy than others, some swifter, and drawing after them more persistent trains than those of other showers.

LESSON XXV.—*Luminous Meteors* (continued). *Cause of the Phenomena of Meteors. Orbits of Shooting Stars. Detonating Meteors. Meteorites: their Classification. Falls. Chemical and Physical Constitution.*

310. Now let us take the case of a single meteor entering our atmosphere. Why do we get such a brilliant appearance? In the first place, we have the Earth travelling at the rate of 1,000 miles a minute, plunging into a mass of bodies whose velocity is at first equal to its own, and is then increased to 1,200 miles a minute by the Earth's attraction. The particle then enters our atmosphere at the rate of 30 miles a second; its motion is arrested by the friction of that atmosphere, which puts *a break on it*, and as the wheel of a tender gets hot under the same circumstances, and as a cannon-ball gets hot when the target impedes its further flight, so does the meteoric particle get hot. So hot does it get that, at last, as great heat is always accompanied by light, we see it: it becomes vaporized, and leaves a train of luminous vapour behind it.

311. It would seem that all the particles which compose the November shower are small: it has been estimated that some of them weigh but two grains. They begin to burn at a height of 74 miles, and are burnt up and disappear at a height of 54 miles; the average length of their visible paths being 42 miles. It is supposed that the November-shower meteors are composed of more easily destructible or of more inflammable materials than aërolitic bodies.

312. What has been said about the appearance of the November meteors applies to the other star-showers, notably to the August and April ones, the meteors of which also travel round the Sun in cometary orbits. And this brings us to one of the most surprising discoveries of modern times—a discovery for which our consideration of the fate of Biela's comet has in some degree prepared us. It has been ascertained that four well-known comets follow each an identical track with a meteor-stream; and the number of probable or suspected similar coincidences now amounts to 76. The August meteors (called "Perseids" from the situation of their radiant-point in the constellation Perseus) were the first to have a comet—the bright one of 1862—thus associated with them. Temple's comet of 1866, the comet 1861 I., and Biela's were immediately afterwards found to pursue tracks undistinguishable respectively from those belonging to the "Leonids" (November meteors), the "Lyraids" (April meteors), and the "Andromedes"

(Biela meteors). We must therefore come to the conclusion that the meteor-swarms composing comets are nothing more than denser aggregations in streams of meteorites which revolve in orbits round the sun.

313. In the case of the November and August meteors and shooting-stars generally, the mass is so small that it is entirely changed into vapour and disappears without noise. There are other classes of meteoric bodies, however, with much more striking effects. At times meteors of great brilliancy are heard to explode with great noise; these are called **detonating meteors.** On Nov. 15, 1859, a meteor of this class passed over New Jersey; it was visible in the full sunlight, and was followed by a series of terrific explosions, which were compared to the discharge of a thousand cannons.* Other meteors are so large that they reach the Earth before complete vaporization takes place, and we then get what is called a fall of **meteoric irons,** or **meteoric stones,** often accompanied by loud explosions.

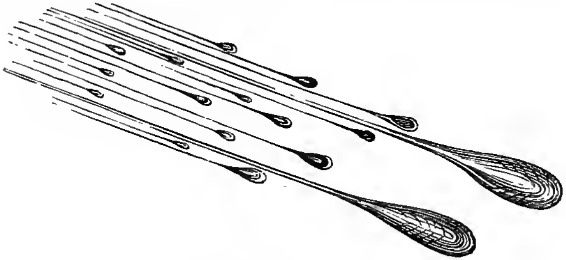


FIG. 31.—Fire-ball, as observed in a telescope.

314. Meteorites is the name given to those masses which, owing to their size, resist the action of the atmosphere, and actually complete their fall to the Earth. They are divided into **aërolites,** or meteoric *stones;*

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* Professor Loomis.

aërosiderites, or meteoric *iron*; and **aërosiderolites**, which includes the intervening varieties.

315. We do not know whether these meteors which occasionally appear, and which are therefore called **sporadic meteors**—a term which includes meteors commonly so called, *bolides*, stonefalls, and ironfalls—belong to groups cometic or otherwise, although, like the falling stars, they affect particular dates; but, as they are independent of geographical position, it has been imagined that there may be some astronomical and perhaps a physical difference between them and the ordinary falling or shooting stars.

316. Among the largest aërolitic falls of modern times we may mention the following. On April 26th, 1803, at 2 P.M. a violent explosion was heard at L'Aigle (in Normandy); and at a distance of eighty miles round, a few minutes before the explosion was heard, a luminous meteor with a very rapid motion appeared in the air. Two thousand stones fell, so hot as to burn the hands when touched, and one person was wounded by a stone upon the arm. The shower extended over an area nine miles long and six miles wide, close to one extremity of which the largest of the stones was found. A similar shower of stones fell at Stannem, between Vienna and Prague, on the 22nd of May, 1812, when 200 stones fell upon an area eight miles long by four miles wide. The largest stones in this case were found, as before, near the northern extremity of the ellipse. A third stonefall occurred at Orgueil, in the south of France, on the evening of the 14th of May, 1864. The area in which the stones were scattered was eighteen miles long by five miles wide, and the luminous effects of their fall were visible from Paris to the Pyrenees. At Knyahinya, in Hungary, on the 9th of June, 1866, a luminous meteor was seen, and an aërolite weighing six hundredweight, and nearly one thousand lesser stones, fell on an area measuring ten miles in length by four miles wide. The large mass was found, as in the other cases, at one extremity of the oval area; the fall was followed by a loud explosion, and a smoky streak was visible in the sky for nearly half an hour.*

317. A chemical examination of these fragments (a magnificent collection of which is to be seen in the British Museum) shows that, although in their composition they are unlike any other natural product, their elements are all known to us, and that they are all built up of the same materials, although in each variety some particular element may predominate. In the main, they are composed of metallic iron and various compounds of silica, the iron forming as much as 95 per cent. in some cases, and only 1 per cent. in others; hence the three classifications referred to in Art. 314. The iron is always associated with a certain quantity of nickel, and sometimes with manganese cobalt, copper, tin, and chromium. Among the silicates may be mentioned olivine, a mineral found abundantly in volcanic rocks, and augite.

318. Besides these substances, a compound of iron, phosphorus, and nickel, called schreibersite, is generally found: this compound is unknown in terrestrial chemistry. Carbon has also been detected.

319. The substances found in meteorites up to the present time are as follows :—

Aërosiderites.—Nickel-iron, copper, manganese. Troilite = Ferrous sulphide. Graphite. Schreibersite = iron and nickel phosphide. Daubréeite = iron and chromium sulphide.

Aërosiderolites. — (**a**) Non-carbonaceous ... Olivine = silicate of magnesium and iron. Enstatite = Silicate of magnesium. Nickel-iron, manganese. Troilite. Chromite = iron and chromium oxides. Augite = silicate of

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* Professor Herschel.

calcium, magnesium, iron and manganese. Silicate of calcium, sodium, and aluminium.

(β) Carbonaceous ... Carbon in combination with hydrogen and oxygen. Sulphates of magnesium, calcium, sodium and potassium.

Gases, too, especially hydrogen and carbonic-oxide, are usually occluded in these bodies, and escape from them on the application of heat.

The first substances volatilised out of the meteorites constituting celestial bodies (See Art. 65) by the heat due to collisions, are magnesium, manganese, iron and sodium, that is, the constituents which are volatilised at the lowest temperatures.

320. Thinking that, unlike terrestrial rocks, meteorites are probably portions of cosmical matter which has not been acted on by water or volcanic heat, Mr. Sorby was led to study their microscopical structure. He has thus been able to ascertain that the material was at one time certainly in a state of fusion; and that the most remote condition of which we have positive evidence was that of small, detached, melted globules, the formation of which cannot be explained in a satisfactory manner, except by supposing that their constituents were originally in the state of vapour, as they now exist in the atmosphere of the Sun; and, on the temperature becoming lower, condensed into these "ultimate cosmical particles." These afterwards collected together into larger masses, which have been variously changed by subsequent metamorphic action, and broken up by repeated mutual impact, and often again collected together and solidified. The meteoric irons are probably those portions of the metallic constituents which were separated from the rest by fusion when the metamorphism was carried to that extreme point.

CHAPTER IV.

APPARENT MOVEMENTS OF THE HEAVENLY BODIES.

LESSON XXVI.—*The Earth a moving Observatory. The Celestial Sphere. Effects of the Earth's Rotation upon the apparent Movements of the Stars. Definitions.*

321. In the previous chapters we have studied in turn the whole universe, of which we form a part; the nebulæ and stars of which it is composed; the nearest star to us —the Sun; and lastly, the system of bodies which centre in this star, our own Earth being among them.

We should be now, therefore, in a position to see exactly what "the Earth's place in Nature"—what its relative importance—really is. We find it, in fact, to be a small planet travelling round a small star, and that the whole solar system is but a mere speck in the universe—an atom of sand on the shore, a drop in the infinite ocean of space.

322. But, however small or unimportant the Earth may be compared to the universe generally, or even to the Sun, it is all in all to us inhabitants of it, and especially so from an astronomical point of view; for although in what has been gone through before, we have in imagination looked at the various celestial bodies from all points of view, our bodily eyes are chained to the Earth—the Earth is, in fact, our Observatory, the very centre of the *visible* creation; and this is why, until men knew better, it was thought to be the very centre of the *actual* one.

323. More than this, the Earth is not a fixed observatory; it is a moveable one, and, as we know, has a double movement, turning round its own axis while it travels round the Sun. Hence, although the stars and the Sun are at rest, they appear to us, as every child knows, to have a rapid movement, and rise and set every twenty-four hours. Although the planets go round the Sun, their circular movements are not visible to us as such, for our own annual movement is mixed up with them.

Having described the heavens then as they *are*, we must describe them as they *seem*. The **real movements** must now give way to the **apparent ones**; we must, in short, take the motion of our observatory, the Earth, into account.

324. To make this matter quite clear, before we proceed, let the Earth be supposed to be at rest: neither turning round on its own axis, nor travelling round the Sun. What would happen is clearly this—that the side of it turned towards the Sun would have a perpetual day, the other side of it perpetual night. On one side the Sun would appear at rest—there would be no rising and setting; on the other side the stars would be seen at rest in the same manner: the whole heavens would be, as it were, dead.

325. Again, let us suppose the Earth to go round the Sun as the Moon goes round the Earth, turning once on its axis each revolution, which would result in the same side of the Earth always being turned towards the Sun. The inhabitants of the lit-up hemisphere would, as before, see the Sun motionless in the heavens; but in this case, those on the other side, although they would never see the Sun, would still see the stars rise and set once a year.

These examples should give you an idea of the way in which the various apparent movements of the heavenly bodies are moulded by the Earth's real movements, and we shall find that the former are mainly of two kinds—**daily apparent movements** and **yearly apparent movements,** which are due, the first to the Earth's daily rotation, or turning on its axis, and the second to the Earth's yearly revolution or journey round the Sun. In each case the apparent movement is, as it were, a reflection of the real one, and in the opposite direction to the real one ; exactly what we observe when we travel smoothly in a train or balloon. When we travel in an express train, the objects appear to fly past us in the opposite direction to that in which we are going ; and in a balloon, in which not the least sensation of motion is felt, to the occupant of the car it is always the Earth which appears to fall down from it, and rush up to meet it, while the balloon itself rises or descends.

326. We will first study the **effects of the Earth's rotation on the apparent movements of the stars.** The daily motion of the Earth is very different in different parts—at the equator and at a pole, for instance. An observer at a pole is simply turned round without changing his place, while one at the equator is swung round a distance of 24,000 miles every day. We ought, therefore, to expect to see corresponding differences in the apparent motions of the heavens, if they are really due to the actual motions of our planet. Now this is exactly what is observed, not only is the apparent motion of the heavens from east to west—the real motion of the Earth being from west to east—but those parts of the heavens which are over the poles appear at rest, while those over the equator appear in most rapid motion. In short, the apparent motion of the **celestial sphere**—the name given to the apparent vault of the sky—to which the stars appear to be fixed, and to which, in fact, their positions are always referred, is exactly similar to the real motion of the terrestrial one, our Earth ; but, as we said before, in an opposite direction.

327. Before we proceed further, however, we must say something more about this celestial sphere, and explain the terms employed to point out the different parts of it.

328. In the first place, as the stars are so far off, we may imagine the centre of the sphere to lie either at the centre of the Earth or in our eye, and we may imagine it as large or as small as we please. The points where the terrestrial poles would pierce this sphere, if they were long enough, we shall call the **celestial poles**; the great circle lying in the same plane as the terrestrial equator we shall call the **celestial equator,** or **equinoctial**; the point overhead the **zenith**; the point beneath our feet the **nadir.**

Now, as the whole Earth is belted by *parallels of latitude* and *meridians of longitude*, so are the heavens belted to the astronomer with *parallels of declination* and *meridians of right ascension.* If we suppose the plane in which our equator lies extended to the stars, it will pass through all the points which have no declination (0°). Above and below we have north and south declination, as we have north and south latitude, till we reach the pole of the equator (90°). As we start from the *meridian of Greenwich* in the measure of *longitude*, so do we start from a certain point in the celestial equator occupied by the Sun at the vernal equinox, called the *first point of Aries*, in the measure of *right ascension.* As we say such a place is so many degrees east of Greenwich, so we say such a star is so many hours, minutes, or seconds east of the first point of Aries.

329. In short, as we define the position of a place on the Earth by saying that its latitude and longitude (in degrees) are so-and-so, so do we define the position of a heavenly body by saying that, referred to the celestial sphere, its declination (in degrees) and right ascension (in time reckoned from Aries) are so-and-so.

Sometimes the distance from the north celestial pole is given instead of that from the celestial equator. This is called **north-polar distance.**

These terms apply to the celestial sphere generally. When we consider that portion of it visible in any one place, or the **sphere of observation,** there are other terms employed, which we will state in continuation. In any place the visible portion of the celestial sphere seems to rest either on the Earth or sea. The line where the heavens and Earth seem to meet is called the **visible horizon**; the plane of the visible horizon meets the Earth at the spectator. The **rational,** or **true horizon,** is a great circle of the heavens, the plane of which is parallel to the former plane, but which, instead of passing through the spectator, passes through the centre of the Earth. A **vertical line** is a line passing from the zenith to the nadir, and therefore through the spectator; and therefore, again, it is at right angles to the planes of the horizon, or upright with respect to them. If it is desired to point out the position of a heavenly body not on the celestial sphere generally, but on that portion of it visible on the horizon of a place at a given moment of time, this is done by determining either its **altitude** or its **zenith distance,** and its **azimuth** (instead of its declination and right ascension).

Altitude is the angular height above the horizon.

Zenith-distance is the angular distance from the zenith.

Azimuth is the angular distance between two planes, one of which passes through the north or south point (according to the hemisphere in which the observation is made), and the other through the object, both passing through the zenith.

The **celestial meridian** of any place is the great circle on the sphere corresponding to the terrestrial meridian of that place, cutting therefore the north and south points.

The **prime vertical** is another great circle passing through the east and west points and the zenith.

LESSON XXVII.—*Apparent Motions of the Heavens, as seen from different parts of the Earth. Parallel, Right, and Oblique Spheres. Circumpolar Stars. Equatorial Stars, and Stars invisible in the Latitude of London. Use of the Globes.*

330. We are now in a position to proceed with our inquiry into the apparent movement of the celestial sphere. In what follows we shall continue to talk of the Sun or a star rising or setting, although the reader now understands that it is, in fact, the plane of the observer's horizon which changes its direction with regard to the heavenly body, in consequence of its being carried round by the Earth's motion. When stars are so situated that they are just visible at any point along the horizon to the east they are said to rise; when the rotation of the Earth has brought the plane of the horizon under the meridian or line which passes through a star and the N. and S. points it is said to culminate or pass the meridian, or transit; and when the plane of the horizon is carried to the nadir of the point it occupied when it rose to the star, the stars then occupy positions along the opposite—that is, the western horizon, and they are said to set.

331. Let Fig. 32 represent our imaginary celestial sphere, and N. an observer at the north pole of the Earth. To him the north pole of the heavens and the zenith coincide, and his true horizon is the celestial equator. Above his head is the pivot on which the heavens appear to revolve, as underneath his feet is the pivot on which the Earth actually revolves; and round this point the stars appear to move in circles, the circles getting larger and larger as the horizon is approached. The stars never rise or set, but always keep the same distance from the horizon. The observer is merely carried round by the

Earth's rotation, and the stars seem carried round in the opposite direction.

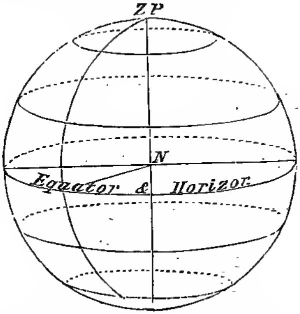

FIG. 32.—The Celestial Sphere, as viewed from the Poles. A parallel sphere.

332. We will now change our position. In Fig. 33 the celestial sphere is again represented, but this time we

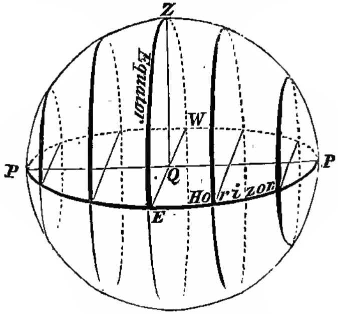

FIG. 33.—The Celestial Sphere, as viewed from the Equator. A right sphere.

suppose an observer, Q, at its centre, to be on the Earth's equator. In this position we find the celestial equator in the zenith, and the celestial poles *PP* on the true horizon, and the stars, instead of revolving round a fixed point overhead, and never rising or setting, rise and set every twelve hours, travelling straight up and down along circles which get smaller and smaller as we leave the zenith and approach the poles. The spectator is carried up and down by the Earth's rotation, and the stars appear to be so carried. Yet another figure, to show what happens half-way between the poles and the equator. At *O*, in Fig. 34, we imagine an observer to be placed on our Earth, in lat. 45° (that is, half-way between the equator in lat. 0°, and the north pole in lat. 90°). Here the north celestial pole will be half-way between the zenith and the horizon (see Figs. 32 and 33); and close to the pole he will see the stars describing circles, inclined,

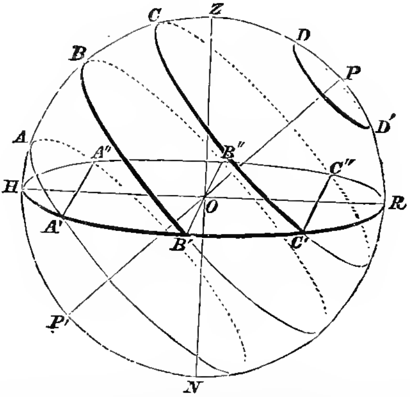

FIG. 34.—The Celestial Sphere, viewed from a middle latitude. An Oblique sphere. In this woodcut *DD'* shows the apparent path of a circumpolar star; *BB'B''* the path and rising and setting points of an equatorial star; *CC'C''* and *AA'A''* those of stars of mid-declination, one north and the other south.

however, and not retaining the same distance from the horizon. As the eye leaves the pole, the stars rise and set obliquely, describe larger circles, gradually dipping more and more under the horizon, until, when the celestial equator, $B B' B''$, is reached, half their journey is performed below it. Still going south, we find the stars rising less and less above the horizon, until, as there were northern stars that never dip below the horizon, so there are southern stars which never appear above it.

333. In lat. 45° south, the southern celestial pole would in like manner be visible; the stars we never see in the northern hemisphere never set; the stars which never set with us, never rise there; the stars which rise and set with us set and rise with them.

334. Now it is evident that if we divide the celestial sphere into two hemispheres, northern and southern, an observer at the north pole sees the northern stars only; one at the south pole the southern stars only; while one at the equator sees both north and south stars. An observer in a middle north latitude sees all the northern stars and some of the southern ones; and another in a middle southern latitude sees all the southern stars and some of the northern ones.

335. Hence, in middle latitudes, and therefore in England, we may divide the stars into three classes:—

I. Those northern stars which never set (northern circumpolar stars).
II. Those southern stars which never rise (southern circumpolar stars).
III. Those stars which both rise and set.

336. It is easily gathered from Figs. 32—34 that the height of the celestial pole above the horizon at any place is equal to the latitude of that place; for at the equator, in lat. 0°, the pole was on the horizon, and consequently its altitude was nothing; at the pole in lat. 90° it was in the zenith and its altitude was consequently 90°; while in lat. 45° its altitude was 45°. In London, therefore, in lat. 51½°, its altitude will be 51½°, and hence stars of less than that distance from the pole will always be visible, as they will be above the horizon when passing below the pole. All the stars, therefore, within 51° of the north pole will form Class I.; all those within 51° of the south pole Class II.; and the remainder—that is, all stars from lat. 39° N (90°—51°=39°) to 39° S.—will form Class III.

337. In these and similar inquiries the use of the terrestrial and celestial globes is of great importance in clearing our ideas.

To use either properly we must begin by making each a counterpart of what is represented—that is, the north pole must be north, the south pole south, and moreover the axis of either globe must be made parallel with the Earth's axis.

338. This is accomplished generally by the use of a **compass**, the indication of that instrument being corrected by its known variation. This variation at present is about 18° to the west of the true north; therefore the true north lies 18° to the east of magnetic north, and the **brazen meridian** of the globe must be placed accordingly. Secondly, the **wooden horizon** of the globe must be level; it will then represent the horizon of the place.

339. This done, the pole—the north pole in our case—must be elevated to correspond with the latitude of the place where the globe is used. At the poles this would be 90°, at the equator 0°, and at London 51½°.

340. If we then turn the terrestrial globe from west to east, we shall exactly represent the lie, and the direction of motion of the Earth. If we then turn the celestial globe from east to west, we shall exactly represent the apparent motions of the heavens to a spectator on the Earth supposed to occupy the centre of the globe, as in Figs. 32-34. The wooden horizon will represent the true horizon; and why some stars never set and others never rise in these latitudes, will at once be apparent.

341. At the present time the northern celestial pole lies in **Ursa Minor**, and a star in that constellation very nearly marks the position of the pole, and is therefore called **polaris**, or the **pole-star**. We shall see further on (Lesson XLIII.), that the direction in which the Earth's axis points is not always the same, although it varies so slowly

FIG. 35.—Southern Circumpolar Constellations. (These constellations are invisible in high and middle north latitudes, and therefore in Europe.)

that a few years do not make much difference. As a consequence, the position of the celestial pole, which is defined by the Earth's axis prolonged in imagination to the stars,

FIG. 36.—The Northern Circumpolar Constellations.

varies also. One of the most striking circumpolar constellations is **Ursa Major** (the Great Bear), the **Plough,** or **Charles' Wain,** as it is otherwise called. Two stars in this are called the **pointers,** as they point to the pole-star, and enable us at all times to find it easily.

The other more important circumpolar constellations are Cassiopeia, Cepheus, Cygnus, Draco, Auriga (the brightest star of which, Capella, is very near the horizon when below the pole), and Perseus. The principal southern circumpolar constellations which never rise in this country, are Crux, Centaurus, Argo, Ara, Lepus, Eridanus, and Dorado. Nearly all the other constellations mentioned in Arts. 37–39 belong to Class III.

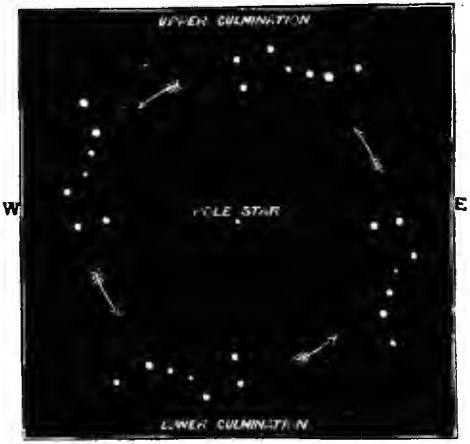

FIG. 37.—The Constellation of the Great Bear, in four different positions, after intervals of 6 hours, showing the effect of the apparent revolution of the celestial sphere upon circumpolar stars.

342. If, then, we would watch the heavens on a clear night from hour to hour, to get an idea of these apparent motions, we may best accomplish this either by looking eastward to see the stars rise, westward to see them set, or northward to the pole to watch the circular movement round that point. If, for instance, we observe the Great Bear, we shall see it in six hours advance from one of its positions shown in the accompanying figure, to the next.

343. As the Earth's rotation is accomplished in 23h. 54m. 56s., it follows that the apparent movement of the celestial sphere is completed in that time; and were there no clouds, and no Sun to put the stars out in the day-time—eclipsing them by his superior brightness—we should see the grand procession of distant worlds ever defiling before us, and commencing afresh after that period of time.

This leads us to the effect of the Earth's yearly journey round the Sun upon the apparent movement of the stars.

LESSON XXVIII.—*Position of the Stars seen at Midnight. Depends upon the two Motions of the Earth. How to tell the Stars. Celestial Globe. Star-maps. The Equatorial Constellations. Method of Alignments.*

344. We see stars only at night, because in the day-time the Sun puts them out; consequently the stars we see on any night are the stars which occupy that half of the celestial sphere opposite to the point in it occupied at that time by the Sun. We have due south, at midnight, the very stars which occupy the celestial meridian 180° from the Sun's place, as the Sun, if it were not below the horizon in England, would be seen due north.

345. Now as we go round the Sun, we are at different times on different sides, so to speak, of the Sun; and if we could see the stars beyond him, we should see them change; but what we cannot do at mid-day, in consequence of the Sun's brightness, we can easily do at midnight; for if the stars behind the Sun change, the stars exactly opposite to his apparent place will change too, and these we can see in the south at midnight.

346. It is clear, in fact, that in one complete revolution of the Earth round the Sun every portion of the visible celestial sphere will in turn be exposed to view in the south at midnight; and as the revolution is completed in 365 days, and there are 360° in a great circle of the sphere, we may say broadly that the portion of the heavens visible in the south at midnight advances 1° from night to night, which 1° is passed over in 4 minutes, as the whole 360° are passed over in nearly 24 hours.

347. This advance is a consequence of the difference between the lengths of the day as measured by the fixed stars and by the moving Sun, as we shall explain presently. We may here say, that as the solar day is longer than the sidereal one, the stars by which the latter is measured gain upon the solar day at the rate we have seen; so that, as seen at the same hour on successive nights, the whole celestial vault advances to the westward, the change due to one month's apparent yearly motion being equal to that brought about in two hours by the apparent daily motion.

348. Hence the stars south at midnight (or opposite the Sun's place) on any night, were south at 2 A.M. a month previously, and so on; and will be south a month hence at 10 o'clock P.M., and so on.

349. The best way to obtain a knowledge of the various constellations and stars is to employ a celestial globe. We first, as seen in Arts. 337–9, place its brass meridian in the plane of the meridian of the place in which the globe is used, and make the axis of the globe parallel to the axis of the Earth, and therefore of the heavens, by elevating the north pole (in our case) until its height above the wooden horizon is equal to the latitude of the place. We next bring under the brazen meridian the actual place in the heavens occupied by the Sun at the time: this place is given for every day in the almanacs.

We thus represent exactly the position of the heavens at mid-day, by bringing the Sun's place to the brazen meridian, and the index is then set at 12. The reason for this is obvious ; it is always 12, or noon, at a place when the Sun is in the meridian of that place. We then, if the time at the place is after noon, move the globe on till the index and the time correspond ; if the time is before noon, we move the globe back—that is, from west to east, till the index and time correspond in like manner.

350. When the globe has been *rectified*, as it is called, in this manner, we have the constellations which are rising on the eastern horizon, just appearing above the eastern part of the wooden horizon. Those setting are similarly near the western part of the wooden horizon. The constellations in the zenith at the time will occupy the highest part of the globe, while the constellations actually on the meridian will be underneath the brazen meridian of the globe.

351. Further, it is easy at once to see at what time any stars will rise, culminate, or set, when the globe is rectified in this manner. All that is necessary is, as before, to bring the Sun's place, given in the almanac, to the meridian, and set the index to XII. To find the time at which any star rises, we bring it to the eastern edge of the wooden horizon, and note the time, which is the time of rising. To find the time at which any star sets, we bring it similarly to the western edge of the wooden horizon and note the time, which is the time of setting. To find the time at which any star culminates, or passes the meridian, we bring the star under the brass meridian and note the time, which is the time of meridian passage.

352. In the absence of the celestial globe, some such table as the following is necessary, in which are given the positions occupied by the constellations at stated hours during each month in the year. When the positions of the constellations are thus known, some star-maps (the small ones published by the Society for Promoting Useful

Knowledge are amply sufficient) should be referred to, in which various bright stars which go to form each constellation should be well studied; the constellation should then be looked for in the position indicated by the table, in the sky itself. When any constellation is thus recognised, the star-map should again be studied, in order that the stars in its vicinity may next be traced.

CONSTELLATIONS VISIBLE IN THE LATITUDE OF LONDON THROUGHOUT THE YEAR.

[Proctor's "Constellation Seasons" may be consulted with advantage. The constellations as given here have been taken from the maps in that work instead of from a celestial globe.]

JAN. 20, 10 P.M. (Feb. 19, 8 P.M.; Dec. 21, midnight).
N—S. Draco, *polaris*, *Auriga, Orion, Canis Major.
E—W. Leo, Lynx, * Perseus, Pisces.
NE—SW. Boötes, Ursa Major, * Taurus, Eridanus.
SE—NW. Hydra, Gemini, * Cassiopeia, Cygnus.

FEB. 19, 10 P.M. (March 21, 8 P.M.; Jan. 20, midnight).
N—S. Cygnus, Draco, *polaris*, *Lynx, Gemini, Canis Minor.
E—W. Virgo, Coma Berenices, Ursa Major, * Auriga, Argo, Taurus, Aries.
NE—SW. Corona Borealis, Ursa Major, * Orion, Eridanus.
SE—NW. Leo, * Cassiopeia, Andromeda.

MARCH 21, 10 P.M. (April 20, 8 P.M.; Feb. 19, midnight).
N—S. Cepheus, *polaris*, *Ursa Major, Leo Minor, Leo, Hydra.
E—W. Serpens, Boötes, * Taurus.
NE—SW. Hercules, Draco, * Cancer, Canis Minor, Canis Major.
SE—NW. Virgo, Leo, * Camelopardalis, Perseus.

* The asterisk placed in the line denotes that the zenith separates the two constellations between which the asterisk is placed. When the asterisk is prefixed to any constellation, the constellation itself occupies the zenith.

APRIL 20, 10 P.M. (May 21, 8 P.M ; March 21, midnight).

N—S. Cassiopeia, Cepheus, *polaris*, *Ursa Major, Coma Berenices, Virgo, Corvus.
E—W. Cphiuchus, Hercules, Corona Borealis, Boötes, * Gemini.
NE—SW. Cygnus, Draco, * Leo, α *Hydræ.*
SE—NW. Libra, Boötes, * Auriga, Perseus.

MAY 21, 10 P.M. (June 21, 8 P.M. ; April 20, midnight).

N—S. Cassiopeia, *polaris*, *η *Ursæ Majoris*, *Arcturus* (in Boötes).
E—W. Aquila, Lyra, Hercules, * Ursa Major, Leo Minor, Cancer.
NE—SW. Cygnus, Draco, * Canes Venatici, Coma Berenices, β *Leonis.*
SE—NW. Ophiuchus, Serpens, Boötes, * Ursa Major, Lynx, Auriga.

JUNE 21, 10 P.M. (July 22, 8 P M. ; May 21, midnight).

N—S. Perseus, Camelopardalis, *polaris*, * Draco, Hercules, Corona Borealis, Serpens, Scorpio.
E—W. ε *Pegasi*, Cygnus, Lyra, * η *Ursæ Majoris*, Canes Venatici, Leo.
NE—SW. α *Andromedæ*, Cepheus, * Boötes, Virgo.
SE—NW. Sagittarius, Aquila, Hercules, * Ursa Major, Gemini.

JULY 22, 10 P.M (Aug. 23, 8 P M. ; June 21, midnight).

N—S. Auriga, Camelopardalis, *polaris*, * Draco, Hercules, Sagittarius.
E—W. Pegasus, Cygnus, * Boötes, Virgo.
NE—SW. Andromeda, Cassiopeia, Cepheus, * Hercules, Serpens, Libra.
SE—NW. Capricornus, Aquila, Lyra, * Ursa Major, Leo Minor.

Aug. 23, 10 p.m. (Sept. 23, 8 p.m.; July 22, midnight).

N—S. Lynx, *polaris*, Draco, * Cygnus, Vulpecula, Aquila, Capricornus.

E—W. Pisces, α *Andromedæ*, * Draco, Hercules, Corona Borealis, Boötes.

NE—SW. Perseus, Cassiopeia, Cepheus, * Lyra, Ophiuchus.

SE—NW. Aquarius, Pegasus, * Draco, Ursa Major.

Sept. 23, 10 p.m. (Oct. 23, 8 p.m.; Aug. 23, midnight).

N—S. Ursa Major, *polaris*, * Lacerta, Pegasus, Aquarius, Piscis Australis.

E—W. Aries, Andromeda, * Cygnus, Lyra, Hercules.

NE—SW. Auriga, Cassiopeia, * Cygnus, Aquila.

SE—NW. Cetus, Pisces, α *Andromedæ*, * Draco, Boötes.

Oct. 23, 10 p.m. (Nov. 22, 8 p.m.; Sept. 23, midnight).

N—S. Ursa Major, *polaris*, * Cassiopeia, Andromeda, γ *Pegasi*, Pisces, Cetus.

E—W. Orion, Taurus, Perseus, * Cygnus, Aquila.

NE—SW. Lynx, Camelopardalis, * Pegasus, Capricornus.

SE—NW. Eridanus, Cetus, Aries, Andromeda, * Cepheus, β *Draconis*, Hercules.

Nov. 22, 10 p.m. (Dec. 21, 8 p.m.; Oct. 23, midnight).

N—S. η *Ursæ Majoris*, Draco, *polaris*, * Perseus, Triangula, Aries, Cetus.

E—W. Canis Minor, Gemini, Auriga, * Lacerta, Delphinus, Aquila.

NE—SW. Leo Minor, Camelopardalis, * Andromeda, β *Pegasi*, Aquarius.

SE—NW. Lepus, Orion, Taurus, * Cassiopeia, Cepheus, Lyra.

DEC. 21, 10 P.M. (Jan. 20, 8 P.M.; Nov. 22, midnight).

N—S. Hercules, Draco, *polaris*, *Perseus, Taurus, Eridanus.

FIG. 38.—Equatorial Constellations, visible in the south on Jan. 20, at 10 P.M.

E—W. Leo, Gemini. Auriga, *Andromeda, Pegasus.

NE—SW. Ursa Major, *Aries, Cetus.

SE—NW. Canis Major, Orion, Taurus, *Cassiopeia, Cepheus, Cygnus.

353. In Fig. 36 some of the circumpolar constellations have already been represented. In Fig. 38 are given

FIG. 39.—Equatorial Constellations, visible in the south on May 21, at 10 P.M.

some of the constellations in the equatorial zone visible on Jan. 20th to the south.

The central constellation is Orion, one of the most marked in the heavens; when all the bright stars in this asterism are known, many of the surrounding ones may easily be found, by means of alignments. For instance,

FIG. 40.—Equatorial Constellations, visible in the south near the zenith, Oct. 23, at 10 P.M.

the line formed by the three stars in the belt, if produced eastward, will pass near Sirius, the brightest star in the heavens.

354. Fig. 39 represents in like manner the appearance of the heavens a little south of the zenith in May: the bright star Arcturus (*a* Boötis) being then nearly on the meridian. The constellation Hercules is easily recognised by means of the trapezium formed by four of its stars.

355. In Fig. 40 the square of Pegasus is a very marked object, and this once recognised in the sky, may, by means of star-maps, be made the start-point of many new alignments.

356. The first magnitude stars should be first known; then the second; and so on till the positions of all the brighter ones in the different constellations are impressed upon the memory—no difficult task after a little practice, and comparison of the sky itself with good small maps.

LESSON XXIX.—*Apparent Motion of the Sun. Difference in Length between the Sidereal and Solar Day. Celestial Latitude and Longitude. The Signs of the Zodiac. Sun's apparent Path. How the Times of Sunrise and Sunset, and the Length of the Day and Night, may be determined by means of the Celestial Globe.*

357. The effect of the Earth's daily movement upon the Sun is precisely similar to its effect upon the stars; that is, the Sun appears to rise and set every day; but in consequence of the Earth's yearly motion round it, it appears to revolve round the Earth more slowly than the stars; and it is to this that we owe the difference between star-time and sun-time, or, in other words, between the lengths of the sidereal and solar days.

358. How this difference arises is shown in Fig. 41, in which are seen the Sun, and the Earth in two positions in its orbit, separated by the time of a complete rotation. In the first position of the Earth are shown one observer, *a*, with the Sun on his meridian, and another, *b*, with a star on his: the two observers being exactly on opposite sides of the Earth, and in a line drawn through the centres of the Earth and Sun. In the second position, when the same star comes to *b*'s meridian, *a* sees the Sun still to the east of his, and he must be carried by the Earth's rotation to *c* before the Sun occupies the same apparent position in the heavens it formerly did—that is, before the Sun is again in his meridian. The solar day, therefore, will be longer than the sidereal one by the time it takes *a* to travel this distance.

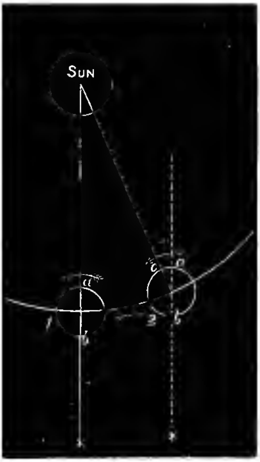

FIG. 41.—Diagram showing how the difference between the lengths of the Sidereal and Mean day arises.

Of course, were the Earth at rest, this difference could not have arisen, and the solar day is a result of the Earth's motion in its orbit, combined with its rotation.

359. Moreover, the Earth's motion in its orbit is not uniform, as we shall see subsequently; and, as a consequence, the apparent motion of the Sun is not uniform, and solar days are not of the same length; for it is evident that if the Earth sometimes travels faster, and therefore further, in the interval of one rotation than it does at others, the observer *a* has further to travel before he gets to *c*; and as the Earth's rotative movement is uniform, he requires more time. In a subsequent chapter it will be shown how this irregularity in the apparent motion of the Sun is obviated.

360. The apparent yearly motion of the Sun is so important that astronomers map out the celestial sphere by a second method, in order to indicate his motion more easily; for as the plane of the celestial equator, like the plane of the terrestrial equator, does not coincide with the plane of the ecliptic, the Sun's distance from the celestial equator varies every minute. To get over this difficulty, they make of the plane of the ecliptic a sort of second celestial equator. They apply the term **celestial latitude** to angular distances from it to the **poles of the heavens,** which are 90° from it north and south. They apply the term **celestial longitude** to the angular distance—reckoned on the plane of the ecliptic—from the position occupied by the Sun at the vernal equinox, reckoning from left to right up to 360°. This latitude and longitude may be either **heliocentric** or **geocentric**—that is, reckoned from the centre either of the Sun or Earth respectively.

361. The celestial equator in this second arrangement is represented by a circle called the **zodiac,** which is not only divided, like all other circles, into degrees, &c., but into signs of 30° each. These, with their symbols, are as follow:—

Spring Signs.	Summer Signs.	Autumn Signs.	Winter Signs.
♈ Aries.	♋ Cancer.	♎ Libra.	♑ Capricorn.
♉ Taurus.	♌ Leo.	♍ Scorpio.	♒ Aquarius.
♊ Gemini.	♏ Virgo.	♐ Sagittarius.	♓ Pisces.

At the time these signs were adopted the Sun entered the constellation Aries at the vernal equinox, and occupied in succession the constellations bearing the same names; but at present, owing to the **precession of the equinoxes,** which we shall explain subsequently, the signs no longer correspond with the constellations, which must therefore not be confounded with them.

362. Now it follows, that, as these two methods of dividing the celestial sphere, and of referring the places of the heavenly bodies to it, are built, as it were, one on the plane of the terrestrial equator, and the other on the plane of the ecliptic, (1) the angle formed by the celestial equator with the plane of the ecliptic is the same as that formed by the terrestrial one,—that is, 23½° nearly: and (2) the poles of the heavens are each the same distance, —that is, 23½° from the celestial poles.

Moreover, if we regard the centre of the celestial sphere as lying at the centre of the Earth, it is clear that the two planes will intersect each other at that point, and that half of the ecliptic will be north of the celestial equator and half below it; and there will be two points opposite to each other at which the ecliptic will cross the celestial equator.

363. Now as the Sun keeps to the ecliptic, it follows that at different parts of its path it will cross the celestial equator, be north of it, cross it again, and be south of it, and so on again; in other words, its latitude remaining the same, its declination or distance from the celestial equator will change.

364. Hence it is, that although the Sun rises and sets every day, its daily path is sometimes high, sometimes low. At the vernal equinox,—that is, when it occupies one of the points in which the zodiac cuts the equator,—it rises due east, and sets due west, like an equatorial star; then gradually increasing its north declination, its daily path approaches the zenith, and its rising and setting points advance northwards, until it occupies the part of the zodiac at which the planes of the ecliptic and equator are most widely separated. Here it appears to stand still; we have the summer solstice (*sol*, the sun, and *stare*, to stand), and its daily path is similar to that of a star of 23½° north declination. It then descends again through the autumnal equinox to the winter solstice, when its apparent path is similar to that of a star of 23½° south declination, and its rising and setting points are low down southward.

365. The use of the celestial globe is very important in rendering easily understood many points connected with the Sun's apparent motion. Having rectified the globe, as directed in Arts. 337-9 and 349, the top of the globe will represent the zenith of London, a miniature terrestrial globe, with its axis parallel to the celestial one, being supposed to occupy the centre of the latter. By bringing different parts of the ecliptic to the brass meridian the varying meridian height of the Sun, on which the seasons depend (Lesson XIII.), is at once shown.

366. In addition to this, if we find from the almanac the position of the true Sun in the ecliptic on any day, and bring it to the brass meridian, the globe represents the positions of the Sun and stars at noonday; we may, however, neglect the stars. The index-hand is, therefore, set to 12. If the globe be perfectly rectified, and we turn it westward till the Sun's place is close to the wooden horizon, the globe then represents sunset, and the index will indicate the time of sunset. If, on the other hand, we turn the Sun's place eastward from the brass meridian till it is close to the eastern edge of the wooden horizon, the globe represents in this case sunrise, and the index will indicate the time of sunrise.

367. If the path of the Sun's place when the globe is turned from the point occupied at sunrise to the point occupied at sunset be carefully followed with reference to the horizon, the **diurnal arc** described by the Sun at different times of the year will be shown.

368. It is clear, that at apparent noon and midnight the Sun is mid-way between the eastern and western parts of the horizon—one part of the diurnal arc being above the horizon, the other below it. The time occupied, therefore, from noon to sunset is the same as from sunrise to noon. Similarly, the time from midnight to sunrise is equal to that from sunset to midnight.

369. As civil time divides the twenty-four hours into two portions, reckoned from midnight and noon, we have therefore a convenient method of learning the length of the day and night from the times of sunrise and sunset. For instance, if the Sun rises at 7, the time from midnight to sunrise is seven hours; but this time is equal, as has been seen, to the time from sunset to midnight, therefore the night is fourteen hours long. Similarly, if the Sun sets at 8, the day is twice eight, or sixteen hours long. So that—if we neglect the equation of time—

> Double the time of the Sun's setting gives the length of the day.
>
> Double the time of the Sun's rising gives the length of the night.

LESSON XXX.—*Apparent Motions of the Moon and Planets. Extreme Meridian Heights of the Moon: Angle of her Path with the Horizon at different Times. Harvest Moon. Varying Distances, and varying apparent Size of the Planets. Conjunction and Opposition.*

370. The Moon, we know, makes the circuit of the Earth in a lunar month,—that is, in 29½ days; in one day, therefore, she will travel, supposing her motion to be uniform, eastward over the face of the sky a space of nearly 13°, so that at the same time, night after night, she shifts her place to this amount, and therefore rises and sets later. Now, if the Moon's orbit were exactly in the plane of the ecliptic, we should not only have two eclipses every month (as was remarked in Art. 233), but she would appear always to follow the Sun's beaten track. We have seen, however, that her orbit is inclined 5° to the plane of the ecliptic, and therefore to the Sun's apparent path. It follows, therefore, that when the Moon is approaching her descending node, her path dips down (and her north latitude decreases), and that when she is approaching her ascending node, her path dips up (and her southern latitude decreases). Further, although the plane of her path can never be more than 5° from the Sun's path, she may be much more than 5° from that of the Sun's path, *at any one time*, for she may be at the extreme south of the ecliptic, while the Sun is at the extreme north, and *vice versa.* The greatest difference between the meridian altitudes of the Moon is twice $5^\circ + 23\frac{1}{2} = 57^\circ$; that is to say, she may be 5° north of a part of the ecliptic, which is 23½° north of the equator, or she may be 5° south of a part of the ecliptic, which is 23½° south of the equator.

371. But let us suppose the Moon to move actually in the ecliptic—this will make what follows easier. It is clear that the full Moon at midnight occupies exactly the opposite point in the ecliptic to that occupied by the Sun at noon-day. In winter, therefore, when the Sun is lowest, the Moon is highest; and so in winter we get more moonlight than in summer, not only because the nights are longer, but because the Moon, like the Sun in summer, is best situated for lighting up the northern hemisphere.

372. Although, as we have seen, the Moon advances about 13° in her orbit every 24 hours, the time between two successive moonrises varies considerably, and for a reason which should easily be understood. If the Moon moved along the equator,—or, in other words, if her orbit were in the plane of our equator,—the interval would always be about the same, because the equator is always inclined the same to our horizon; but she moves nearly along the ecliptic, which is inclined 23° to the equator; and because it is so inclined, she approaches the horizon at vastly different angles at different times. In Art. 362 we saw that half of the ecliptic is to the north and half to the south of the equator, the former crossing the latter in the signs Aries and Libra. Now when the Moon is furthest from these two points twice a month, her path is parallel with the equator, and the interval between two risings will be nearly the same for two or three days together; but mark what happens if she be near a node, *i.e.* in Aries or Libra. In Aries the ecliptic crosses the equator to the north; in Libra the crossing is to the south. In Fig. 42 the line **HO** represents the horizon, looking east; **EQ** the equator, which in England is inclined about 38° to the horizon. The dotted line **EC** represents the direction of the ecliptic when the sign Libra is on the horizon; and the dotted line **E′C′** the direction of the ecliptic when the sign Aries is on the horizon.

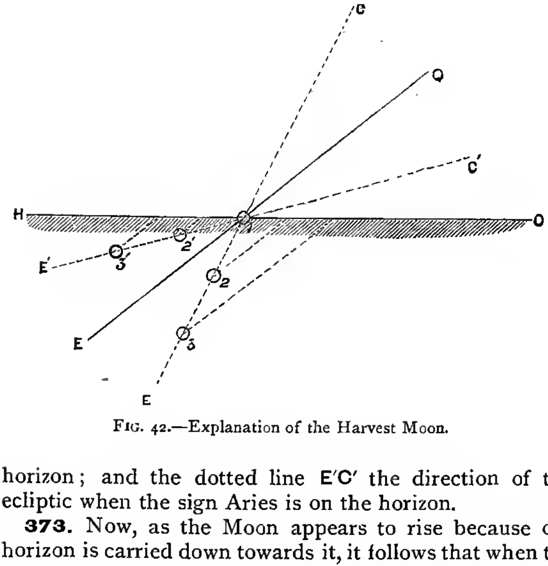

FIG. 42.—Explanation of the Harvest Moon.

373. Now, as the Moon appears to rise because our horizon is carried down towards it, it follows that when the Moon occupies the three successive positions shown on the line **E′C′** she will rise nearly at the same time on successive evenings, because, as her path is but little inclined to the horizon, she therefore seems to travel nearly along the horizon; whereas, in the case of the line **EC**, her path is more inclined to the horizon than the equator itself. This, of course, happens every month, as the Moon courses the whole length of the ecliptic in that time; but when the *full* Moon happens at this node, as it does once a year, the difference comes out very strongly, and this full Moon is called the **harvest moon,** as it is the one which falls always within a fortnight of Sept. 23, the time of harvest.

374. The **planets,** when they are visible, appear as stars, and, like the stars, they rise and set by virtue of the Earth's rotation. Their apparent motions among the stars caused by the Earth's revolution round the Sun, combined with their own actual movements, therefore need only occupy our attention.

375. Let us glance at Plate V., and suppose that all the planets there shown—the Earth among them—are revolving round the Sun at different rates of speed, as is actually the fact; it will be at once clear that the distances of the planets from each other and from the Earth are perpetually varying; the distances of all from the Sun, however, remaining within the limits defined by the degree of ellipticity of their orbits.

376. At some point of the Earth's path she will have each planet by turns on the same side of the Sun as herself, and on the opposite side; it is evident therefore that the extreme distances will vary in the case of superior planets by the diameter of the Earth's orbit,—that is, roughly, by 186,000,000 miles. But this is not all; as the orbits are elliptical, when the Earth and any one planet are near each other, the distance will not always be the same; for as these approaches occur in different parts of the orbit, at one time we may have both the Earth and planet at their perihelion or aphelion points, or one may be in perihelion and the other in aphelion. The same when the Earth and any planet are on opposite sides of the Sun. This will be exemplified presently.

377. The following table shows the average least and greatest distances of each planet from the Earth, not taking into consideration the variation due to the ellipticity of the orbits :—

	Least Distances. Miles.	Greatest Distances. Miles.
Mercury	56,978,000	128,952,000
Venus	23,720,000	160,210,000
Mars	48,685,000	234,615,000
Jupiter	390,713,000	576,643,000
Saturn	793,814,000	979,744,000
Uranus	1,690,418,000	1,876,348,000
Neptune	2,701,035,000	2,886,965,000

The first column, in fact, is the difference between the distances of any one planet and the Earth from the Sun, and the second column is their sum. To this change of distance is to be ascribed the change of **brilliancy** of the various planets, due to their varying apparent sizes, as of course they appear larger when they are near us than they do when they are on the other side of the Sun ; and also their **phases,** which, in the case of the planets whose orbits lie between us and the Sun, are similar to those of the Moon, and for a like reason. The difference of size will of course depend upon the difference of distance, and the difference of distance will be greatest for those planets whose orbits lie nearest that of the Earth, as shown in the table. Thus Venus when nearest the Earth appears six times larger than when it is furthest away, because it is really six times nearer to us ; Mars in like manner appears five times larger ; while in the case of Uranus and Neptune, as the diameter of the Earth's orbit is small compared with their distance from the Sun, their apparent sizes are hardly affected.

In the case of the planets which lie between us and the Sun, phases similar to those of the Moon are seen from the Earth, because sometimes the planet is between us and the Sun, similarly to what happens at New Moon ;

sometimes the Sun is between us and the planet, and consequently we see the lit-up hemisphere. At other times, as shown in Fig. 43, the Sun is to the right or left of the planet as seen from the Earth; and we see a part of both the lit-up and dark portions. Among the superior planets, Mars is the only one which exhibits a marked phase, which resembles that of the gibbous Moon.

378. To distinguish the planets which travel round the Sun within the Earth's orbit, from those which lie beyond us, the former, *i.e.* Mercury and Venus, are termed **inferior planets**; and the latter, *i.e.* Mars, Jupiter, Saturn, Uranus and Neptune, are termed **superior planets.** When an *inferior planet* is in a line *between the Earth and Sun*, it is said to be in **inferior conjunction** with the Sun; when it is in the same line, but *beyond the Sun*, it is said to be in **superior conjunction.** When a superior planet is on the opposite side of the Sun,—that is, when the Sun is between us and it,—we say it is in **conjunction**; when in the same straight line, but with the Earth in the middle, we say it is in **opposition,** because it is then in the part of the heavens opposite to the Sun.

LESSON XXXI.—*Apparent Motions of the Planets (continued). Elongations and Stationary Points. Synodic Period, and Periodic Time.*

379. If an observer could watch the motions of the planets from the Sun, he would see them all equally pursue their beaten tracks, always in the same direction, with different velocities, but with an almost even rate of speed in the case of each. Our Earth, however, is not only a moveable observatory, the motion of which complicates the apparent movements of the planets in an extraordinary degree, but from its position in the system all the planets are not seen with equal ease. In the first place, it is evident that only the superior planets are ever visible at midnight, as they alone can ever occupy the region opposite to the Sun's place at the time, which is the region of the heavens brought round to us at midnight by the Earth's rotation. Secondly, it is evident not only that the inferior planets are always apparently near the Sun, but that when nearest to us their dark sides are turned towards us, as they are then between us and the Sun, and the Sun is shining on the side turned away from us.

380. The greatest angular distance, in fact, of Mercury and Venus from the Sun, either to the east (left) or west (right) of it, called the **eastern** and **western elongations,** is 29° and 47° respectively. As a consequence, our only chance of seeing these planets is either in the day-time (generally with the aid of a good telescope), or just before sunrise at a western elongation, or after sunset at an eastern elongation. When Venus is visible in these positions, she is called the **morning star** and **evening star** respectively.

381. In Fig. 43 are shown a planet which we will first take to represent the Earth in its orbit, and an inferior planet at its conjunctions and elongations. In the first place it is obvious that, as stated in Art. 377, such a planet must exhibit phases exactly as the Moon does, and for the same reason; and secondly, that the rate and direction, as seen from the Earth, which for the sake of simplicity we will suppose to remain at rest, will both vary. At superior conjunction the planet will appear to progress in the true or **direct** direction pointed out by the outside arrow, but when it arrives at its eastern elongation it will appear to be stationary, because it is then for a short time travelling exactly towards the Earth. From this point, instead of journeying from right to left, as at superior conjunction, it will appear to us to travel from left to right, or **retrograde,** until it reaches the point of westerly elongation, when for a short time it will travel exactly from the Earth, and again appear stationary, after which it recovers its direct motion.

The only difference made by the Earth's own movements in this case is, that as its motion is slower than and in the same direction as that of the inferior planet, the times between two successive conjunctions or elongations will be longer than if the Earth were at rest.

382. As seen from the Earth, the superior planets appear to reach **stationary points** in the same manner, but for a different reason. At the moment a superior planet appears stationary, the Earth, as seen from that planet, has reached its point of eastern or western elongation. In fact, let P in Fig. 43 represent a superior planet at rest, and let the inferior planet represented be the Earth. From the western elongation through superior conjunction, the motion of the planet referred to the stars beyond it will be *direct—i.e.* from *1 to *2, as shown by the outside arrow; when the Earth is at its eastern elongation, as seen from the planet, the planet as seen from the Earth will appear at rest, as we are advancing for a short time straight to it. When this point is passed, the apparent motion of the planet will be reversed; it will appear to retrograde from *2 to *1, as shown by the inside arrow.

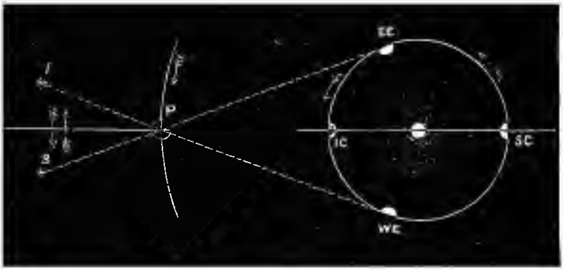

FIG. 43.—Diagram explaining the Retrogradations, Elongations, and Stationary Points of Planets.

383. As in the former case, the only difference when we deal with the planet actually in motion, will be that the times in which these changes take place will vary with the actual motion of the planet; for instance, it will be much less in the case of Neptune than in the case of Mars, as the former moves much more slowly.

384. In consequence of the Earth's motion, the period in which a planet regains the same position with regard to the Earth and Sun is different from the actual period of the planet's revolution round the Sun. The time in which a position, such as conjunction or opposition, is regained, is called a **synodic period.** They are as follow for the different planets:—

	Mean Solar Days.
Mercury	115·87
Venus	583·92
Mars	779·94
Jupiter	398·87
Saturn	378·09
Uranus	369·66
Neptune	367·49

Now these synodic periods are the periods actually observed, and from which the times of revolution of the planets round the Sun, or their periodic times, have been found out. This is easily done, as follows: Let us represent the periodic times of any two planets by O and I; O representing the outside planet of the two, and I the inside one; and let us begin with the Earth and Mercury. As the periodic time is the time in which a complete circuit round the Sun, or 360°, is accomplished; in one day, as seen from the Sun, the portion of the orbit passed over would be equal to 360° divided by I and O; or $\frac{360^\circ}{I}$ and $\frac{360^\circ}{O}$, the difference between these, or $\frac{360^\circ}{I} - \frac{360^\circ}{O}$, will be the number of degrees which the inside planet gains daily on the outside one.

385. The actually observed interval from one conjunction of the two planets to the next, we will represent by T; but it is evident that in this time the inner one has gained exactly one complete revolution, or 360°, upon the outer one; in fact, the outer one will have advanced a certain distance, and the inner one will have completed a revolution, and in addition advanced the same distance before the two planets are together again. Therefore, $\frac{360^\circ}{T}$ will represent the daily rate of separation, which we have seen is also shown by $\frac{360^\circ}{I} - \frac{360^\circ}{O}$;

we may therefore say $\frac{360^\circ}{T} = \frac{360^\circ}{I} - \frac{360^\circ}{O}$ . . . (1)

In this case we want to know I, or the periodic time of Mercury, and we know by observation, T, the synodic period of Mercury and the Earth, which is given in the previous table as 115·87 days, and O, the time of revolution of the Earth = 365·256 days. We therefore transpose the equation to get the unknown quantity on one side, and the known ones on the other: we get

$$\frac{360^\circ}{I} = \frac{360^\circ}{T} + \frac{360^\circ}{O}$$

Dividing by 360°, we also get—

$$\frac{1}{I} = \frac{1}{T} + \frac{1}{O}.$$

Substituting the known values, we have

$$\frac{1}{I} = \frac{1}{115{\cdot}87} + \frac{1}{365{\cdot}256}.$$

Finding the value of this fraction, we get

$$\frac{1}{I} = \frac{1}{87{\cdot}7},$$

and therefore

$$I = 87{\cdot}7 \text{ days.}$$

386. Next let us take the Earth and Jupiter. In this case, as Jupiter is now the outside planet, we must transpose equation (1):—

$$\frac{360^\circ}{T} = \frac{360^\circ}{I} - \frac{360^\circ}{O}$$

into

$$\frac{360^\circ}{O} = \frac{360^\circ}{I} - \frac{360^\circ}{T}; \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

as O, or the periodic time, is the unknown quantity, and I and T are the two known ones. Proceeding as before, we get

$$\frac{1}{O} = \frac{1}{365{\cdot}256} - \frac{1}{398{\cdot}87};$$

$$\text{or } \frac{1}{O} = \frac{1}{4332{\cdot}9}$$

$$\text{or } O = 4332{\cdot}9 \text{ days.}$$

The periodic time of Jupiter is therefore 4332·9 days.

387. We may also use equation (1) when, having the periodic times of two planets given, we wish to determine their synodic time. In this case T is the unknown quantity, and I and O the known ones. Let us take the Earth and Mars, whose periodic times are nearly 365·256 and 686·9 respectively. We have

$$\frac{1}{T} = \frac{1}{I} - \frac{1}{O},$$

$$\text{or } \frac{1}{T} = \frac{1}{365{\cdot}256} - \frac{1}{686{\cdot}9},$$

which is equal to

$$\frac{1}{T} = \frac{1}{779{\cdot}9},$$

$$\text{or } T = 779{\cdot}9 \text{ days.}$$

LESSON XXXII.—*Apparent Movements of the Planets (continued). Inclinations and Nodes of the Orbits. Apparent Paths among the Stars. Effects on Physical Observations. Mars. Saturn's Rings.*

388. If the motions of the planets were confined to the plane of the ecliptic, the motions, as seen from the Earth, would be along the same path as that followed by the Sun; but as we have seen, the orbits are all inclined somewhat to that plane. Here is a table of the present inclinations, and positions of the ascending nodes (Art. 233):—

	Inclination of Orbit.			Longitude of Ascending Node.	
	°	′	″	°	′
Mercury	7	0	5	45	57
Venus	3	23	29	74	51
Mars	1	51	6	47	59
Jupiter	1	18	52	98	25
Saturn	2	29	36	111	56
Uranus	0	46	28	72	59
Neptune	1	46	59	130	6

389. A moment's thought will convince us that the apparent distance of a planet from the plane of the ecliptic will be greater, as seen from the Earth, if the planet is near the Earth at the time of observation; and it also follows that as the distance of the planet from the Earth must thus be taken into account, the distance above or below the plane of the ecliptic will not appear to vary so regularly when seen from the Earth as it would do could we observe it from the Sun.

390. Moreover, it should be clear that when the planet is at a node, it will always appear in the ecliptic.

391. Fig 44 represents the path of Venus, as seen from the Earth from April to October 1868. A study of it should make what has already been said about the apparent motions of the planets quite clear. From April to June the planet's north latitude is increasing, while the node and stationary point—which in this case are coincident, though they are not always so—are reached about the 25th of June. The southern latitude rapidly increases until, on the 9th August, the other stationary point is reached, after which the south latitude decreases again.

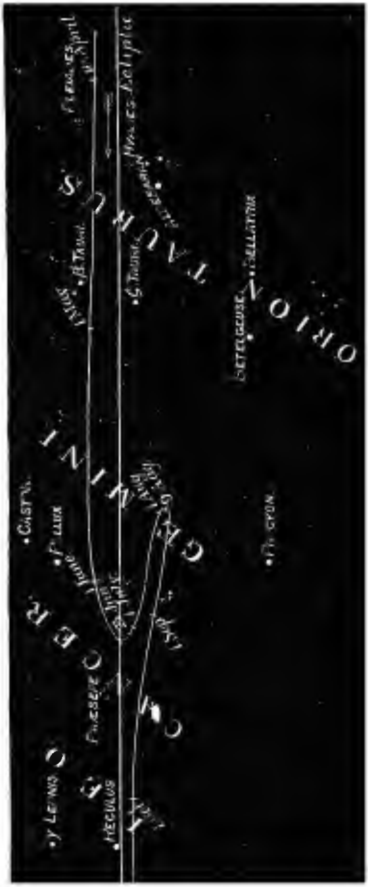

FIG. 44.—Path of Venus among the Constellations, 1868.

392. In Fig. 45 is represented the path of Saturn from 1862 to 1865 A comparison of this with the preceding figure shows how the distance of a planet from the Earth influences the shape of its path. In this case, as the planet's own motion is, unlike that of Venus, apparently slow, the Earth's circular motion is as it were reflected, and between each opposition we have a loop, the ends of which are represented by the stationary points.

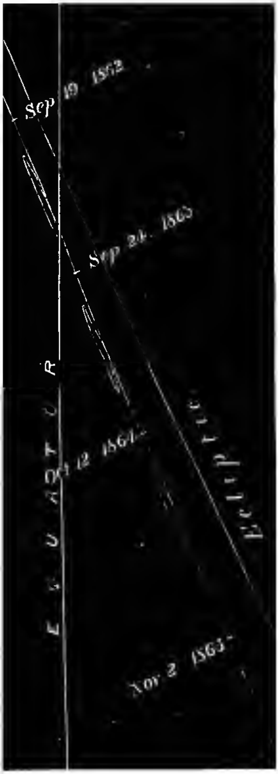

FIG. 45.—Saturn's apparent Path from 1862 to 1865. (Proctor.)

Moreover, it will be seen that the planet during the time was north of the ecliptic, or in that part of its orbit situated above the plane of the Earth's motion round the Sun, and that the north latitude was increasing. Still, for all this, it was situated south of the equator, and its south declination, or its distance south of that line, was increasing. Hence, year by year, although it is getting more above the ecliptic, it is getting more below the equator. Let this be compared with what was said about the motion of the Moon in Art. 370, and it will be evident that when on the meridian the planet's height above the horizon will decrease, until the planet itself reaches that part of the ecliptic 23½° south of the equator—in fact, until its position is near that occupied by the Sun in mid-winter.

393. The apparent path of a planet, then, is moulded, as it were, by the motions of the Earth and the inclination

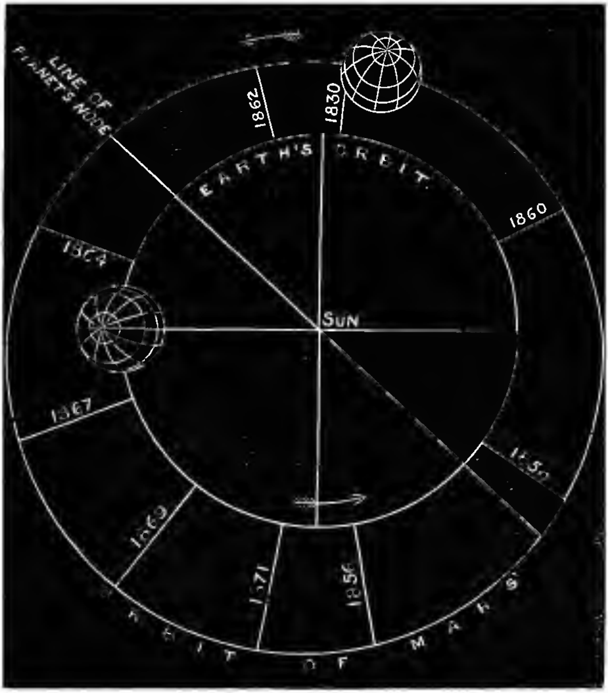

Fig. 46.—The Orbits of Mars and the Earth.

of its own orbit. If we examine into the position of the orbit of Mars, for instance, more closely than we have hitherto done, we shall see how the ellipticity of the orbit and its inclination affect our observations of the physical features. Fig. 46 shows the exact positions in space of the orbits of the Earth and Mars, and the amount and direction of the inclination of their axes, and the line of Mars' nodes: both planets are represented in the positions they occupy with respect to the Sun at the winter solstices of their northern hemispheres. The lines joining the two orbits indicate the positions occupied by both planets at successive oppositions of Mars, at which times, of course, Mars, the Earth, and the Sun are in the same straight line (leaving the inclination of Mars' orbit out of the question).

394. It is seen at a glance that at the oppositions of 1830 and 1860 the two planets were much nearer together than in 1867 or 1869.

The figure also enables us to understand that in the case of an inferior planet, if we suppose the perihelion of the Earth to coincide in direction, or, as astronomers put it, to be in the same heliocentric longitude as the aphelion of the planet, it will be obvious that the conjunctions which happen in this part of the orbits of both will bring the bodies nearer together than will the conjunctions which happen elsewhere. Similarly, if we suppose the aphelion of the Earth to coincide with the perihelion of a superior planet, as in the case of Mars, it will be obvious that the opposition which happens in that part of the orbit will be the most favourable for observation. The Earth's orbit, however, is so nearly circular that the variation practically depends more upon the eccentricity of the orbits of the other planets than upon our own.

The figure also shows us that when Mars is observed at the solstice indicated, we see the southern hemisphere of the planet better than the northern one; while at those oppositions which occur when the planet is at the opposite solstice, the northern hemisphere is most visible. But we see the northern hemisphere in the latter case better than we do the southern one in the former, because in the latter case the planet is to the north of the ecliptic, and therefore in a better position for observation in northern

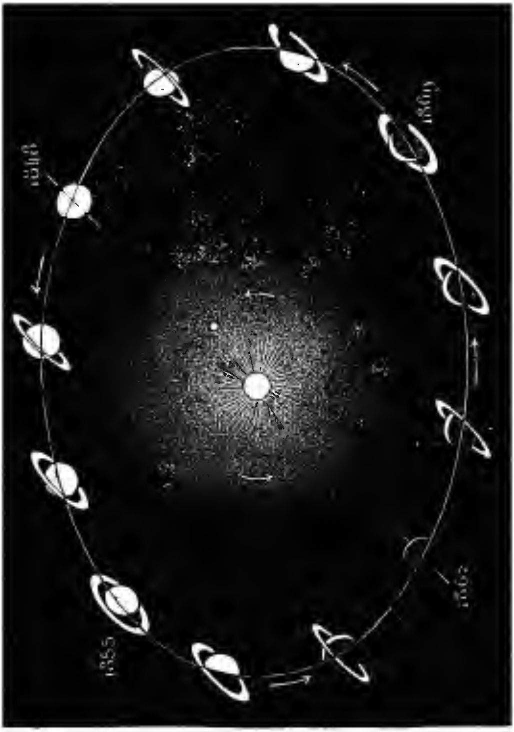

FIG. 47.—Explanation of the varying appearances of Saturn's rings, as seen from Uranus or Neptune.

latitudes; and in the former it is below the ecliptic, and we see less of the southern hemisphere than we should do were the planet situated in the ecliptic.

395. Fig. 47 shows the same effect of inclination in the case of the rings of Saturn. The plane of the rings is inclined to the axis, and, like the axis, always remains parallel to itself. A study of the figure will show that twice in the planet's year the plane of the rings must pass through the Sun; and while the plane is sweeping across the Earth's orbit, the Earth, in consequence of its rapid motion, may pass two or three times through the plane of the ring. Hence the ring about this time may be invisible from three causes: (1) Its plane may pass

FIG. 48.—Appearance of Saturn when the plane of the ring-system passes through the Earth.

FIG. 49.—Saturn, as seen when the north surface of the rings is presented to the Earth.

through the Sun, and its extremely thin edge only will be lit up. (2) The plane may pass through the Earth ; and (3) the Sun may be lighting up one surface, and the other may be presented to the Earth. These changes occur about every fifteen years, and in the mid-interval the surface of the rings—sometimes the northern one, at others the southern—is presented to the Earth in the greatest angle.

In Plate X. Saturn was represented with the south surface of the rings presented to the Earth. In Fig. 48 the appearance when the plane of the ring passes through the Earth is given ; and in Fig. 49 we have the aspect of the planet when the north surface of the ring is visible.

CHAPTER V.

THE MEASUREMENT OF TIME.

LESSON XXXIII.—*Ancient Methods of Measurement. Clepsydræ. Sun-Dials. Clocks and Watches. Mean Sun. Equation of Time.*

396. Having dealt with the apparent motions of the heavenly bodies, we now come to what those apparent motions accomplish for us, namely the division and exact Measurement of Time. For common purposes, time is measured by the Sun, as it is that body which gives us the primary division of time into day and night; but for astronomical purposes the stars are used, as the apparent motion of the Sun is subject to variation.

397. The correct measurement of time is not only one of the most important parts of practical astronomy, but it is one of the most direct benefits conferred on mankind by the science; it enters, in fact, so much into every affair of life, that we are apt to forget that there was a period when that measurement was all but impossible.

398. Among the contrivances which were to the ancients what clocks and watches are to us, we may mention **clepsydræ** and **sun-dials.** Of these, the former seem the more ancient, and were used not only by the Greeks and Romans, but by other nations, both Eastern and Western, the ancient Britons among them. This instrument in its simplest form resembled the hour-glass, water being used instead of sand, and the flow of time being measured by the flow of the water. After the time of Archimedes, clepsydræ of the most elaborate construction were common; but while they were in use, the days, both winter and summer, were divided into twelve hours from sunrise to sunset, and consequently the hours in winter were shorter than the hours in summer; the clepsydra, therefore, was almost useless except for measuring intervals of time, unless different ones were employed at different seasons of the year.

399. The sun-dial also is of great antiquity; it is referred to as in use among the Jews 742 B.C. This was a great improvement upon the clepsydra; but at night and in cloudy weather it could of course not be used, and the rising, culmination, and setting of the various constellations were the only means available for roughly telling the time during the night. Indeed, Euripides, who lived 480—407 B.C., makes the Chorus in one of his tragedies ask the time in this form :—

> "What is the star now passing?"

and the answer is—

> "The Pleiades show themselves in the East;
> The Eagle soars in the summit of heaven."

It is also on record that as late as A.D. 1108 the sacristan of the Abbey of Cluny consulted the stars when he wished to know if the time had arrived to summon the monks to their midnight prayers; and in other cases, a monk remained awake, and to measure the lapse of time repeated certain psalms, experience having taught him in the day, by the aid of the sun-dial, how many psalms could be said in an hour. When the proper number of psalms had been said, the monks were awakened.*

400. To understand the construction of a sun-dial, let

---

* Arago.

us imagine a transparent cylinder, having an opaque axis, both axis and cylinder being placed parallel to the axis of the earth. If the cylinder be exposed to the sun, the shadow of the axis will be thrown on the side of the cylinder away from the sun; and as the sun appears to travel round the earth's axis in 24 hours, it will equally

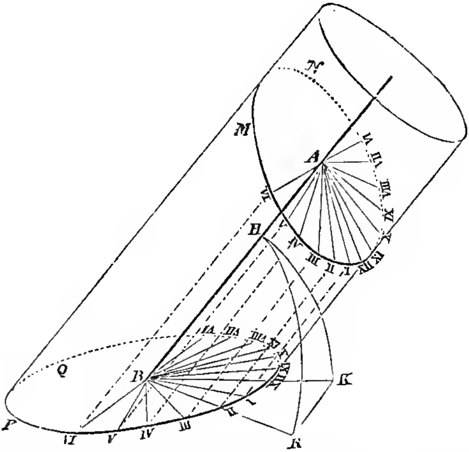

FIG. 50.—Sun-dial. (*AB*, axis of cylinder; *MN*, *PQ*, two Sun-dials, constructed at different angles to the plane of the horizon, showing how the imaginary cylinder determines the hour-lines.)

appear to travel round the axis of the cylinder in 24 hours, and it will cast the shadow of the cylinder's axis on the side of the cylinder as long as it remains above the horizon. All we have to do, therefore, is to trace on the side of the cylinder 24 lines 15° apart (15 × 24 — 360), taking care to have one line on the north side. When the sun is south at noon, the shadow of the axis will be thrown on this line, which we may mark XII., when the sun has advanced one hour to the west, the shadow will be thrown on to the next line to the east, which we may mark I., and so on.

401. The distance of the sun above the equator will evidently make no difference in the lateral direction of the shadow.

402. In practice, however, we do not want such a cylinder; all we want is a projection called a **style,** parallel to the earth's axis, like the axis of the cylinder, and a **dial.** The dial may be upright or horizontal, or inclined in any way so as to receive the shadow of the style, but the lines on it indicating the hours will always be determined by imagining such a cylinder, slicing it down parallel to the plane of the dial, and then joining the hour-lines on its surface with the style where it meets the dial. We shall return to the sun-dial after we have said something about clocks and watches.

403. The principle of both **clocks** and **watches** is that a number of wheels, locked together by cogs, are forced to turn round, and are prevented doing so too quickly. The force which gives the motion may be either a weight or a spring: the force which arrests the too rapid motion may either proceed from a pendulum, which at every swing locks the wheels, or from some equivalent arrangement.

404. The invention of clocks is variously ascribed to the sixth and ninth centuries. The first clock in England was made about 1288, and was erected in Old Palace Yard. Tycho Brahe used a clock, the motion of which was retarded or regulated by means of an alternating balance formed by suspending two weights on a horizontal bar, the movement being made faster or slower by altering the distances of the weights from the middle of the bar. But the Clock, as an accurate measurer of time, dates from the time of Galileo (1639) and Huygens (1656).

405. In both clocks and watches we mark the flow of time by seconds, such that sixty of them make a minute, sixty of which make an hour, twenty-four of which make a day. Those people who are not astronomers are quite satisfied with this, and a day is a word with a certain meaning. The astronomer, however, is compelled to qualify it—to put some other word before it—or it means very little to him, because, as we have seen (Art. 358), the term day may mean either the return of a particular meridian to the same star again or to the sun again. The term, as it is commonly used, means neither the one nor the other, because long ago, when it was found that in consequence of the motion of the earth not being uniform in its orbit round the sun (Art. 359), the days, as measured by the sun, were not equal in length, astronomers suggested, with a view of establishing a convenient and uniform measure of time for civil purposes, that a day should be the average of all the days in the year. So that our common day is not measured by the *true sun*, as a sun-dial measures it, but by what is called the **mean** (or *average*) **sun.**

406. For a long time after clocks and watches were made with considerable accuracy, it was attempted to make them keep time with the sun-dial, and for this purpose they were regulated once a day, or once a week, ignorant people taxing the maker with having supplied an imperfect instrument, as it would not keep time with the sun.

407. Let us inquire into the motion of the imaginary mean sun, by means of which the irregularities of the sun's apparent daily motion, and the unequal hours we get as a consequence from sun-dials, are obviated.

408. In the first place, the real sun's motion is in the ecliptic, and is variable. Secondly, the sun crosses the equator twice a year at the equinoxes, at an angle of 23½°, and midway between the equinoxes—that is, at the solstices—its path is almost parallel with the equator. Therefore, the sun's ecliptic motion, referred to the equator, is variable for two causes:—

I. The real motion is variable.

II. The motion is at different angles to the equator, and therefore referred to that line is least when the angle is greatest.

409. Let us first deal with the first cause—the inequality of the real sun's motion. When the earth is nearest the sun, about Jan. 1, the sun appears to travel through 1° 1′ 10″ of the ecliptic in 24 hours; at aphelion, about July 1, the daily arc is reduced to 57′ 12″. The first thing to be done therefore is to give a constant motion to the mean or imaginary sun. As the real sun passes through 360° in 365d. 5h. 48m. 47·8s., we have

One year : one day : : 360° : daily motion;

and this rule of three sum tells us that the mean daily motion = 59′ 8″·33; and this therefore is the rate at which the mean sun is supposed to travel.

410. If the true sun moved in the equator instead of in the ecliptic, a table showing how far the mean and true sun were apart for every day in the year would at once enable us to determine mean time.

411. But the true sun moves along the ecliptic, while the mean sun must be supposed to move along the equator; so that it may be carried evenly round by the earth's rotation. This brings out the second cause of the inequality of the solar days. At some times of the year (at the solstices) the true sun moves almost parallel to the equator, at other times (at the equinoxes) it cuts the equator at an angle of 23½°; and when its motion is referred to the equator, time is lost. This will be rendered evident if on a celestial globe we place wafers, equally distant from the first point of Aries, both on the equator and the ecliptic, and bring them to the brass meridian.

412. We have, then, the mean sun, not supposed to move along the ecliptic at all, but along the equator, at an uniform rate of 0° 59′ 8″·3 a day $\left(=\frac{360^\circ}{365\frac{1}{4}\text{ days}}\right)$, and started, so to speak, from the first point of Aries, where the ecliptic and equator cut each other, and at such a rate that, supposing the true sun to move along the ecliptic at an uniform rate, the positions of the true sun referred to the equator will correspond with the mean sun at the two solstices and the two equinoxes, this cause alone being considered.

413. If the motion of the true sun were uniform, a correct clock would correspond with a correct sun-dial at these periods; between these periods they would indicate different times, as the true sun would lose time in climbing the heavens at its start from the point of intersection in Aries, and so on.

414. But we know the motion of the true sun is not uniform; it moves fastest when the earth is in perihelion, slowest when the earth is in aphelion; and if we also take this irregular motion into account, we find that the motion of the real sun in the ecliptic is nearly equal to the motion of the mean sun in the equator four times a year, namely,—

April 15th.
June 15th.
August 31st.
Dec. 24th.

415. At these dates we shall find the sun-dial and clock corresponding, but at the following dates we shall find differences as follows:—

	Minutes.
Feb. 11th	+ 14½
May 14th	— 4
July 25th	+ 6
Nov. 1st	— 16¼

which are the differences in time between the true and mean sun. Hence it is that in the almanacks we find what is termed the **equation of time** given, which is the time we must add to or substract from the time shown by a sun-dial, to make the dial correspond with a good clock. For instance, at the period of the year at which the mean

Plate XII.

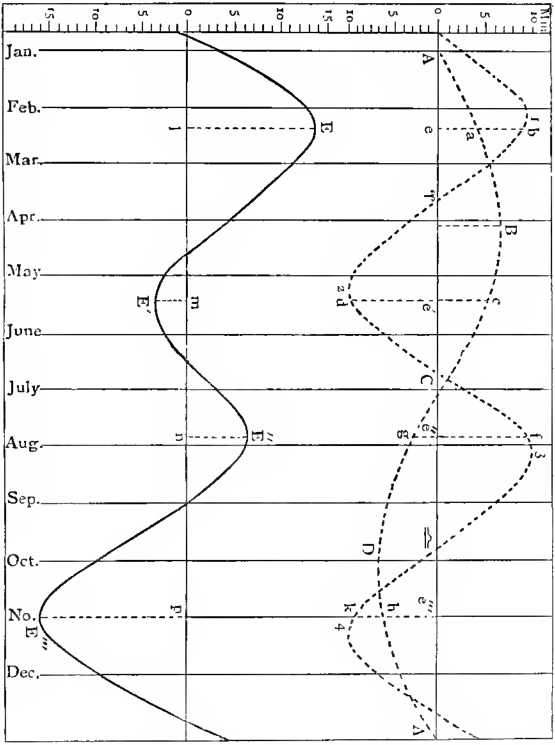

Diagram showing how the equation of time is derived from two components. Ordinates above the datum lines are positive (+), those below are negative (−). The curve A B C D represents the differences between the mean and true Suns at different times of the year, due to the irregularity of the earth's motion round the Sun, and the curve 1 2 3 4 represents the differences due to the obliquity of the ecliptic. The equation of time curve E E′E″E‴, is derived by taking the algebraical sum of the ordinates of the other two. Sometimes the ordinates of the two components act against each other, but at other times they act together. Thus, on April 15 the + due to curve A B C D is exactly neutralised by the − due to 1 2 3 4, and the equation of time is *nil*, but on Feb. 11 they act together and the resulting equation of time is + 14½ minutes.

sun is before the true sun, the clock will get behind the dial, and we must add the equation of time to the time shown by the true sun.

416. When the earth is in perihelion, or—what comes to the same thing—when the sun is in perigee, the *real sun* moves fastest, and therefore will gain on the mean sun, and the dial will be before the clock. When the sun is in apogee, the *mean sun* will move fastest, and the clock will be before the dial. The equation of time will therefore be additive or subtractive, or, as it is expressed, + or − with regard to the time shown by the true sun, or to apparent time.

417. So, to refer back to Art. 415, in November we must deduct 16¼m. from the apparent time, and in February we must add 14½m. to apparent time, to get clock time. In November, therefore, the true sun sets 16m. earlier than it would do if it occupied the position of the mean sun, by which our clocks are regulated. In February it sets 15m. later, and this is why the evenings begin to lengthen after Christmas more rapidly than they would otherwise do.

418. We cannot obtain mean time at once from observation; but, from an observation of the true sun with the aid of the equation of time, which is the angular distance in time between the mean and the true sun, we may readily deduce it. Suppose the true sun to be observed on the meridian of Greenwich, Jan. 1, 1887: it would then be apparent noon at that meridian; the equation of time at this instant is 3m. 46·69s. as given in the almanacs, and *is to be added to apparent time;* hence the corresponding mean time is Jan. 1, 0h. 3m. 46·69; that is to say the mean sun had passed the meridian previously to the true sun, and at the instant of observation the mean time clock ought to indicate this time.

In Plate XII. we have a graphic representation of the equation of time. Above and below the datum lines are scales of minutes. The curve A B C D represents the portion of the equation of time due to the inequality of the real sun's motion, and the curve 1 2 3 4 represents the inequality due to the obliquity of the ecliptic. The curve E E′ E″ E‴ is the algebraical sum of these, and represents the differences between mean time and true time all the year round.

LESSON XXXIV.—*Difference of Time. How determined on the Terrestrial Globe. Greenwich Mean Time. Length of the Various Days. Sidereal Time. Conversion of Time.*

419. Having said so much of solar days, both apparent and mean, we must next consider the start-points of these reckonings. We have—I. the **apparent solar day,** reckoned from the instant the true sun crosses the meridian through about 24 hours, till it crosses it again; II. the **mean solar day,** reckoned by the mean sun in the same manner. Both these days are used by astronomers. III. The **civil day** commences from the preceding midnight, is reckoned through 12 mean hours only to noon, and then recommences, and is reckoned through another 12 hours to the next midnight. The civil reckoning is therefore always 12 hours in advance of the astronomical reckoning; hence the well known rule for determining the latter from the former, viz.:—For P.M. civil times, make no change; but for A.M. ones, diminish the day of the month by 1 and add 12 to the hours. Thus: Jan. 2, 7h. 49m. P.M. civil time, is Jan. 2, 7h. 49m. astronomical time; but January 2, 7h. 49m. A.M. civil time is January 1, 19h. 49m. astronomical time. The distinction, however, between civil and astronomical reckoning is about to disappear, Greenwich civil time, counting from midnight to midnight, and from 0 to 24 hours will be adopted in the "Nautical Almanac" for 1891.

420. Now the position of the sun, as referred to the centre of the earth, is independent of meridians, and is the same for all places at the same absolute instant; but the time at which it transits the meridian of Greenwich, and any other meridian, will be different. In a mean solar day, or 24 mean solar hours, the earth, by its rotation from west to east, has caused every meridian in succession from east to west to pass the mean sun; and since the motion is uniform, all the meridians distant from each other 15° will have passed the mean sun, at intervals of one mean hour; the meridian to the eastward passing first, or being, as compared with the sun, always one mean hour in advance of the westerly meridian. When it is 6 hours after mean noon at a place 15° west of Greenwich, it is therefore 7 hours after mean noon at Greenwich. When it is noon at Greenwich, it is past noon at Paris, because the sun has apparently passed over the meridian of Paris before it reached the meridian of Greenwich. Similarly, it is not yet noon at Bristol, for the sun has not yet reached the meridian of Bristol.

421. In civilized countries, at the present moment, not only is the use of mean time universal, but the mean time of the principal city or observatory is alone used. In England, for instance, **Greenwich mean time** (written G.M.T. for short) is used; in France, **Paris mean time**; in Switzerland, **Berne mean time,** and so on. This has become necessary owing, among other things, to the introduction of railways, so that with us Greenwich mean time is often called **railway time.** Formerly, before local time was quite given up, the churches in the West of England had two minute-hands, one showing local time, the other Greenwich time.

422. On the Continent, railway stations near the frontier of two states have their time regulated by their principal observatories. At Geneva, for instance, we see two clocks, one showing Paris time, and the other Berne time; and it is very necessary to know whether the time at which any particular train we may wish to travel in starts, is regulated by Paris or Berne time, as there is a considerable difference between them.

423. Expressed in mean time, the length of the day is as follows :—

	h.	m.	s.
Apparent solar day (Art. 419)	variable.		
Mean solar day (Art. 419)	24	0	0
Sidereal day (Art. 538)	23	56	4·09
Mean lunar day	24	54	0

424. It will be explained further on (Chap. VII.) that sidereal time is reckoned from the first point of Aries, and that when the mean sun occupies the *first point of Aries*, which it does at the vernal equinox, the indications of the mean-time clock and the sidereal clock will be the same; but this happens at no other time, as the sidereal day is but 23h. 56m. 4s. (mean time) long, so that the sidereal clock loses about four minutes a day, or one day a year (of course the coincidence is established again at the next vernal equinox), as compared with the mean time one.

425. A sidereal clock represents the rotation of the earth on its axis, as referred to the stars, its hour-hand performing a complete revolution through the 24 sidereal hours between the departure of any meridian from a star and its next return to it; at the moment that the vernal equinox, or a star whose right ascension is 0h. 0m. 0s. is on the meridian of Greenwich, the sidereal clock ought to show 0h. 0m. 0s., and at the succeeding return of the star, or the equinox, to the same meridian, the clock ought to indicate the same time.

426. Sidereal time at mean noon, therefore, is the angular distance of the first point of Aries, or the true vernal equinox, from the meridian, at the instant of mean noon: it is therefore the right ascension of the mean sun, or the time which ought to be shown by a sidereal clock at Greenwich, when the mean-time clock indicates 0h. 0m. 0s.

427. The sidereal time at mean noon for each day is given in the "Nautical Almanac." Its importance will be easily seen from the following rules :—

RULE I.—**To convert mean solar into sidereal time:**—To the sidereal time at the *preceding* mean noon add the sidereal interval corresponding to the given mean time: the sum will be the sidereal time required.

RULE II.—**To convert sidereal into mean solar time:**—To the time at the *preceding* sidereal noon, add the mean interval corresponding to the given sidereal time; the sum will be the mean solar time required.

428. Tables of intervals are given in the Appendix, showing the value of seconds, minutes, &c., of sidereal time in mean time, and *vice versâ*.

429. Suppose, for instance, we wish, under Rule I., to convert 2h. 22m. 25·62s. mean time at Greenwich, Jan. 7, 1887, into sidereal time, we proceed as follows:—

	h.	m.	s.		h.	m.	s
Sidereal time at the *preceding* mean noon *i.e.* Jan. 7, from "Nautical Almanac"					19	6	56·42
For mean time intervals.	2	0	0	We get in the table, equivalent sidereal intervals.	2	0	19·713
		22	0			22	3·614
			25				25·069
			0·62				0·622
The sum is the sidereal time required . .					21	29	45·44

430. Suppose we wish, under Rule II., to convert 21h. 28m. 11·36s. sidereal time at Greenwich, Jan. 7, 1887, into mean time, we proceed as follows:—

	h.	m.	s.		h.	m.	s
Mean time at the *preceding* sidereal noon, *i.e.* Jan. 6					4	56	11·48
For sidereal intervals.	21	0	0	The table gives the equivalent mean intervals.	20	56	33·579
		28	0			27	55·413
			11				10·970
			0·36				0·359
The sum is the mean time required, Jan. 7 .					2	20	51·80

431. If the place of observation be not on the meridian of Greenwich, the sidereal time must be corrected by the *addition* of 9·8565s. for each hour (and proportional parts for the minutes and seconds) of longitude, if the place be to the west of Greenwich: but by its *subtraction*, if to the east. Thus in 9h. 10m. 6s. west longitude, the sidereal time at mean noon, Jan. 7, 1887, instead of being, as in the foregoing examples, 19h. 6m. 56·42s. must be corrected by adding 1m. 30·37s., thus giving 19h. 8m. 26·79s. for the time to be used, instead of that set down in the column.

LESSON XXXV.—*The Week. The Month. The Year. The Calendar. Old Style. New Style.*

432. Although the **week,** unlike the day, month, and year, is not connected with the movements of any heavenly body, the names of the seven days of which it is composed were derived by the Babylonians from the seven celestial bodies then known. The order of succession established by them was continued by the Romans, their names being as follow:—

Dies Saturni . .	Saturn's day . .	Saturday.
Dies Solis . .	Sun's day	Sunday.
Dies Lunæ . .	Moon's day . . .	Monday.
Dies Martis . . .	Mars' day . . .	Tuesday.
Dies Mercurii . .	Mercury's day . .	Wednesday.
Dies Jovis . . .	Jupiter's day . .	Thursday.
Dies Veneris .	Venus's day . . .	Friday.

433. We see at once the origin of our English names for the first three days; the remaining four are named from Tiu, Woden, Thor, and Friga, Northern deities equivalent to Mars, Mercury, Jupiter, and Venus in the classic mythology.

434. We next come to the **month.** This is a period of time entirely regulated by the moon's motion round the earth (see Lesson XVI.).

The **lunar month** is the same as the *lunation* or *synodic month*, and is the time which elapses between consecutive new or full moons, or in which the moon returns to the same position relatively to the earth and sun.

The **tropical month** is the revolution of the moon with respect to the moveable equinox.

The **sidereal month** is the interval between two successive conjunctions of the moon with the same fixed star.

The **anomalistic month** is the time in which the moon returns to the same point (for example, the perigee or apogee) of her moveable elliptic orbit.

The **nodical month** is the time in which the moon accomplishes a revolution with respect to her nodes, the line of which is also moveable.

The **calendar month** is the month recognised in the almanacs, and consists of different numbers of days, such as January, February, &c.

435. The lengths of these various months are as follow :—

	Mean Time.			
	d.	h	m	s.
Lunar, or Synodic month	29	12	44	2·84
Tropical month	27	7	43	4·71
Sidereal „	27	7	43	11·54
Anomalistic month	27	13	18	37·40
Nodical „	27	5	5	35·60

436. We next come to the **year.** This is a term applied to the duration of the earth's movement round the sun, as the term "day" is applied to the duration of the earth's movement round its own axis ; and there are various sorts of years, as there are various sorts of days. Thus, we may take the time that elapses between two successive conjunctions of the sun, as seen from the earth, with a fixed star. This is called the **sidereal year.**

437. Again, we may take the period that elapses between two successive passages through the vernal equinox. This is called the **solar,** or **tropical year,** and its length is shorter than that of the sidereal one, because, owing to the precession of the equinoxes, the vernal equinox in its recession meets the sun, which therefore passes through it sooner than it would otherwise do.

438. Again, we may take the time that elapses between two successive passages of the earth through the perihelion or aphelion point; and as these have a motion forward in the heavens, it follows that this year, called the **anomalistic** one, will be longer than the sidereal one.

439. The exact lengths of these years are as follow :—

	Mean Time.			
	d.	h.	m.	s.
Mean sidereal year	365	6	9	9·6
Mean solar, or tropical year .	365	5	48	46·054440
Mean anomalistic year . . .	365	6	13	49·3

440. It is seen from this table that the solar year does not contain an exact number of solar days, but that in each year there is nearly a quarter of a day over. It is said that the inhabitants of ancient Thebes were the first to discover this. The calendar had got in such a state of confusion in the time of Julius Cæsar, that he called in the aid of the Egyptian astronomer Sosigenes to reform it. He recommended that one day, every four years, should be added by reckoning the sixth day before the kalends of March twice ; hence the term **bissextile.**

441. With us, in every fourth year one additional day is given to February. Now this arrangement was a very admirable one, but it is clear that the year was *over-corrected.* Too much was added, and the matter was again looked into in the sixteenth century, by which time the over-correction had amounted to more than ten days, the vernal equinox falling on March 11, instead of March 21. Pope Gregory, therefore, undertook to continue the good work begun by Julius Cæsar, aud made the following rule for the future:—Every year divisible by 4 to be a bissextile, or leap-year, containing 366 days; every year not so divisible to consist of only 365 days; every secular year (1800, 1900, &c.) divisible by 400 to be a bissextile, or leap-year, containing 366 days; every secular year not so divisible to consist of 365 days.

442. The period by which the addition of one day in four years exceeds the proper correction amounts to nearly three days in 400 years; by the new arrangement there are only 97 intercalations in 400 years, instead of 100. This brings matters within 22·38s. in that period, which amounts to 1 day in 3866 years.

443. The **Julian calendar** was introduced in the year 44 B.C.; the reformed **Gregorian** one in 1582. It was not introduced into this country till 1752, in consequence of religious prejudices. With us the correction was made by calling the day after Sept. 3, 1752, Sept. 14. This was called the **new style** (N.S.), as opposed to the **old style** (O.S.). In Russia the old style is still retained, although it is customary to give both dates, thus: 1887 $\frac{\text{Jan. 23.}}{\text{Feb. 4.}}$

444. It is impossible to overrate the importance of these various improvements devised for a better knowledge of the length of the tropical or solar year: if the calendar were not exactly adjusted to it, the seasons would not commence on the same day of the same month as they do now, but would in course of time make the complete circuit of all the days in the year; January, or any other month, might fall either in spring, summer, autumn, or winter.

445. At present, owing to a change of form in the Earth's orbit (Chap. IX.), the tropical year diminishes in length at the rate of $\frac{6}{10}$ths of a second in a century, and it is shorter now than it was in the time of Hipparchus by about 12 seconds.*

446. If the tropical and the anomalistic year were of

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* Hind.

equal lengths, it would follow that, as the seasons are regulated by the former, they would always occur in the same part of the Earth's orbit. As it is, however, the line joining the aphelion and perihelion points, termed the **line of apsides,** slowly changes its direction at such a rate that in a period of 21,000 years it makes a complete revolution. We have seen before (Art. 167) that at present we are nearest to the sun about Christmas time. In A.D. 6485 the perihelion point will correspond to the vernal equinox.

447. As the length of the seasons, compared with each other, depends upon the elliptical shape of the Earth's orbit, it follows that variations in the relative lengths will arise from the variation in the position of its largest diameter.

CHAPTER VI.

LIGHT.—THE TELESCOPE AND SPECTROSCOPE.*

LESSON XXXVI.—*What Light is; its Velocity; how determined. Aberration of Light. Reflection and Refraction. Index of Refraction. Dispersion. Lenses.*

448. Modern science teaches us that light consists of undulations or waves of a medium called **ether,** which pervades all space. These undulations—these **waves** of light—are to the eye what sound-waves are to the ear, and they are set in motion by bodies at a high temperature—the Sun, for instance—much in the same manner as the air is thrown into motion by our voice, or the surface of water by throwing in a stone; but though a wave motion results from all these causes, the way in which the wave travels varies in each case.

449. As we have seen, light, although to us it seems instantaneous, requires time to travel from an illuminat*ing* to an illuminat*ed* body, although it travels very quickly. What has already been said about the planet Jupiter and his moons will enable us readily to understand how the velocity of light was determined by Roemer. He found that the eclipses of the moons (which he had calculated

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* Sir John Herschel's work on "The Telescope," and Sir Henry Roscoe's or Schellen's work on "Spectrum Analysis," should here be consulted by the teacher.

beforehand) happened 16m. 36s. later when Jupiter was in conjunction with the Sun than when he was in opposition. Now we know (Art. 377) that Jupiter is further from us in the former case than in the latter, by exactly the diameter of the Earth's orbit. He soon convinced himself that the difference of time was due to the light having so much further to travel. Now the additional distance, *i.e.* the diameter of the Earth's orbit, being 186,000,000 miles, it follows by a rule-of-three sum that light travels about 186,300 miles a second. This fact has been abundantly proved since Roemer's time, and what astronomers call the **aberration of light** is one of the proofs.

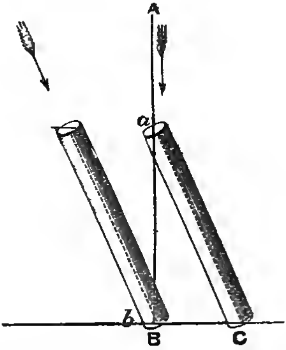


FIG. 51.—Showing how a tube in movement from C to B must be inclined so that the drop *a* may fall to *b* without wetting the sides.

450. We may get an idea of the aberration of light by observing the way in which, when caught in a shower, we hold the umbrella inclined in the direction in which we are hastening, instead of over head, as we should do were we standing still. Let us make this a little clearer. Suppose I wish to let a drop of water fall through a tube without wetting the sides: if the tube is at rest there is no difficulty, it has only to be held upright in the direction **AB**; but if we must move the tube the matter is not so easy. The diagram shows that the tube must be *inclined*, or else the drop in the centre of the tube at *a* will no longer be in the centre of the tube at *b*; and the faster the tube is moved the more must it be inclined. Now we may liken the drop to rays of light, and the tube to the telescope, and we find that to see a star we must incline our telescopes in this way. By virtue of this, each star really seems to describe a small circle in the heavens, representing on a small scale the Earth's orbit; the extent of this apparent circular motion of the star depending upon the relative velocity of light, and of the Earth in its orbit, as in Fig. 51 the slope of the tube depends upon the relative rapidity of the motion of the tube and of the drop; and we learn from the actual dimensions of the circle that light travels about 10,000 times faster than the Earth does—that is, about 186,000 miles a second. This velocity has been experimentally proved by M. Foucault and more recently by Professor Newcomb, by means of a turning mirror.

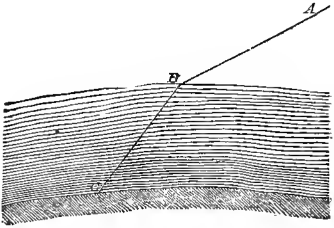


FIG. 52.—Showing how a ray coming from a star in the direction *A B* changes its direction, in consequence of the refraction of the atmosphere.

451. Now a ray of light is *reflected* by bodies which lie in its path, and is *refracted*, or bent out of its course, when it passes obliquely from a transparent medium of a certain density, such for instance as air, into another of a different density, such as water.

452. By an effect of **refraction** the stars appear to be higher above the horizon than they really are. In Fig. 52, *A B* represents a pencil of light coming from a star. In its passage through our atmosphere, as each layer gets denser as the surface of the Earth is approached, the ray is gradually refracted until it reaches the surface at *C*, so that from *C* the star seems to lie in the direction *C B*.

453. The refraction of light can be best studied by means of a piece of glass with three rectangular faces, called a prism. If we take such a prism into a dark room, and admit a beam of sunlight through a hole in the shutter, and let it fall obliquely on one of the surfaces of the prism, we shall see at once that the direction of the ray is entirely changed. In other words, the angle at which the light falls on the first surface of the prism is different from the angle at which it leaves it. The difference between the angles, however, is known to depend upon a law which is expressed as follows: The sines of the angles of incidence and refraction have a constant proportion or ratio to one another. This

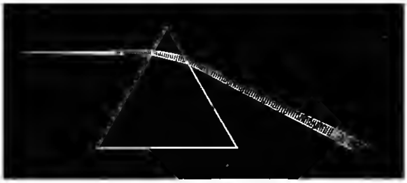


FIG. 53.—A Prism, showing its action on a beam of light.

ratio, called the **index of refraction**, varies in different substances. For instance, it is—

2·9 for chromate of lead.
2·0 for flint glass.
1·5 for crown glass.
1·3 for water.

454. If we receive a beam after its passage through the prism on a piece of smooth white paper, we shall see that this is not all. Not only has the ray been bent out of its original course bodily, so to speak, but instead of a spot of white light the size of the hole which admitted the beam, we have a lengthened figure of various colours, called a **spectrum.**

455. This spectrum will be of the same breadth as the spot which would have been formed by the admitted light, had it not been intercepted by the prism. The lengthened figure shows us, therefore, that the beam of light in its passage through the prism must have been opened out, the various rays of which it is composed having undergone different degrees of deviation, which are exhibited to us by various colours—from a fiery brownish red where the refraction is least, to a faint reddish violet at the point of greatest divergence. This is called **dispersion.**

456. If we pass the light through prisms of different materials, we shall find that although the colours always maintain the same order, they will vary in breadth or in degree. Thus, if we employ a hollow prism, filled with oil of cassia, we shall obtain a spectrum two or three times longer than if we used one made of common glass. This fact is expressed by saying that different media have different dispersive powers—that is, disperse or open out the light to a greater or less extent.

457. Every species of light preserves its own relative place in the general scale of the spectrum, whatever be the media between which the light passes, but only in order, not in degree; that is, not only do the different media vary as to their general dispersive effect on the different kinds of light, but they affect them in different proportions. If, for instance, the green, in one case, holds a certain definite position between the red and the violet, in another case, using a different medium, this position will be altered.

This is what is termed by opticians the irrationality of the dispersions of the different media—or shortly, the **irrationality of the spectrum.**

458. What has been stated will enable us to understand the action of a common magnifying-glass or **lens.** Thus as a prism acts upon a ray of light as shown in the above Fig. 53, two prisms arranged as in Fig. 54 would cause two beams coming from points at *a* and *b* to converge to one point at *c*. A lens, we know, is a round piece of glass, generally thickest in the middle, and we may look upon it as composed of an infinite number of prisms. Fig. 55 shows a section of such a lens, which section, of course, may be taken in any direction through its centre, and a little thought will show that the light which falls on

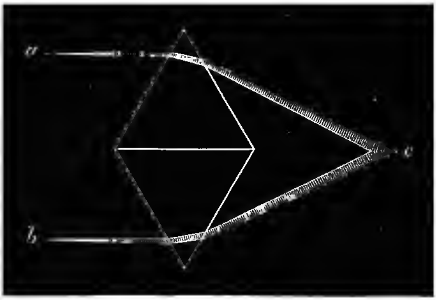


FIG. 54.—Action of two Prisms placed base to base.

its whole surface will be bent to *c*, which point is called the **focus**. If we hold a common burning-glass up to the sun, and let the light fall on a piece of paper, we shall find that when held at a certain distance from the lens a hole will be burned through it ; this distance marks the focal distance of the lens. If we place an arrow, *a b* (Fig. 56), in front of the lens *m n*, we shall have an image of an arrow behind at *a′ b′*, every point of the arrow sending a ray to every point in the surface of the lens ; each point of the arrow, in fact, is the apex of a cone of rays resting on the lens, and a similar cone of rays, after refraction, paints every point of the image. At *a*, for instance, we have the apex of a cone of rays, *m a n*, which rays are refracted so as to form the cone of rays, *m a′ n*, painting the point *a′* in

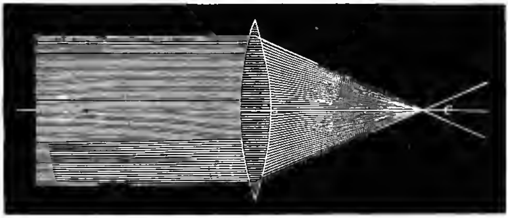


FIG. 55.—Action of a Convex Lens upon a beam of parallel rays.

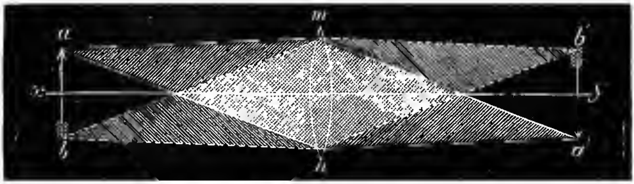


FIG. 56.—Showing how a Convex Lens, *m n*, with an arrow, *a b*, in front of it, throws an inverted image, *a′ b′*, behind it.

the image. So with *b*, and so with every other point. We see that the action of a lens, like the one in the figure, thickest in the middle, called a **convex lens,** is to **invert the image.** The line *x y* is called the **axis** of the lens.

459. Such, then, is a lens, and such a lens we have in our eye; and behind it, where the image is cast, as in the diagram, we have a membrane which receives the image as the photographer's ground glass or prepared paper does; and when the image falls on this membrane, which is called the retina, the optic nerves telegraph as it were an account of the impression to the brain, and *we see.*

LESSON XXXVII.—*Achromatic Lenses. The Telescope. Illuminating Power. Magnifying Power.*

460. Now in order that we see, it is essential that the rays should enter the eye parallel or nearly so, and the nearer anything is to us the larger it looks; but if we attempt to see anything quite close to the eye, we fail, because the rays are no longer parallel—they are divergent. Here the common magnifying-glass comes into use; we place the glass close to the eye, and place the object to be magnified in its focus,—that is, at *c* in Fig. 55: the rays which diverge from the object are rendered parallel by the lens, and we are enabled to see the object, which appears large because it is so close to us.

461. Similarly if we place a shilling twenty feet off, and employ a convex lens, the focal length of which is five feet, half way between our eye and the shilling, we shall have formed in front of the eye an image of the shilling, which being within six inches of the eye, while the real shilling is twenty feet off, will appear forty times larger, although in this case the image is of exactly the same size as the shilling. So much for the action of a single convex lens.

462. Now, if instead of arranging the prisms as shown in Fig. 54, with their bases together, we place them point to point, it is evident that the rays falling upon them will no longer converge, or come together to a point. They will in fact separate, or diverge. We may therefore suppose a lens formed of an infinite number of prisms, joined together in this way; such a lens is called a concave lens, and the shape of any section of such a lens and its action are shown in Fig. 57.

463. In some lenses one surface is flat, the other being either concave or convex; so besides the **bi-convex** and **bi-concave,** already described, we have **plano-convex** and **plano-concave** lenses.

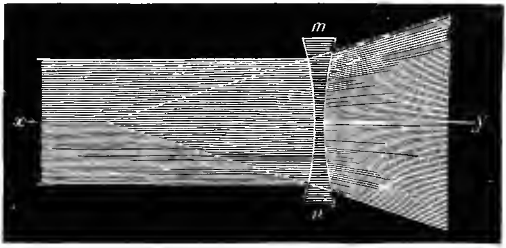


FIG. 57.—Showing the action of a Bi-Concave Lens on a beam of parallel rays.

464. Now we have already seen (Art. 458) that a lens is but a combination of prisms; we may therefore expect that the image thrown by a lens will be coloured. This is the case; and unless we could get rid of such effects, it would be impossible to make a large telescope worth using. It has been found possible however to get rid of them, by using two lenses of different shapes, and made of different kinds of glass, and combining them together, so making a combination called an **achromatic,** or colourless, **lens.**

465. This is rendered possible by the varying dispersive powers (Art. 455) of different bodies. If we take two exactly similar prisms made of the same material, and place one on its side and the other behind it on one of its angles, the beam of light will be unaffected: one prism will exactly undo the work done by the other, and the ray will neither be refracted nor dispersed; but if we take away the second prism and replace it by one made of a substance having a higher dispersive power, we shall of course be able to undo the dispersive work done by the first prism with a smaller thickness of the second.

But this smaller thickness will not undo all the refractive work of the first prism.

Therefore the beam will leave the second prism colourless, but refracted; and this is exactly what is wanted; the **chromatic aberration** is corrected, but the compound prism can still refract, or bend the light out of its course.

466. An achromatic lens is made in the same way as an achromatic prism. The dispersive powers of flint and crown glass are as ·052 to ·033. The front or convex lens is made of crown glass. The **chromatic aberration** of this is corrected by another bi-concave lens placed behind it of flint glass. The second lens is not so concave as the first is convex, so the action of the first lens is predominant as far as refraction goes; but as the second lens acts more energetically as regards dispersion, although it cannot make the ray parallel to its original direction, it can make it colourless, or nearly so. If such an achromatic lens be truly made, and its curves properly regulated, it is said to have its spherical aberration corrected as well as its chromatic one, and the image of a star will form a nearly colourless point at its focus.

467. A little examination into the construction of the telescope will show us that the principle of its construction is identical with the construction of the eye, but the process carried on by the eye is extended: that is to say, in the eye *nearly parallel rays fall on a lens, and this lens throws an image;* in the telescope *nearly parallel rays fall on a lens, this lens throws an image,* and then *another lens enables the eye to form an image of the image* by rendering the rays again parallel. These parallel rays then enter the eye just as the rays do in ordinary vision.

A telescope, then, is a combination of lenses.

468. In the figure, for instance, let A represent the first or front lens, called the *object-glass,* because it is the lens nearest to the object viewed; and let C represent the other, called the *eye-lens,* because it is nearest the eye; and let B represent the image of a distant arrow, the beam of rays from which is seen falling on the object-glass from the left. This beam is refracted, and we get an inverted image at the focus of the object-glass, which is also the focus of the eye-lens. Now, the rays leave the eye-piece adapted for vision as they fall on the object-glass, *so the eye can use them* as it could have used them if no telescope had been there.

469. What then has the telescope done? What is its power? This question we will soon

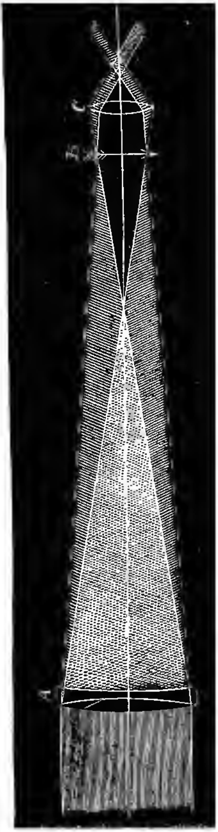


FIG. 58.—Construction of the Astronomical Telescope.

answer; and, first, as to what is called its **illuminating power.** The **aperture** of the object-glass, that is to say, its diameter, being larger than that of the pupil of our eye, its surface can collect more rays than our pupil; if this surface be a thousand times greater than that of our pupil, for instance, *it collects a thousand times more light*, and consequently the image of a star formed at its focus has a thousand times more light than the image thrown by the lens of our eye on our retina.

But this is not quite true, because light is lost by reflexion from the object-glass and by its passage through it. If, then, we have two object-glasses of the same size, one highly polished and the other less so, the illuminating power of the former will be the greater.

470. The **magnifying power** depends upon two things. First, it depends upon the focal length of the object-glass; because if we suppose the focus to lie in the circumference of a circle having its centre in the centre of the lens, the image will always bear the same proportion to the circle. Suppose it covers 1°; it is evident that it will be larger in a circle of 12 feet radius than in one of 12 inches. That is, it will be larger in the case of a lens with 12 feet focal length than in one of 12 inches focal length.

471. Having this image at the focus, the magnifying power of the *eye-piece* comes into play. This varies with the eye-piece employed, the ratio of the focal length of the object-glass to that of the eye-piece giving its exact amount; that is to say, if the focus of the object-glass is 100 inches, and that of the eye-piece one inch, the telescope will magnify 100 times. Bearing in mind that what an astronomer wants is a good clear image of the object observed, we shall at once recognise that useful magnifying power depends upon the perfection of the image thrown by the object-glass and upon the illuminating power of which we have already spoken. If the object-glass does not perform its part properly, a slight magnification blurs the image, and the telescope is useless.

Hence many large telescopes are inferior to much smaller ones in the matter of magnifying power, although their illuminating power is so much greater.

472. The eye-pieces used with the astronomical telescope vary in form. The telescope made by Galileo, similar in construction to the modern opera-glass, was furnished with a bi-concave eye-piece. As the action of the eye-piece is to render the rays parallel, this eye-piece is used between the object-glass and the focus, at a point where its divergent action (Art. 462) corrects the convergent action of the object-glass.

A convex eye-piece for the same reason is placed outside the focus, as shown in Fig. 58.

Such eye-pieces however colour the light coming from the image in the same way as the object-glass would colour the light going to form the image, if its chromatic aberration were not corrected.

473. It was discovered by Huygens however that this defect might be obviated in the case of the eye-piece by employing two plano-convex lenses, the flat sides next the eye, a larger one nearest the image, called the field-lens, and a smaller one near the eye, called the eye-lens. This construction is generally used, except for **micrometers** (Art. 519), a name given to an eye-piece with spider-webs in the focus of the eye-piece for measuring the sizes of the different objects. In this case the flat sides are turned away from the eye.

474. The **telescope-tube** keeps the object-glass and the eye-piece in their proper positions, and the eye-piece is furnished with a **draw-tube**, which allows its distance from the object-glass to be varied.

LESSON XXXVIII.—*The Telescope* (continued). *Powers of Telescopes of different Apertures. Large Telescopes. Methods of Mounting the Equatorial Telescope.*

475. Very many of the phenomena of the heavens may be seen with a small telescope. In our climate a telescope with an object-glass of six inches aperture is probably the size which will be found the most constantly useful; a larger aperture being frequently not only useless, but hurtful. Still, 4¼ or 3¾ inches are useful apertures, and if furnished with object-glasses made of course by the *best* makers, views of the sun, moon, planets, and double stars may be obtained sufficiently striking to set many seriously to work as amateur observers.

Thus, in the matter of double stars, a telescope of two inches aperture, with powers varying from 60 to 100, will show the following stars double:—

Polaris.
α Piscium.
μ Draconis.
γ Arietis.
ζ Herculis.
ζ Ursæ Majoris.
α Geminorum.
γ Leonis.
ξ Cassiopeiæ.

A 4-inch aperture, powers 80–120, reveals the duplicity of—

β Orionis.
ε Hydræ.
ε Boötis.
α Lyræ.
ξ Ursæ Majoris.
γ Ceti.
δ Geminorum.
σ Cassiopeiæ.
ε Draconis.

And a 6-inch, powers 240–300—

ε Arietis.
δ Cygni.
32 Orionis.
λ Ophiuchi.
20 Draconis.
κ Geminorum.
ε Equulei.
ζ Herculis.

476. Observations should always be commenced with the lowest power, or eye-piece, gradually increasing it until the limit of the aperture, or of the atmospheric condition at the time, is reached : the former being taken as equal to the number of hundredths of inches which the diameter of the object-glass contains. Thus, a 3¾-inch object-glass, if really good, should bear a power of 375 on double stars where light is no object ; the planets, the moon, &c., will be best observed with a much lower power.

477. In the case of stars, owing to their immense distance, no increase in their size follows the application of higher magnifiers. With planets this is different, each increase of power increases the size of the image, and therefore decreases its brilliancy, as the light is spread over a larger area. Hence the magnifying power of a good telescope is always much higher for stars than for planets, although at the best it is always limited by the state of the air at the time of observation.

478. It is always more or less dangerous to look at the Sun directly with a telescope of any aperture above two inches, as the dark glasses, without which the observer would be at once blinded, are apt to melt and crack.

A diagonal reflector, however, which reflects an extremely small percentage of light to the eye, and by reason of its prismatic form refracts the rest away from the telescope, affords a very handy method of solar observation.

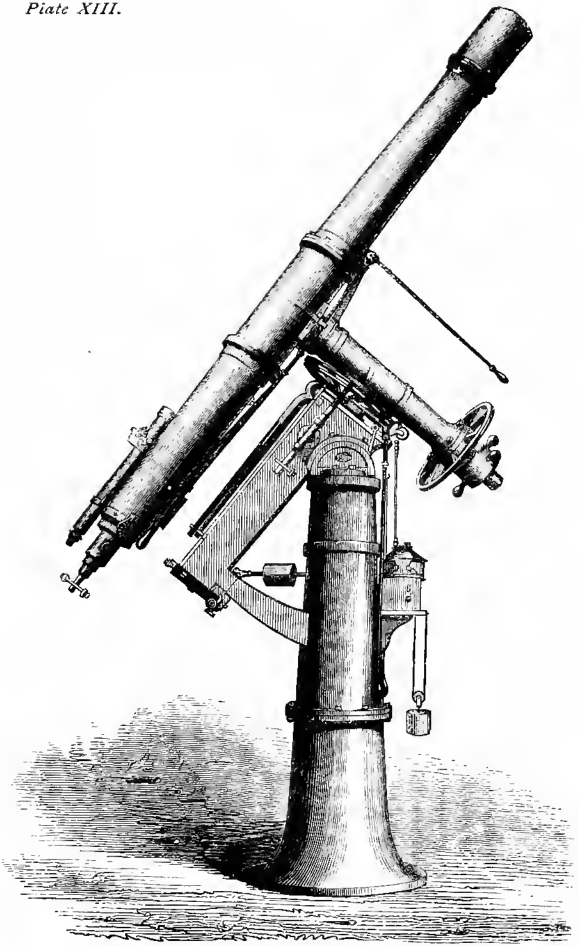
Care should be taken that the object-glass is properly adjusted. This may be done by observing the image of a large star out of focus. If the light be not equally distributed over the image, or the circles of light which are always seen in a good telescope are not perfectly circular, the telescope should be sent back to the optician for adjustment.

479. The testing of a good glass refers to two different qualities which it should possess. Its quality, as to material and the fineness of its polish, should be such that the maximum of light shall be transmitted. Its quality as to the curves should be such that the rays passing through every part of its area shall converge absolutely to the same point, with a chromatic aberration sufficient to surround objects with a faint dark blue light.

480. To give an idea of the great accuracy with which a fine object-glass refracts the light transmitted, we will take for example an object-glass of 8 inches aperture and 10 feet focal length, which, if a fine one, will separate the components of γ^2 Andromedæ, whose angular distance is about half a second—that is, it will depict at its focus two minute discs of light fairly separated, the distance of whose centres, as above stated, is half a second. To come at the value of this half-second, as measured on a scale of inches and parts of an inch, we must consider the centre of the object-glass to be the centre of a circle whose radius is the focal length of the object-glass. The focal value of a degree of such a circle is 2·0944, or nearly $2\frac{1}{10}$ inches; of a minute, ·0349 of an inch; of a second, ·0005818, or $\frac{3}{5000}$ of an inch nearly; of half a second, ·0002909 inch, which is little more than the fourth part of the one-thousandth of an inch. Light from a fixed star passing through four refracting surfaces, and half an inch or more in thickness of glass, and filling 50 square inches of surface, and travelling 120 inches down the tube, is so accurately concentrated at the focal point as all to pass through the smallest hole that could be made with the most delicate needle-point through a piece of fine paper. This requires a degree of accuracy in the figuring and polishing of the material of the lenses almost inconceivable.

481. We have so far confined our attention to the principles of the ordinary astronomical telescope, and we have dealt with it in its simplest form. There are other kinds; the construction of some of which depends upon *reflection;* that is to say, the light is reflected by a concave mirror instead of being refracted by a lens; but we need not dwell upon them. Let us next inquire what the very largest telescope really can do. The largest **refractor**—as the refracting telescopes are called—in the world has recently been completed by Messrs. Alvan Clark

Plate XIII.



Eight-inch Equatorial Telescope, with the Cooke mounting.

and Sons, American opticians of great eminence, for the Pulkowa Observatory, near St. Petersburg. The object-glass is 30 inches in diameter. Now, the pupil of our eye is one-fifth of an inch in diameter : this object-glass, therefore, will grasp 22,500 times more light than the eye can : if used when the air is pure, it should easily bear a power of 3,000 on the Moon ; in other words, the Moon will appear as it would were it 3,000 times nearer to us, or at a distance of 78 miles, instead of, roughly, 234,000 ; measuring from the surfaces of the Earth and Moon, and not from their centres.

The largest **reflector** in the world has been constructed by the late Earl of Rosse ; its mirror, or *speculum*, is six feet in diameter, and its illuminating power is such that it enables us to see, "as clearly as the heavens shine to us on a cloudless evening, the details of a starry universe, stretching into space five hundred times further than those depths at which we are accustomed to gaze almost in oppressive silence."*

482. An astronomer wants telescopes for two kinds of work : he wants to watch the heavenly bodies, and study their physical constitution ; and he wants to note their actual places and relative positions ; so that he *mounts* or arranges his telescope in several different ways.

483. For the first requirement it is only essential that the instrument should be so arranged that it can command every portion of the sky. This may be accomplished in various ways : the best method of accomplishing it is shown in Plate XIII., which represents an 8-inch telescope, equatorially mounted—or, shortly, an **equatorial**—that is, an instrument so mounted that a heavenly body may be followed from rising to setting by one continuous motion of the telescope, which motion may be communicated by clockwork.

484. In this arrangement a strong iron pillar supports a head-piece, in which is fixed the **polar axis** of the instru-

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* Nichol.

ment parallel to the axis of the Earth, which polar axis is made to turn round once in twenty-four hours by the clock shown to the right of the pillar.

485. It is obvious that a telescope attached to such an axis will always move in a circle of declination, and that a clock, carrying the telescope in one direction as fast as the Earth is carrying the telescope from a heavenly body in the opposite one, will keep the telescope fixed on the object. It is inconvenient to attach the telescope directly to the polar axis, as the range is then limited: it is fixed, therefore, to a **declination axis,** placed above the polar axis, and at right angles to it, as shown in the plate.

486. For the other kinds of work, telescopes, generally of small power except in important observatories, are mounted as **altazimuths, transit-instruments, transit-circles,** and **zenith-sectors.** These descriptions of mounting, and their uses, will be described in Chap. VII.

LESSON XXXIX.—*The Solar Spectrum. The Spectroscope. Kirchhoff's Discovery. Physical Constitution of the Sun.*

487. A careful examination of the solar spectrum has told us the secret of the enormous importance of solar radiation (Art. 124). Not only may we liken the gloriously coloured bands which we call the spectrum to the key-board of an organ—each ray a note, each variation in colour a variation in pitch—but as there are sounds in nature which we cannot hear, so there are rays in the sunbeam which we cannot see.

488. What we do see is a band of colour stretching from red, through yellow, green, blue, violet, indigo, to lavender, but at either end the spectrum is continued.

There are dark rays before we get to the red, and other dark rays after we leave the lavender—the former heat rays, the latter chemical rays; and this accounts for the threefold action of the sunbeam: heating power, lighting power, and chemical power.

489. When a cool body, such as a poker, is heated in the fire, the rays it first emits are entirely invisible, or dark: if we looked at it through a prism, we should see nothing, although we can easily perceive by the hand that it is radiating heat. As it is more highly heated, the radiation from the poker gradually increases, until it becomes of a dull red colour, the first sign of incandescence; in addition to the dark rays it had previously emitted, it now sends forth waves of red light, which a prism will show at the red end of the spectrum: if we still increase the heat and continue to look through the prism, we find, added to the red, orange, then yellow, then green, then blue, indigo, and violet, and when the poker is white-hot all the colours of the spectrum are present. If, after this point has been reached, the substance allows of still increased heating, it will give out with increasing intensity the rays beyond the violet, until the glowing body can rapidly act in breaking up chemical combinations, a process which requires rays of the highest refrangibility—the so-called chemical, actinic, or ultra-violet rays.

490. We owe the discovery of the prismatic spectrum to Sir Isaac Newton, but the colouring is but one part of it. Dr. Wollaston in the year 1802 discovered that there were dark lines crossing the spectrum of sunlight in different places. These have been called **Fraunhofer's lines,** as an eminent German optician of that name afterwards mapped the plainest of them with great care: he also discovered that there were similar lines in the spectra of the stars. The explanation of these dark lines we owe to Stokes, and more particularly to Kirchhoff. The law which explains them was, however, first proved by Balfour Stewart.

491. We shall observe the lines best if we make our sunbeam pass through an instrument called a **spectroscope,** in which several prisms are mounted in a most careful manner. We find the spectrum crossed at right angles to its length by numerous dark lines—gaps—which we may compare to silent notes on an organ. Now if we light a match and observe its spectrum, we find that it is *continuous*—that is, from red through the whole gamut of colour to the visible limit of the violet: there are no gaps, no silent notes, no dark lines, breaking up the band.

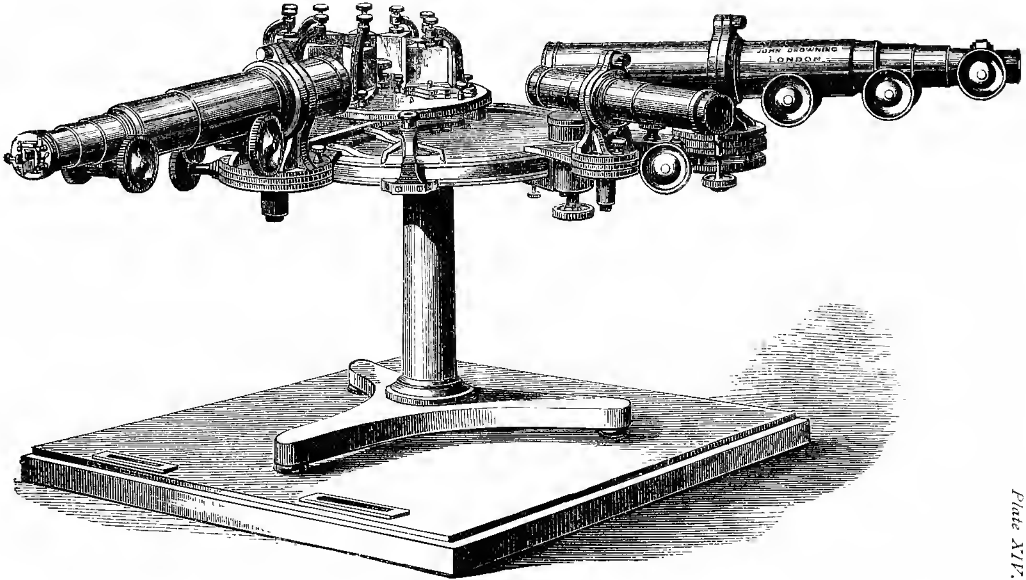
Another experiment. Let us burn something which does not burn white; some of the metals will answer our purpose. We see at once by the brilliant colours that fall upon our eye from the vivid flame that we have here something different. The prism tells us that the spectrum, instead of being continuous as before, now consists of two or three lines of light in different parts of the spectrum, as if, on an organ, instead of pressing down all the keys, we but sounded one or two notes in the bass, tenor, or treble.

Again, let us try still another experiment. Let us so arrange our prism, that while a sunbeam is decomposed by its upper portion, a beam proceeding from such a light-source as sodium, iron, nickel, copper, or zinc, may be decomposed by the lower one. We shall find in each case, that when the *bright lines* of which the spectrum of the metal consists flash before our eyes, they will occupy absolutely the same positions in the lower spectrum as some of the *dark bands*, the silent notes, do in the upper solar one.

492. Here, then, is the germ of Kirchhoff's discovery, on which his hypothesis of the physical constitution of the Sun is based; and here is the secret of the recent additions to our knowledge of the stars, for stars are suns.

Vapours of metals, and gases, absorb those rays which the same vapours of metals and gases themselves emit.

Plate XIV.



THE KEW SPECTROSCOPE.

493. By experimenting in this manner, the following generalisations have been established :—

I.—When solid or liquid or densely gaseous bodies are incandescent, they give out continuous spectra.

II.—When a solid or liquid body reduced to a state of gas, or any gas itself, is rendered incandescent, the spectrum consists of bright lines only, and these lines are different for different substances.

III.—When light from a solid or liquid passes through a gas, the gas absorbs those particular rays of light of which its own spectrum consists.

This third law is the one established by Kirchhoff in 1859.

494. We are now in a position to inquire what has become of those rays which the dark lines in the solar spectrum tell us are wanting—those rays which were arrested in their path, and prevented from bearing their message to us. Before they left the regions of our incandescent Sun, *they were arrested by those particular metallic vapours and gases in his atmosphere, with which they beat in unison;* and the assertion, that this and that metal exists in a state of vapour in the Sun's atmosphere, is based upon their non-arrival; for so various and constant are the positions of the bright bands in the spectra we can observe here, and so entirely do they correspond with certain dark bands of the spectrum of the Sun, that it has been affirmed, that the chances in favour of the hypothesis being right are something like 300,000,000 to 1.

495. So much for the Sun. Fraunhofer was the first to apply this method to the stars; and we have within the last score of years reaped a rich harvest of facts, in the actual mapping down of the spectra of several of the brightest stars, and the detailed examination of a very large number. In fact, a spectroscopic star catalogue to include all northern stars down to 7½ magnitude, is now in preparation, of which the first part, giving the spectra of 4,051 stars was published in 1883. The plan of structure in all of them can be referred back to meteor-swarms. We find vapours sifting out the rays which come from the interior incandescent masses, which may consist of red- or white-hot meteorites, or of dense vapours produced by the volatilization of meteorites, according to the stage of condensation. (See Art. 65.)

495a. Fraunhofer examined light coming from all parts of the Sun. In 1866 Lockyer proposed a detailed examination of its surface and of the surrounding regions. In 1868 Janssen and Lockyer succeeded in rendering the red prominences visible by these means wherever the Sun shines, thereby opening a field of research which has proved of the highest importance.

LESSON XL.—*Importance of this method of Research. Physical Constitution of the Stars, Nebulæ, Moon, and Planets. Construction of the Spectroscope. Celestial Photography.*

496. A few words will show the high significance of these facts from an astronomical point of view. They tell us, that as the spectrum of the Sun's light contains dark lines, the light is due to solid or liquid particles in a state of great heat, or as it is called, *incandescence*, and that the light given out by these particles is sifted, so to speak, by its atmosphere, which consists of the vapours of the substances incandescent in the photosphere. Further, as the lines in the reversed spectra occupy the same positions as the bright lines given out by the glowing particles would do, and as we can by experimenting on the different metals *match* many of the lines exactly, we can thus see which kind of light is thus abstracted, and what substance gives out this light: having done this, we know what substances (Art. 123) are present in the Sun.

497. Again, we learn by the same method that many of the stars are, more or less, like the Sun, for when they are analyzed in the same manner we find nearly the same appearances; and here again in the same manner we can tell what substances are present in the stars Art. 67).

498. The spectra of the nebulæ, instead of resembling that of the Sun and stars,—that is, showing a band of colour with black lines across it,—consist of a few bright lines merely.

499. On August 29, 1864, Dr. Huggins directed his telescope, armed with the spectrum apparatus, to the planetary nebula in Draco. At first he suspected that some derangement of the instrument had taken place, for no spectrum was seen, but only a short line of light, perpendicular to the direction of dispersion. He found that the light of this Nebula, unlike any other extra-terrestrial light which had yet been subjected to prismatic analysis, was not composed of light of different refrangibilities, as in the case of the Sun and stars, and it therefore could not form a spectrum. A great part of the light from this Nebula is monochromatic, and was seen in the spectroscope as a bright line. A more careful examination showed another line, narrower and much fainter, a little more refrangible than the brightest line, and separated from it by a dark interval. Beyond this again, at about three times the distance of the second line, a third exceedingly faint line was seen.

500. The strongest line was at first considered as due to nitrogen, but subsequent investigation has shown it to be due to magnesium vapour at a low temperature. The faintest of the lines of the Nebula coincides with the line of hydrogen, corresponding to the line F in the solar spectrum. The origin of the other bright line has not yet been determined, but it is seen in the spectra of some meteorites.

501. Here, then, we have three little lines for ever disposing of the notion that nebulæ may be clusters of stars. How trumpet-tongued does such a fact speak of the resources of modern science! As we have already learned (Art. 96), nebulæ are merely clouds of meteorites which are rendered luminous by the heat due to collisions. The spectra of some of them are almost perfectly continuous, and this is because the meteorites composing them are only hot enough to be incandescent, and do not give off sufficient vapour to produce a spectrum of lines. When the temperature is increased by the condensation due to gravity, hydrogen and magnesium vapour fill the interspaces and give us a spectrum of bright lines. There are no absorption lines in the spectra of nebulæ, because they are masked by the radiation from the greater volume of interspace.

It is a comparatively simple matter to reproduce the spectra of nebulæ in the laboratory. A few pieces of a meteorite containing a fair percentage of magnesium, or a few pieces of olivine, are placed in a glass tube fitted with platinum points, so that an electric discharge can be made to pass along them. The tube having been exhausted by a Sprengel pump, and the meteorites heated, the spectrum of the glow is seen to contain the hydrogen lines which are seen in nebulæ, and the chief nebula line, which has already been stated to be due to magnesium; in some cases the middle line, between the hydrogen line F, and the magnesium line, is also seen, but this makes its appearance much more rarely than the principal line.

The chief nebula line may also be observed by burning magnesium ribbon in front of the slit of a spectroscope. The brightest part of the spectrum seen is a fluting, the brightest edge of which coincides with the nebula line. In most of the nebulæ, only a line is seen to correspond to this fluting, but on one occasion, at Greenwich, the spectrum of the nebula in Orion was observed to give a fluting in place of the ordinary line. We know that under certain conditions only the remnants of flutings are seen, so that they put on the appearance of lines.

502. In our own system, that moonshine is but sunshine second-hand, and that the Moon has no sensible atmosphere, is proved by the fact, that in the spectroscope there is no difference, except in brilliancy, between the two; and that the planets have atmospheres is shown in like manner, since in their light we find the same lines as in the solar spectrum, with the addition of other lines due to the absorption of their atmospheres.

503. In the frontispiece are given a representation of the solar spectrum, two maps of stellar spectra, and the spectrum of the nebula 37, H iv. The double line of sodium, showing the absorption as well as the radiation, is also given to explain the coincidences referred to in the next article, on which our knowledge of the substances present in the atmospheres of the Sun and stars depends. The light given out by the vapour of sodium consists mainly of the double line shown in the plate. A black double line, in exactly the same position in the spectrum, is seen in the spectra of the Sun, Vega, and α Orionis. Similarly, the spectrum of the vapour of iron contains 400 or 500 bright lines matched by co-incident lines in the spectrum of the Sun. The feebleness of the light of the stars does not permit all these lines to be observed if they are present. It is seen in the plate that one of the bright lines in the spectrum of the nebula is coincident with one of the lines of hydrogen, while another (the least refrangible) agrees in position with the edge of the fluting in the spectrum of magnesium. The great Orion nebula and a few others show, in addition, a fourth bright line, found to be identical with the dark-blue ray of hydrogen. Photographed spectra of some of the nebulæ show a low-temperature magnesium line in the ultra-violet.

504. The spectrum of α *Orionis*, which is a partially condensed meteor-swarm, consists of dark flutings and lines. The flutings are due to the vapours of magnesium, manganese, iron, lead, and barium, and some of the lines are due to sodium, magnesium, calcium, iron, and bismuth. The absorption is brought about by the metallic vapours surrounding the incandescent meteorites. This is one of the best examples of the bodies belonging to Group II.

504a. Stellar spectra were divided by Secchi into four classes, but having regard to the meteoric origin of the various orders of celestial bodies, it will be well to adopt the following classification.

Group I. Radiation lines and flutings are predominant. This group includes nebulæ and the so-called "stars" with bright-line spectra. β Lyræ and γ Cassiopeiæ belong to this group. In the last species of the group, absorption begins. The radiation is chiefly that of hydrogen and magnesium.

Group II. Mixed radiation and absorption predominant. The radiation is chiefly that of carbon vapour, which fills the interspaces, and the absorption is due to layers of vapours of magnesium, manganese, iron, lead, barium, &c., which surround the incandescent meteorites.

The stars of this class are reddish and their spectra consist of dark flutings fading gradually towards the red, superposed upon the bright flutings of carbon, which fade towards the blue. Many variable stars belong to this group, notably "Mira" in the Whale, and the "new star" recently observed in Orion.

There is a considerable variation in the spectra of this group, according to the proportion of meteorites to interspace and carbon radiation to metallic absorption. In fact, it is convenient to subdivide this group into fifteen species, according to the number and intensities of the flutings present.

Group III. Line absorption predominant, the temperature also increasing. The various species will be marked by increasing simplicity of spectrum. The meteorites have all been volatilized.

Group IV. Simplest line absorption predominant. The spectra are characterized by the strong absorption of hydrogen, while the metallic lines are thin and faint.

The stars of this group are the hottest. Vega (α Lyræ) belongs to this group. (See Frontispiece.)

Group V. Line absorption predominant with decreasing temperature. The various species will be marked by decreasing complexity of spectrum.

The mass of meteoric vapour is now cooling, and the phenomena will be very nearly the same as those of Group III.

The Sun, Capella, and Pollux belong to this group. The lines are narrow and very numerous, the substances which they indicate being those known to exist in meteorites. The spectrum of the Sun can be almost perfectly reproduced by volatilizing a mixture of meteorites in the electric arc.

Group VI. Carbon absorption predominant. The central portion of the mass of meteoric vapour has now become very densely gaseous or liquid, or solid, and is surrounded by an atmosphere consisting largely of carbon. None of the stars of this group are brighter than the fifth magnitude, and are usually of a deep red tint. This classification is the one which the most recent researches in celestial physics has led to, and it will be seen that the basis of it is the differences brought about by differences of temperature. The substances present in all the bodies are the same, or, at least, there is no reason why there should be any differences in composition, and there is no necessity to assume any such differences in order to explain the various phenomena presented to us. We begin with sparse swarms of meteorites at low temperatures, pass through the various phenomena of increasing temperatures to stars like Vega, then through those of decreasing temperatures, finally ending with cold condensed and consolidated masses. Further, it is possible that bodies of the latter kind may collide as individual meteorites do, and by such collisions become again resolved into swarms of meteorites, and thus complete the celestial cycle.

504b. The spectroscope not only gives us information as to the chemical constitution of the heavenly bodies, but tells us also something of their movements. And, what is very fortunate, the kind of movements which can be determined spectroscopically are just those of which the eye takes no direct account, because they result in no visible displacement. They are motions in the line of sight, that is, straight towards, or straight from the eye. Now the effect produced by very rapid motion of this kind upon light entering the eye from the moving object, is quite analogous to the rise and fall in the pitch of a steam-whistle when an express train dashes through a station. While the train is coming up, the shrillness of the whistle is increased because the vibrations of sound are crowded into the ear by the swiftness of its approach; and the sound sinks as it retreats just for the opposite reason. In the same way, the vibrations of light are pushed together, or pulled asunder by the enormously more rapid movements of the stars. The whole gamut, so to speak, of the spectrum, is shifted a little towards the blue or red according as the star, or other heavenly body, is advancing or retreating; and the amount of this shifting can be measured by the comparison of the well-known bright or dark lines thus altered in position with the same lines as they ordinarily appear. It is in this way that the tremendous cyclone movements in the sun and atmosphere mentioned in Art. 250, have been ascertained; and even the rate of the sun's rotation can be determined by the slightly varied positions of the Fraunhofer lines in light taken from the right and left limbs, the effect of rotation being to bring the left limb continually forward while the right limb retreats from the eye with equal speed. Dr. Huggins in 1868 first succeeded in measuring the velocities of stars in the line of sight, and the work is now regularly carried on at Greenwich. Subjoined are some of the results:—

STARS APPROACHING THE EARTH.

Name of Star.	Miles per second.
Arcturus	42
Alpha Lyræ (Vega)	36
Alpha Cygni (Deneb)	37
Beta Geminorum (Pollux)	35
Alpha Ursæ Majoris (Dubhe)	46
Alpha Andromedæ	32
Delta Andromedæ	50
Beta Ceti	54
Alpha Pegasi (Markab)	32
Alpha Arietis	10

STARS RECEDING FROM THE EARTH.

Name of Star.	Miles per second.
Alpha Tauri (Aldebaran)	45
Alpha Trianguli	58
Beta Andromedæ	45
Capella	29
Alpha Orionis (Betelgeux)	16
Beta Orionis (Rigel)	12

Sirius must at present be included amongst the stars *approaching* the earth, its rate of approach, as determined in 1886, being about thirty miles a second. But ten years previously, it was *receding* with about equal velocity, after which it gradually slackened, and in 1883, reversed its motion. Similar changes appear to have affected the movements of Procyon during the same interval.

505. The star spectroscope, Fig. 59, with which Dr. Huggins's earlier results were obtained, is attached to the eye end of an equatorial. As the spectrum of the *point* which the star forms at the focus is a *line*, the first thing done in the arrangement adopted is to turn this line into a band, in order that the lines or breaks in the light may be rendered visible.

The other parts of the arrangement are as follows :— A plano-convex cylindrical lens, of about fourteen inches focal length, is placed with its axial direction at right angles to the direction of the slit, and at such a distance

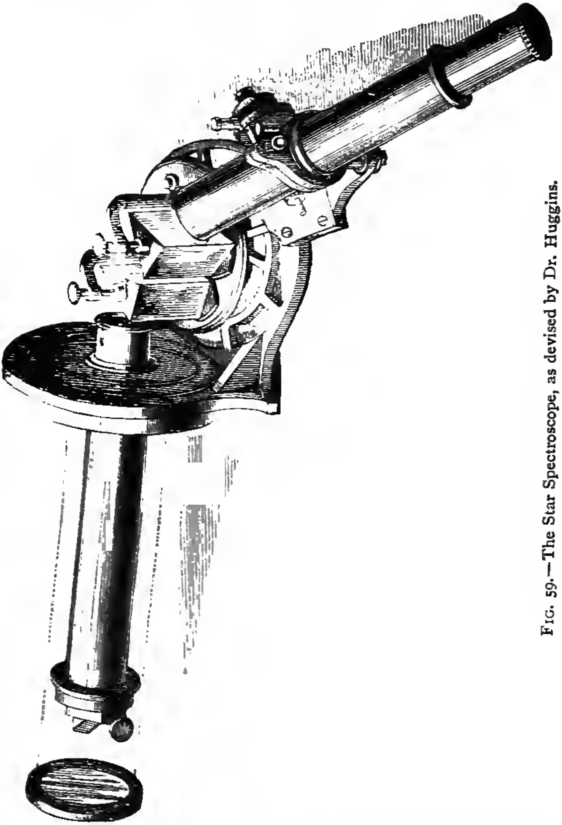


FIG. 59.—The Star Spectroscope, as devised by Dr. Huggins.

before the slit, within the converging pencils from the object-glass, as to give exactly the necessary breadth to the spectrum. Behind the slit, at a distance equal to its focal length, is an achromatic lens of 4½ inches focal length. The dispersing portion of the apparatus consists of two prisms of dense flint glass, each having a refracting angle of 60°. The spectrum is viewed through a small achromatic telescope, provided with proper adjustments, and carried about a centre suitably adjusted to the position of the prisms by a fine micrometer screw. This measures to about the $\frac{1}{2000}$th part of the interval between A and H of the solar spectrum. A small mirror attached to the instrument receives the light, which is to be compared directly with the star spectrum, and reflects it upon a small prism placed in front of one half of the slit. This light was usually obtained from the induction-spark taken between electrodes of different metals, raised to incandescence by the passage of an induced electric current.

506. The spectroscope represented in Plate XIII. is a very powerful one, made by Mr. Browning for Mr. Gassiot, and was for some time employed at the Kew Observatory for mapping the solar spectrum. The light enters at a narrow slit in the left-hand collimator, which is furnished with an object-glass at the end next the prism, to render the rays parallel before they enter the prisms. In the passage through the prisms the cylindrical beam of light is made to describe a circular path, widening out as it goes, and in consequence enters the telescope on the right of the drawing.

It is often convenient to employ what is termed a **direct-vision spectroscope**—that is, one in which the light

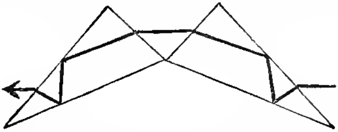


FIG. 60.—Path of the ray in the Herschel-Browning spectroscope.

enters and leaves the prisms in the same straight line. How this is managed in the Herschel-Browning spectroscope, one of the best of its kind, may be gathered from Fig. 60.

507. In both telescopic and spectroscopic observations the visible rays of light are used. The presence of the chemical rays, however, enables photographs of the heavenly bodies to be taken, and **celestial photography,** in the hands of Mr. De la Rue and Mr. Rutherfurd, made its first rapid advance towards its present high state of perfection. The method adopted is to place a sensitive plate in the focus of a reflector or refractor properly corrected for the actinic rays, and then to enlarge this picture to the size required. Mr. De la Rue's pictures of the Moon, some 1¼ inches in diameter, are of such perfection that they bear subsequent enlargement to 3 feet. Prints of the Sun are now regularly taken at Greenwich and South Kensington; and where the record is interrupted by clouds, it is filled in by pictures obtained on the same plan in the Mauritius and in India. The art promises to be one of the great engines of astronomical research in the future. Already a nebula has been discovered in the Pleiades by the camera, which had never previously been seen with the telescope, and stars down to the sixteenth magnitude can be photographed with such distinctness that the laborious process of charting small stars may be said to be superseded by the comparatively expeditious method of printing them, or rather, letting them print themselves. The absolute truthfulness of celestial photographs gives them a special value as records. Mr. Common's splendid picture of the Orion nebula may reveal to future astronomers changes of wonderful interest in that strange mass of glowing vapours. Tebbutt's comet was the first body of the kind successfully photographed, previous attempts having failed through the extreme chemical feebleness of cometary light. Now, however, not only comets themselves, but their spectra, as well as the spectra of stars, nebulæ, sunspots, and even of the solar chromosphere across the blaze of daylight, stamp their impressions with the utmost delicacy on the sensitive plate.

CHAPTER VII.

DETERMINATION OF THE APPARENT PLACES OF THE HEAVENLY BODIES.

LESSON XLI.—*Geometrical Principles. Circle. Angles. Plane and Spherical Trigonometry. Sextant. Micrometer. The Altazimuth and its Adjustments.*

508. That portion of our subject which deals with apparent positions is based upon certain geometrical principles, among which the properties of the circle are the most important.

509. A circle is a figure bounded by a curved line, all the points in which are at the same distance from a point within the circle called the **centre.** The curved line itself is called the **circumference;** a line from any part of the circumference to the centre is called a **radius;** and if we prolong this line to the opposite point of the circumference we get a **diameter.** Consequently, a diameter is equal to two radii.

510. The circumference of every circle, large or small, is divided into 360 parts, called degrees, which, as we have before stated (Art. 159), are divided into minutes and seconds, marked (′) and (″), to distinguish them from minutes and seconds of time, marked (^{m}) and (^{s}).

511. That part of the circumference intercepted by any lines drawn from it to the centre is called an **arc**, and the two lines which join at the centre inclose what is called an **angle**, the angle in each case being measured by the arc of the circumference of the circle intercepted.

512. The arc, and therefore the measured angle, will contain the same number of degrees, however large or small the circle may be—or, in other words, whatever be the diameter. Each degree will, of course, be larger in a large circle than in a small one, but the number of degrees in the whole circumference will always remain the same; and therefore the angle at the centre will subtend the same number of degrees, whatever be the radius of the circle.

513. An angle of 90° is called a **right angle,** and there are therefore four such angles at the centre of a circle. The two lines which form a right angle are said to be at right angles to each other. If we print a T, for instance, like this ⊥, we get two right angles, and the upright stroke is called a **perpendicular.**

514. When the opening of an angle is expressed by the number of degrees of the arc of a circle it contains, it is called the **angular measure** of the angle. Another property of the circle is, that whatever be its size, the diameter, and therefore the radius, always bears the same proportion to the circumference. The circumference is a little more than three times the diameter—more exactly expressed in decimals, it is 3·14159 times the diameter; in other words—

$$\text{diam.} \times 3{\cdot}14159 = \text{circumference};$$

and therefore

$$\text{circumference} \div 3{\cdot}14159 = \text{diameter}.$$

For the sake of convenience, this number 3·14159 is expressed by the Greek letter π. When either the radius, diameter, or circumference is known, we can easily find the others.

515. We next come to the properties of triangles. A triangle is a figure which contains three angles, and it is therefore bounded by three sides. If all three sides are on the same plane, the triangle is called a **plane triangle**; but if they lie on the surface of a sphere, it is called a **spherical triangle,** and the sides, as well as the angles, may be expressed in angular measure; as the angular length of each side is the angle formed by its two ends at the centre of the sphere. For instance, if we on a terrestrial globe draw lines connecting London, Dublin, and Edinburgh, we shall have a spherical triangle, as the Earth is a sphere; and we can express the opening of each angle and the length of each side in degrees. We may treat three stars on the celestial sphere in the same manner. Each angle of a plane triangle is determined as we have already seen; and it is one of the properties of a triangle that the three interior angles taken together are equal to two right angles—that is, 180°. It is clear, therefore, that if we know two of the angles, the third is found by subtracting their sum from 180°.

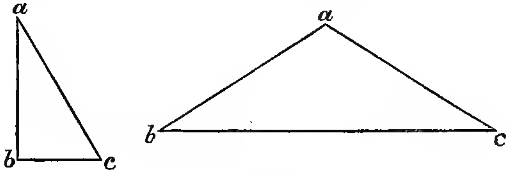


FIG. 61.—Two Triangles.

Here are two triangles, and they look very unlike; but there is one thing in which we have just seen they exactly resemble each other. The angles *a b c* in both are together equal to two right angles. Now one is a right-angled triangle, *i.e.* the angle *b* is a right angle, or an angle that contains 90°; consequently, we know that the other angles, *a* and *c*, are together equal to 90°; and therefore, if we *know* how many degrees the angle *a* or *c* contains, we know how many the other must contain.

Why are we so anxious to know about these angles? Let us see. Here are three more triangles—

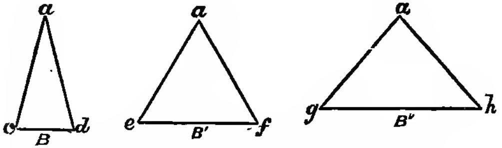


FIG. 62.—Triangles with two equal sides and unequal bases.

apparently very unlike; but still we have made the sides *ac*, *ad*, *ae*, *af*, *ag*, *ah*, all equal. Now look at the upper angles *a*, and look at their bases *B B′ B″*: where the angle is widest, the base is longest; where narrowest, the base is shortest. There is an obvious connexion between the angle and the side opposite to it, not only in the three triangles, but in each one taken separately; and in fact, in any triangle, the sides are respectively proportional, not actually to the opposite angles themselves, but to a certain ratio called the sine (Art. 516) of these angles. Moreover, we can express any side of a triangle in terms of the other sides and adjacent angles, or of the other sides and the angle between them. In short, that branch of mathematics called **trigonometry** teaches us to investigate the properties of triangles so closely that when in any triangle we have two angles, and the length of one side, or one angle and the length of two sides, whether the triangle lie before us on a piece of paper, or have at one of the angles a tower which we cannot reach, or the Sun, or a star, we can find out all about it.

516. Angles are studied by means of certain quantities called **trigonometrical ratios**, which we give here, in order that some terms which will be necessarily used in the sequel may be understood.

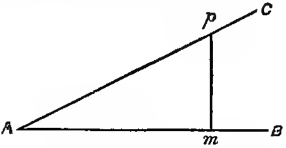


FIG. 63.—Trigonometrical ratios.

BAC may represent any angle, and *PM* is perpendicular to *AB*. Then, for the angle *A*,

$\frac{PM}{AP}$, that is, $\left.\frac{\text{perpendicular}}{\text{hypothenuse},}\right\}$ is called the sine of *A* (written *sin. A*).

$\frac{AM}{AP}$, that is, $\left.\frac{\text{base}}{\text{hypothenuse},}\right\}$ is called the cosine of *A* (written *cos. A*).

$\frac{PM}{AM}$, that is, $\left.\frac{\text{perpendicular}}{\text{base},}\right\}$ is called the tangent of *A* (written *tan. A*).

$\frac{AM}{PM}$, that is, $\left.\frac{\text{base}}{\text{perpendicular},}\right\}$ is called the co-tangent of *A* (written *cot. A*).

$\frac{AP}{AM}$, that is, $\left.\frac{\text{hypothenuse}}{\text{base},}\right\}$ is called the secant of *A* (written *sec. A*).

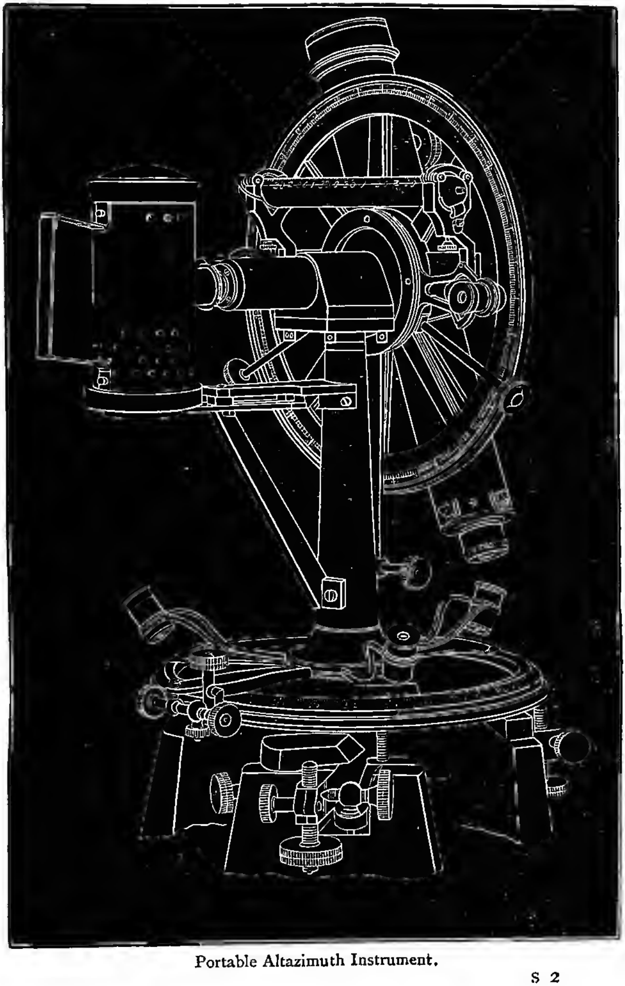
$\frac{AP}{PM}$, that is, $\left.\frac{\text{hypothenuse}}{\text{perpendicular},}\right\}$ is called the co-secant of *A* (written *cosec. A*).

517. We shall return to the use of plane triangles in astronomical methods in the next chapter. It may here be remarked that the apparent places of the heavenly bodies are referred to the celestial sphere by means of spherical triangles, which are investigated by trigonometrical ratios, in the same manner as plane triangles, and hence this part of our subject is called **Spherical Astronomy.**

518. In all the instruments about to be described, angles are measured by means of **graduated arcs,** or **circles** attached to telescopes, the graduation being carried sometimes to the hundredth part of a second of arc by **verniers** or **microscopes.** It is of the last importance, not only that the circle should be correctly graduated, but that it should be correctly centred,—that is, that the centre of movement should be also the centre of graduation. To afford greater precision, spider webs, or fine wires, are fixed in the focus of the telescope to point out the exact centre of the field of view. An instrument with the cross wires perfectly adjusted is said to be correctly collimated.

519. In addition to the fixed wires, moveable ones are sometimes employed, by which small angles may be measured. An eye-piece so arranged is called a **micrometer,** or a **micrometer eye-piece.** The moveable wire is fixed in a frame, set in motion by a screw, and the distance of this wire from the fixed central one is measured by the number of revolutions and parts of a revolution of this screw, each revolution being divided into a thousand parts by a small circle outside the body of the micrometer, which indicates 0ʳ when the moveable and central wires are coincident, and at each complete revolution on either side of the latter. The angular value of each revolution is determined by allowing an equatorial star to traverse the distance between the wires, and turning the time taken into angular measurement. Attached to the micrometer, or to the eye-piece which carries it, is also a **position-circle,** divided into 360°; by this the angle made by the line joining two stars, for instance, with the direction of movement across the field of view, is determined. The use of the position-circle in double-star measurements is very important, and it is in this way that their orbital motion has been determined. The micrometer wires, or the field of view, are illuminated at night by means of a small lamp outside, and a reflector inside, the telescope (see Plate XIV.).

Plate XV.



Portable Altazimuth Instrument.

520. If we require to measure simply the angular distance of one celestial body from another, we employ a **sextant**; but generally speaking, what is to be determined is not merely the angular distance between two bodies, but their apparent position either on the sphere of observation or on the celestial sphere itself.

521. In the former case,—that is, when we wish to determine positions on the visible portion of the sky,—we employ what is termed an *altitude and azimuth instrument*, or, shortly, an **altazimuth**; and if we know the sidereal time, or, in other words, if we know the exact part of the celestial sphere then on the meridian, we can by calculation find out the right ascension and declination (Art. 328), referred to the celestial sphere, of the body whose altitude and azimuth on the sphere of observation we had instrumentally determined.

522. An altazimuth is an instrument with a vertical central pillar supporting a horizontal axis. There are two circles, one horizontal, in which is fitted a smaller (ungraduated) circle with attached verniers fixed to the central pillar, and revolving with it; another, vertical, at one end of the horizontal axis, and free to move in all vertical planes. To this latter the telescope is fixed. When the telescope is directed to the south point, the reading of the horizontal circle is 0°; and when the telescope is directed to the zenith, the reading of the vertical circle is 0°. Consequently, if we direct the telescope to any particular star, one circle gives the zenith distance of the star (or its altitude); the other gives its azimuth. If we fix or *clamp* the telescope to the vertical circle, we can turn the axis which carries both round, and observe all stars having the same altitude, and the horizontal circle will show their azimuths; if we clamp the axis to the horizontal circle, we can move the telescope so as to make it travel along a vertical circle, and the circle attached to the telescope will give us the zenith distances of the stars (or their altitudes), which, in this case, will lie in two azimuths 180° apart. A portable altazimuth is represented in Plate XV., the various parts of which will be easily recognised from the foregoing description.

523. To make an observation with the altazimuth, we must first assure ourselves that the instrument itself is in perfect adjustment—that is, that the circles are truly graduated and centred (Art. 518), and that there is no error of collimation in the telescope. This done, it must be perfectly levelled, so that the vertical circle is in all positions truly vertical, and the horizontal circle truly horizontal. Next, we must know the exact readings of the verniers of the azimuth circle when the telescope is in the meridian, and the exact readings of the verniers of the vertical circle when the telescope points to the zenith. This done, we may point the telescope to the body to be observed, bring it to the cross wires visible in the field of view, and note the exact time. The verniers on the two circles are then read, and from the mean of them the instrumental altitude and azimuth are determined. The observation should then be repeated with the telescope on the opposite side of the central pillar, as by this means some of the instrumental errors are got rid of.

LESSON XLII.—*The Transit Circle and its Adjustments. Principles of its Use. Methods of Taking Transits. The Chronograph. The Equatorial.*

524. When we wish to determine directly the position of a celestial body on the celestial sphere itself, a **transit circle** is almost exclusively used. This instrument consists of a telescope moveable in the plane of the meridian, being supported on two pillars, east and west, by means of a horizontal axis. The ends of the horizontal axis are of exactly equal size, and move in pieces, which, from their shape, are called Ys. When the instrument is in perfect adjustment, the line of collimation of the telescope is at right angles to the horizontal axis, the axis is exactly horizontal, and its ends are due east and west. Under these conditions, the telescope describes a great circle of the heavens passing through the north and south points and the celestial pole ; in other words, the telescope in all positions points to some part of the meridian of the place. On one side of the telescope is fixed a circle, which is read by microscopes fixed to one of the supporting pillars. The cross wires in the eye-piece of the telescope enable us to determine the exact moment of sidereal time at which the meridian is crossed : this time is, in fact, the right ascension of the object. The circle attached shows us its distance from the celestial equator : this is its declination. So by one observation, if the clock be right, the instrument perfectly adjusted, and the circle correctly divided, we get both co-ordinates.

In Plate XVI. is given a perspective view of the great transit circle at Greenwich Observatory, designed by the late Astronomer-Royal, Sir George Airy. It consists of two massive stone pillars, supporting the ends of the horizontal axis of the telescope, which rests on Ys, as shown in the case of one of the pivots in the drawing. Attached to the cube of the telescope (to which the two side-pieces, the eye-piece end and object-glass end, are screwed) are two circles. The one to the right is graduated, and is read by microscopes pierced through the right-hand pillar ; the eye-pieces of these microscopes are visible to the right of the drawing. The other circle is used to fix the telescope, or to give it a slow motion, by means of a long handle, which the observer holds in his hand. The eye-piece is armed with a micrometer, with nine equidistant vertical wires and two horizontal ones.

The wheels and counterpoises at the top of the view are to facilitate the raising of the telescope when the collimators, both of which are on a level with the centre of the telescope—one to the north and one to the south —are examined.

525. As we have already seen (Art. 329) a celestial meridian is nothing but the extension of a terrestrial one; and as the latter passes through the poles of the Earth, the former will pass through the poles of the celestial sphere: consequently, in England the northern celestial pole will lie somewhere in the plane of the meridian. If the position of the pole were exactly marked by the pole-star, that star would remain immoveable in the meridian; and when a celestial body, the position of which we wished to determine, was also in the meridian, if we adjusted the circle so that it read 0° when the telescope pointed to the pole, all we should have to do to determine the north polar distance of the body would be to point the telescope to it, and see the angular distance shown by the circle.

526. But as the pole-star does not exactly mark the position, we have to adopt some other method. We observe the zenith distance (Art. 329) of a circumpolar star when it passes over the meridian above the pole, and also when it passes below it, and it is evident that if the observations are perfectly made, half the sum of these zenith distances will give the zenith distance of the celestial pole itself. When we have found the position of the celestial pole, we can determine the position of the celestial equator, which we know is exactly 90° away from it. As we already know the zenith distance of the celestial pole, the difference between this distance and 90° gives us the zenith distance of the equator. Here, then, we have three points from which with our transit circle we can measure angular distances:—

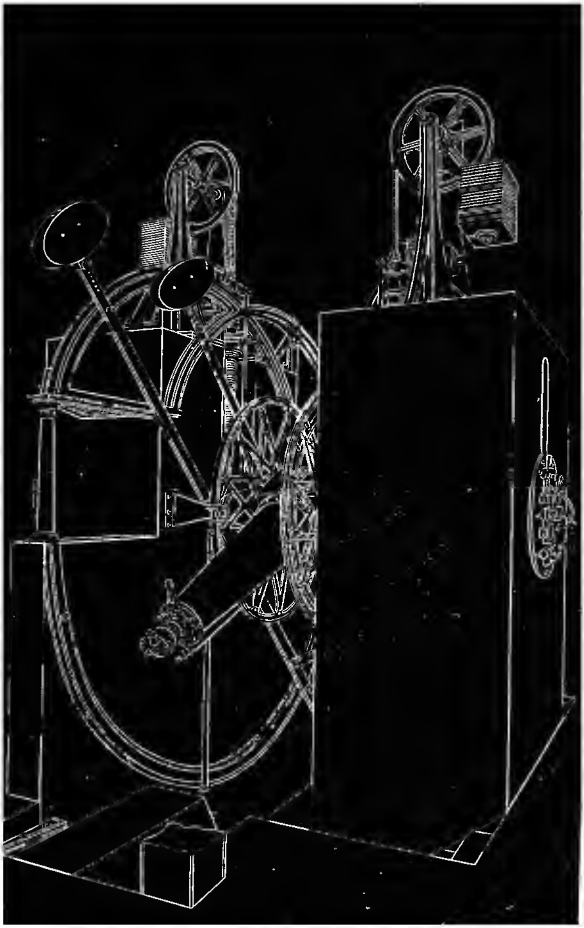
I. From the zenith,
II. From the celestial pole,
III. From the celestial equator,

and we may add,

IV. From the horizon,

as the horizon is 90° from the zenith. Any of these distances can be easily turned into any other.

Plate XVI.



Perspective View of the Transit Circle at Greenwich.

will be determined. That is to say, the Earth itself, by its rotation, performs the most difficult part of the task for us, and every star will in turn be brought into the meridian of our place of observation; all we have to do is to note its angular distance either from the zenith or from the celestial equator, and note the sidereal time: one enables us to determine, or actually gives us, its declination; the other gives us its right ascension.

529. Of course, the method which is good for determining the exact place of a single heavenly body is good for mapping the whole heavens, and in this manner the position of each body has been determined, until the whole celestial sphere has been mapped out, the right ascension and declination of every object having been determined.

The most important of the catalogues in which these positions are contained is due to the German astronomer Argelander. This catalogue contains the positions of upwards of 324,000 stars, from N. Decl. 90° to S. Decl. 2°, and Schönfeld's extension of it to S. Decl. 23° gives 133,650 more. Bessel also published a catalogue of upwards of 50,000 stars. The late Astronomer-Royal and the British Association have published similar lists, and a great number of southern stars have been lately determined with equal care. There are besides catalogues dealing with double stars, variable stars, and red stars exclusively.

530. In order that the angular distance from the zenith, and the time of meridian passage, may be correctly determined, observations of the utmost delicacy are required.

531. The circle of the Greenwich transit, for instance, is read in six different parts of the limb at each observation by microscopes, the eye-pieces of which are shown in Plate XV., and the recorded zenith distance is the mean of these readings.

The other co-ordinate,—that is, the right ascension,—

is obtained with equal care. The transit of the star is watched over nine equidistant wires, in the micrometer eye-piece (called in this case a **transit eye-piece**), the middle one being exactly in the axis of the telescope. The following table of some objects observed at Greenwich on Aug. 7, 1856, will show how the observation made at this central wire is controlled and corrected by the observations made at the other wires on either side of it.

NAME OF OBJECT.	Seconds of Transit over the Wires.									Concluded Transit over the Centre Wire.
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX	
	s	s.	s.	s.	s.	s.	s.	s.	s.	h. m. s.
13 Lyræ. .	...	...	3·0	6·8	**14·3**	22·0	25·9	29·7	33·5	18 50 **14·34**
κ Cygni . .	40·7	45·3	49·8	54·6	**3·5**	12·8	17·5	22·0	26·7	19 13 **3·58**
χ^3 Sagittarii	49·3	52·4	55·5	58·4	**4·4**	10·6	13·8	16·7	19·7	19 16 **4·48**
B. A. C. 6666	59·9	3·1	6·2	9·2	**15·6**	21·8	24·9	28·0	31·1	19 20 **15·48**
c^1 Cygni . .	55·0	59·4	3·7	7·8	**16·8**	25·2	29·7	34·0	38·2	19 37 **16·57**
c^2 Cygni .	57·8	2·1	6·4	10·8	**19·4**	27·9	32·3	36·6	40·9	19 37 **19·28**
Neptune .	...	...	...	...	**11·5**	25·3	39·0	...	...	23 23 **11·52**

532. There are two methods of observing the time of transit over a wire, one called the **eye and ear method,** the other the **electrical method.** In the former, the observer, taking his time from the sidereal clock, which is always close to the transit circle, listens to the beats and estimates at what interval between each beat the star passes behind each wire. An experienced observer in this manner mentally divides a second of time into ten equal parts with no great effort.

533. In the second method a barrel covered with paper is made to revolve at a uniform rate. By means of an electric current, a pricker attached to the keeper of an electro-magnet is made at each beat of the sidereal clock to make a puncture on the revolving barrel. The pricker is carried along the barrel, so that the line of punctures forms a spiral, the pricks being about half an inch apart. Here then we have the flow of time fairly recorded on the barrel. At the beginning of each minute the clock fails to send the current, so that there is no confusion. What the clock does regularly at each beat the observer does when a star crosses the wires of his transit eye-piece. He presses a spring, and an additional current at once makes a puncture on the barrel. The time at which the transit of each wire has been effected is estimated from the position the additional puncture occupies between the punctures made by the clock at each second.

534. By this method, which is also termed the chronographic method, the apparatus used being called a **chronograph,** the observer is enabled to confine his attention to the star, and after observing with the telescope can at leisure make the necessary notes on the punctured paper, which when filled, is taken off the barrel and bound up as a permanent record.

535. With the transit circle the position of a body on the celestial sphere can only be determined when it is on the meridian. The **equatorial** enables this to be done, on the other hand, in every part of the sky, though not with such extreme precision. The object is brought to the cross wires of the micrometer eye-piece, and the declination circle at once shows the declination of the object. The right ascension is determined as follows:—At the lower end of the polar axis is a circle divided into the 24 hours of right ascension. *This circle is not fixed.* Flush with the graduation are two verniers; the upper one fixed to the stand, the lower one moveable with the telescope. The fixed vernier shows the position occupied by the telescope, and therefore by the moveable vernier, when the telescope is exactly in the meridian. Prior to the observation, therefore, the circle is adjusted so that the local sidereal time, or, in other words, the right ascension of the part of the celestial sphere in the meridian, is brought to the fixed vernier. The circle is then carried by the clockwork of the instrument, and when the cross wires of the telescope are adjusted on the object, the moveable vernier shows its right ascension on the same circle.

LESSON XLIII.—*Corrections applied to Observed Places. Instrumental and Clock Errors. Corrections for Refraction and Aberration. Corrections for Parallax. Corrections for Luni-solar Precession. Change of Equatorial into Ecliptic Co-ordinates.*

536. After the astronomer has made his observations of a heavenly body—and has freed them from instrumental and clock errors, if his telescope is not perfectly levelled or collimated, or his circle is not perfectly centred, or if the clock is either fast or slow—he has obtained what is termed the **observed** or **apparent place**. This, however, is worth very little : he must, in order to obtain its **true place,** as seen from his place of observation, apply other corrections rendered necessary by certain properties of light. These properties have been before referred to in Arts. 450 and 451, and are termed the refraction and aberration of light. Refraction causes a heavenly body to appear proportionately higher the nearer it is to the horizon ; in the zenith its action is *nil;* near the horizon it is very decided, so decided that at sunset, for instance, the sun appears above the horizon after it has actually sunk below it.

It will be seen, therefore, that refraction depends only upon the altitude of the body on the sphere of observation.

537. The correction for refraction is applied, therefore, by means of some such table as the following:—

TABLE OF REFRACTIONS.

Apparent Altitude.		Mean Refraction.		Apparent Altitude.		Mean Refraction.	
°	′	′	″	°	′	′	″
0	0	34	54	11	0	4	49
0	20	30	52	12	0	4	25
0	40	27	23	13	0	4	5
1	0	24	25	14	0	3	47
1	30	20	51	15	0	3	32
2	0	18	9	20	0	2	37
2	30	16	1	25	0	2	3
3	0	14	15	30	0	1	40
3	30	12	48	35	0	1	22
4	0	11	39	40	0	1	9
5	0	9	47	45	0	0	58
6	0	8	23	50	0	0	48
7	0	7	20	60	0	0	33
8	0	6	30	70	0	0	21
9	0	5	49	80	0	0	10
10	0	5	16	90	0	0	0

538. This table will give a rough idea of the correction applied; in practice, the corrections are in turn corrected according to the densities of the air at the time of observation. In the case of the transit circle, or altazimuth, the correction for refraction is applied by merely reducing the observed zenith distance by the amount shown in the refraction table.

539. The aberration results from the fact that the observer's telescope carried by the Earth's annual motion round the Sun must always be pointed a little in advance of the star (Art. 451), in order, as it were, to catch the ray of light. Hence the star's *aberration place* will be different from its *real place*, and as the Earth travels round the Sun, and the telescope is carried round with it always pointed ahead of the star's place, the aberration place revolves round the real place exactly as the Earth (if its orbit be supposed circular) would be seen to revolve round the Sun, as seen from the star: the aberration places of all stars, in fact, describe circles parallel to the plane of the Earth's orbit—if the star lie at the pole of the ecliptic the circle will appear as one: the aberration place of a star in the ecliptic, since we are in the plane of the circle will oscillate backwards and forwards; that of one in a middle celestial latitude will appear to describe an ellipse. The diameter of the circle, the major axis of the ellipse, and the amount of oscillation, will in all cases be equal; but the minor axes of the ellipses described by the stars in middle latitudes will increase from the equator to the pole. The invariable quantity is $20''492$, and is termed the **constant of aberration.** It expresses, as we have seen, the relative velocities of light and of the Earth in her orbit. It is determined by the following proportion, bearing in mind

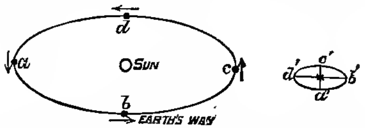


FIG. 64.—Annual change of a Star's position, due to Aberration: *a b c d*, the Earth, in different parts of its orbit; *a′b′c′d′*, the corresponding Aberration places of the Star, varying from the true place in the direction of the Earth's motion at the time.

that the 360° of the Earth's orbit are passed over in 365¼ days, and that light takes 8m. 19s. to come from the Sun:

Days. m. s. ° ″
365¼ : 8 19 :: 360 : 20.492

The mode in which the correction for aberration is applied may be gathered from Fig. 67.

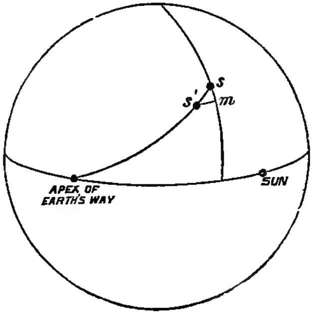


Fig. 65.—*s*, the Star's true place; *s′*, the Aberration place.

540. The direction of the Earth's motion in its orbit, called the Earth's Way, is always 90° behind the Sun's position in the ecliptic at the time; therefore the aberration place of the star will lie on the great circle passing through the star and the spot in the ecliptic lying 90° behind the Sun.

541. Observations of the celestial bodies near the Earth, such as the Moon and some of the planets, when made at different places on the Earth's surface, and corrected as we have indicated, do not give the same result, as their position on the celestial sphere appears different to observers on different points of the Earth's surface. This effect will be readily understood by changing our position with regard to any near object, and observing it projected on different backgrounds in the landscape; the nearer we are to the object the more will its position appear to change.

542. To get rid of these discordances, the observations are further reduced and corrected to what they would have been had they been made at the centre of the Earth. This is called applying the correction for **parallax.**

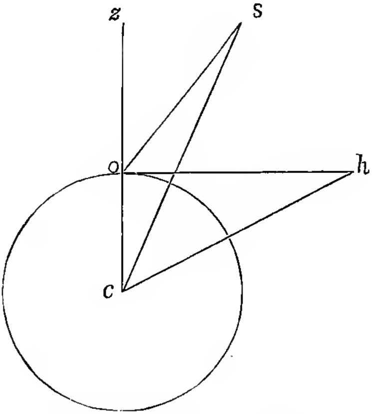


FIG. 66.—Parallax of a heavenly body.

Parallax is the angle under which a line drawn from the observer to the centre of the Earth would appear at the body of which observations are being made. When the body is in the zenith of an observer, therefore, its parallax is *nil;* it is greatest when the body is on the horizon. This is termed the **horizontal parallax.** The line is always equal to the radius of the Earth, but being seen more or less obliquely, the parallax varies accordingly.

543. The value of the correction for parallax is found as follows:—In Fig. 65, let *s* be a star, *z* the zenith, *o* an observer, *c* the centre of the Earth, and *h* the horizon. The angle *o s c* is the parallax of the star *s*. It is one of the properties of triangles that the sides are proportional to the sines of the opposite angles: in the triangle *o s c*, for instance, we have

$$\text{Sin.}\, o\,s\,c : \text{sin.}\, c\,o\,s :: o\,c : c\,s.$$

544. The angle *o s c* is the parallax of the star; let us therefore call it p. The angle $c\,o\,s = 180°$—the zenith distance, which we will write shortly, $180°-z$; *o c* is the Earth's radius, which may be called r, and *c s* the star's distance, which we will call D; so the equation takes this form:—

$$\text{Sin.}\, p : \text{sin.}\,(180° - z) :: r : D.$$

Or (since the sine of $180° - z$ is equal to the sine of z),

$$\text{Sin.}\, p = \frac{r}{D}\text{sin.}\ z \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

It is seen that in the case of horizontal parallax sin. z becomes equal to 1, so that

$$\text{Sin.}\, p = \frac{r}{D} \quad . \quad . \quad . \quad . \quad . \quad (2).$$

As will be seen in the next chapter, this formula enables us to find the distances of all the heavenly bodies that are near enough to have any sensible parallax.

545. From what has been said it will be seen that on the celestial sphere the positions of the heavenly bodies are determined by means of either of two fundamental planes—one of them the plane of the ecliptic, the other the plane of the Earth's equator; and that a point in the line of intersection of these two planes,—that, namely, occupied by the Sun at the vernal equinox, called the first point of Aries, written shortly, ♈,—is the start-point of one of the co-ordinates. Thus :

Declination	is reckoned N. or S. of the plane of the earth's equator.
Celestial latitude	is reckoned N. or S. of the plane of the ecliptic.
Right ascension	and *celestial longitude* are both reckoned from the great circle which passes through the first point of Aries, in the intersection of the two fundamental planes.

546. Now one plane marks the plane of the Earth's yearly motion round the Sun, the other marks the plane of the Earth's daily rotation. If therefore these are changeless, a position once determined will be determined once for all ; but if either the plane of the Earth's yearly motion or the direction of the inclination of the Earth's axis change, then the line of intersection will vary, and corrections will be necessary.

547. We stated in Art. 168 that, *roughly speaking*, the Earth's axis was always pointed in the same direction, or remained parallel to itself ; but *strictly speaking* this is not the case. It is now known that the pole of the Earth is constantly changing its position, and revolves round the pole of the ecliptic in about 25,810 years, so that the pole-star of to-day will not be the pole-star 3,000 years hence.

548. Now a very important fact follows from this ; as the Earth's axis changes, the plane of the equator changes with it ; and so that each succeeding vernal equinox happens a little earlier than it otherwise would do. This is called the **precession of the equinoxes** (because the equinox seems to move backwards, or from left to right, as seen in the heavens from the northern hemisphere of the Earth, so as to meet the Sun earlier), or **luni-solar precession.** The result of this is, that could we see the stars behind the Sun, we should see different ones at each successive equinox. In the time of Hipparchus—2,000 years ago—the Sun at the vernal equinox was in the constellation *Aries*; now-a-days it is in the constellation *Pisces* (Art. 361).

549. The plane of the ecliptic is also subject to variation. This is termed the **secular variation of the obliquity of the ecliptic.**

550. Of these changes, the luni-solar precession is the most important; it causes the intersection of the two fundamental planes to recede 50″37572 annually, the general precession amounting to 50″21129. To this is due the difference in length between the sidereal and tropical years (Art. 439).

551. The cause of these changes, as will be seen in Chap. IX., is the attraction exercised by the Sun, Moon, and planets upon the protuberant equatorial portions of our Earth. The effect is to render both latitudes and longitudes, and right ascensions and declinations variable. Hence the observed position of a heavenly body to-day will not be the position occupied last year, or to be occupied next year, and apparent positions have to be corrected, to bring them to some common epoch—such as 1800, 1850, 1880, &c., so that they may be strictly comparable.

552. As was pointed out in Lesson XXIX., astronomers not only deal with positions on the celestial sphere determined by right ascension and declination, but they require to look at it, as it were, from the ecliptic point of view, and to know the distances of bodies from that plane, still using the same first point of Aries, as in RA. These co-ordinates are termed *celestial latitude* and *longitude*; they are not determined from observation, but are calculated from the true RA. and Decl. by means of spherical trigonometry.

553. The first thing to be done is to determine what is called the **obliquity of the ecliptic** (written ω)—that is, the angle the ecliptic makes with the equator. This is done by observing the declination of the Sun at the two solstices, at which times the declination is exactly equal to the obliquity. At the summer solstice the Sun is north of the equator, at the winter solstice south, by the exact amount of the obliquity.

554. When ω is known, to transform RA. and Decl. into lat. and long. we proceed as follows:—In Fig. 67, let *s* represent the body whose right ascension and declination are known; ♈ the sign for the first point of Aries,

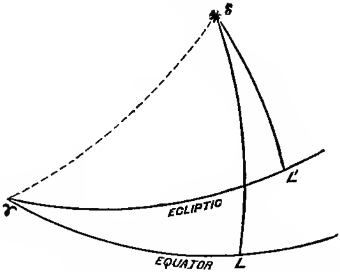


FIG. 67.—Transformation of Equatorial and Ecliptic Co-ordinates.

L part of the equator, so that ♈ *L* = the right ascension of the body, as RA. is measured along the equator from ♈; *s L* part of a meridian of declination, and therefore the declination of the body; the angle *L′* ♈ *L* the obliquity of the ecliptic; and *L′* ♈ the position of the ecliptic with regard to the equator.

This is what we know.

What we want to know are, ♈ *L′*, the longitude, and *s L′*, the latitude. Let us call the right ascension RA., the declination δ, the longitude *l*, the latitude λ, and the obliquity ω.

Before we can determine *l* and λ we must find ♈ *s* and the angle *s* ♈ *L*. The triangle *s L* ♈ is right-angled at *L*, as the meridians of RA. cross the equator at right-angles; by a formula of spherical trigonometry we have

$$\cos. \Upsilon s = \cos. \text{RA}. \cos. \delta \quad . \quad . \quad . \quad . \quad (1).$$

From this is determined Υs. Again, we have

$$\cot. s \Upsilon L = \sin. \text{RA}. \cot. \delta \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

From this is determined the angle $s \Upsilon L$.

In the right-angled triangle $s \Upsilon L'$, in which we want to know $s L'$ and $\Upsilon L'$, we now know Υs; the angle at L', which is a right angle; and the angle; $s \Upsilon L'$ which $=$ $s \Upsilon L - \omega$, or the angle $L' \Upsilon L$. We get the sine of λ from the following equation:—

$$\sin. \lambda = \sin. \Upsilon s \sin. (s \Upsilon L - \omega) \quad . \quad (3).$$

and we get the tan. of l from this:—

$$\tan. l = \tan. \Upsilon s \cos. (s \Upsilon L - \omega) \quad . \quad . \quad . \quad (4).$$

The actual latitude and longitude are then found from a table of sines and tangents.

LESSON XLIV.—*Summary of the Methods by which true Positions of the Heavenly Bodies are obtained. Use that is made of these Positions. Determination of Time: of Latitude: of Longitude.*

555. What has hitherto been said in this chapter may be summarised as follows:—

1. The astronomer, to make observations on his sphere of observation merely, makes use principally either of a sextant or an altazimuth. The positions of a celestial body thus determined may by calculation be referred to the celestial sphere itself, and its RA. and Decl. determined.
2. Observations of a celestial body with regard to the celestial sphere itself are principally made by means

of a transit circle, or an equatorial, by which both apparent right ascension and declination may be directly determined.

3. In all observations the instrumental and clock errors are carefully obviated, or corrected.
4. Besides the instrumental and clock errors there are others—refraction and aberration, which depend upon the finite velocity of light, and its refraction by our atmosphere. These also must be corrected.
5. Besides these, another error, parallax, results from the observer's position on the Earth's *surface*. This is corrected by reducing all observations to the *centre* of the Earth.
6. There are still other errors depending upon the change of the intersection of the two planes to which all measurements are referred. These are got rid of by reducing all observations to a point of time (as parallax was got rid of by reducing them to a point of space—the centre of the Earth). This is accomplished by fixing upon the position of the intersection at a given epoch, such as, 1800, 1880, &c., and reducing all observations to what they would have been had they been made at such epoch, or what they will be when made at such epoch.
7. The right ascension and declination are then easily converted by calculation into celestial longitude and latitude if required.

556. By means of observations freed from all these errors, extending over centuries, astronomers have been able to determine the positions of all the stars, and to map the heavens with the greatest accuracy. They have also discovered the proper motions (Art. 43) of some among the stars.

557. Similarly they have been able to investigate the motions of the bodies of our system so accurately, that they have discovered the laws of their motions. This knowledge enables them to predict their exact positions for many years in advance, and each of the first-rate Powers publishes beforehand, for the use of travellers and navigators an almanac, or **ephemeris,** in which are given, with most minute accuracy, the positions of the principal stars, the planets, and the Sun from day to day, and the positions of the Moon from hour to hour. Such are the English and American "Nautical Almanacs," the French "Connaissance des Temps," the German "Berliner Jahrbuch." These positions enable us to determine I. Time. II. Latitude. III. Longitude.

558. When time only is required, a transit instrument is employed—that is, a simple telescope mounted like the transit circle, *but without the circle*, or with only a small one: the transits of stars, the right ascension of which has been already determined with great accuracy by transit circles, in fixed observatories, being observed. This gives us the local sidereal time; it may, if necessary, be converted into mean solar time by the rule in Art. 427.

559. As we have seen in a previous Lesson (XI.), all that we require to determine our position on the Earth's surface is to learn the latitude and longitude. The determination of the former co-ordinate in a fixed observatory is an easy matter, if proper instruments be at hand. For instance: half the sum of the altitudes (corrected for refraction) of a circumpolar star, at upper and lower culminations, even if its position be unknown, will give us the elevation of the pole, and therefore the latitude of the place. Or, if we determine the zenith distance of a star when passing the meridian, the declination of which has been accurately determined, we determine the latitude. For since declination is referred to the plane of the celestial equator extended to the stars, it is the exact equivalent of terrestrial latitude. If a star of 0° declination is observed exactly in the zenith, it is known that the position of the observer is on the equator; if the declination of a star in the zenith is known to be 45°, then our latitude is 45°; and if a star of, say, N. 39° passes 10″ to the north of our zenith, then our latitude is 38° 59′ 50″, and so on.

560. To determine latitude, then, all that is required is to know either the elevation of the pole or the zenith distance of a heavenly body whose declination is known.

561. On board ship, and in the case of explorers, the problem is for the most part limited to determining the meridian altitude of the Sun or Moon, as the sextant only can be employed. Suppose such an observation to give the altitude as 29° from the south point of the horizon—that is, 61° zenith distance—and that the Nautical Almanac gives its declination on that day as 12° south; if we were in lat. 12° S. the Sun should be overhead, and its zenith distance would be *nil;* as it is 61° to the south, we are 61° to the north of 12° S., or in N. lat. 49°. So, if we observe the meridian altitude as 10° from the north point of the horizon, or zenith distance 80°, and the Nautical Almanac gives the declination at the time as 20° N., our position will be in 60° S. latitude.

562. Next, as to longitude. Longitude is in fact *time*, and difference of longitude is the difference of the times at which the Sun crosses any two meridians, the twenty-four hours solar mean time being distributed among the 360° of longitude, so that 1 hour = 15°, and so on.

563. There are several ways of determining longitude employed in fixed observatories: the most convenient one consists in electrically connecting the two stations, the difference of longitude between which is being sought, and observing the transit of the same stars at each. Thus the transits at station A are recorded on the chronographs at stations A and B, and the transits at station B are similarly recorded at B and A; from both chronographs the interval between the times of transit is accurately recorded in sidereal time, and the mean of all the differences gives the difference of longitude.

564. At sea, the problem, which consists of finding the difference between the local and Greenwich time, is solved generally by one of three methods. The first of these is to carry Greenwich time with the ship by means of very accurate chronometers, and whenever the local time is determined noting the difference between the local time and the chronometer. If, for instance, when noon is thus determined, the chronometer shows three hours at Greenwich, the ship is three hours or 45° to the west of Greenwich; in other words, in long. 45° W.

565. The second method consists of making use of the heavens as a dial-plate, and of the Moon as the hand. In the Nautical Almanac the distances of the Moon from the stars in her course are given for every third hour in Greenwich time. These distances are to be corrected for refraction and parallax. The sailor, therefore, observes the Moon's distance from the stars given in the almanac and corrects his observation for refraction and parallax; referring to the Nautical Almanac, he sees the time at Greenwich, at which the distance is the same as that given by his observation, and knowing the local time (from day observations) at the instant at which his observation was made, the difference of time, or longitude, is readily found.

566. A third method (scarcely, however, available at sea) is to watch the eclipses of Jupiter's satellites, which are visible all over the Earth, whenever seen, at the same instant; the instant at which they actually take place being carefully stated in the Nautical Almanac in Greenwich time. If, therefore, one be observed, and the local time be known, the difference of time or longitude is also known.

CHAPTER VIII.

DETERMINATION OF THE REAL DISTANCES AND DIMENSIONS OF THE HEAVENLY BODIES.

[Airy's "Popular Astronomy," to which the author is greatly indebted for the main statements in this and the following chapters, should here be consulted by the teacher.]

LESSON XLV.—*Measurement of a Base Line. Ordnance Survey. Determination of the Length of a Degree. Figure and Size of the Earth. Measurement of the Moon's Distance.*

567. WE now come to the measurement of the actual distances. We have already said that astronomers use as a basis for their investigations the methods employed by land surveyors, and these methods are based on the measurement of angles. As was stated in Art. 515, when we have two angles and one side of any triangle given, we can by means of trigonometry find out all about the triangle, whether we have at one of its angles a tower we cannot reach, or the Sun, or a star. This problem generally resolves itself into measuring with great accuracy a base line, and then taking at either end of it the angle between the other end and the object. For this purpose it is necessary, however, that the base line shall be of some appreciable length with reference to the distance of the object, or shall subtend a certain angle at the object itself; for it is clear that if at the object the line is so small that it is reduced to a mere point, the lines joining the two ends of it and the object will be parallel.

In Fig. 64, if the lengths of the base lines *B B′ B″* be known, and the base lines subtend a measureable angle at *a*, and the other angles are also known, the distance from *a* to either *c*, *d*, *e*, *f*, *g*, or *h*, in the triangle represented is easily determined. Now if *a* be supposed to represent a distant tower which a land surveyor cannot reach, but the distance of which he is anxious to determine, he will measure his base line on a level field, and observe the angles. Similarly, if *a* be supposed to represent the Moon, Mars, or Venus, under the same conditions, it is clear that if *cd*, *ef*, or *gh*, represent two places on the Earth some thousand miles apart, the distance between which is accurately known, exactly the same process as that employed by the land surveyor in the former case will enable the astronomer to determine the distance of the Moon, Mars, or Venus, because the Moon is always, and the planets named sometimes, sufficiently near to operate upon in this manner. This is called determining the Moon's or a planet's *parallax*.

568. If the parallax is very small, our instruments fail us; we cannot make the instruments large enough and perfect enough to measure the exact angle. This happens in the case of the Sun—that body is too far off to permit of this mode of measuring its distance.

569. There is this difference, however, between the cases: in the former the land surveyor could find the distance of the tower, if he did not know the size of the Earth; but in the latter the size of the Earth must be known to begin with, as it is impossible to measure directly the distance of places far apart; and their real distance can only be calculated from a knowledge of their relative positions on a globe the size of which is accurately known.

Before, therefore, astronomers could determine the distance of the nearest celestial body, the Moon, to say nothing of the more distant ones, it was necessary that the size of the Earth should be accurately known.

570. This has been accomplished by means of surveys, or triangulations, of different parts of the Earth's surface —that of England for instance. Here for a moment we come back to the work of ordinary surveyors. In the first instance, a base line was measured on one of the smoothest spots that could be found. One of those chosen was on the sandy shore on the east side of Lough Foyle, in Ireland: the length of this line was measured with most consummate care by means of bars of metal, the length of which, at a given temperature, was exactly known, and which was, at the time of observation, corrected for expansion or contraction due to variations of temperature. The bars were not placed close together, and the intervals between them were measured by means of microscopes. The base line by these means was measured to within a small fraction of an inch.

571. At the station at each end of this base line was placed a theodolite, or azimuth instrument (Art. 521), for determining the horizontal angles between the other station and the prominent objects visible, such as hill-tops or church towers, &c.: by such means, referring back to Fig. 62, and representing the base line on Lough Foyle by *cd*, *ef*, or *gh*, and any prominent object by *a*, the distance from both stations was determined; in other words, the dimensions of each triangle were determined. Each station, the position of which with reference to the base line was thus established, was made in turn the centre of similar observations, until the length and breadth of the United Kingdom had been covered with a network of triangulation. In each triangle, as the work advanced, the new sides, so to speak, were determined from the length of the side previously calculated from the observations which had gone before, the dimensions of the sides first calculated depending upon the base line actually measured.

572. When all the triangulations were complete, it was possible to show on a large sheet of paper the exact positions of all the stations chosen for the triangulation, and to measure the exact distances between them. The accuracy of the work was verified at the end by calculating the side of a certain triangle on Salisbury Plain, and then testing the accuracy of the calculated length of the side (which depended upon the accuracy of the one previously determined, and so on, till at last it depended upon the accuracy of the base line actually measured in Ireland,) by actually measuring the side itself. The agreement between the two determinations was nearly perfect.

The map of the United Kingdom has been constructed by determining the positions of the principal stations in this way, and then filling in the triangles by a similar process on a smaller scale.

573. Now, how do we connect the map of England with the size of the Earth? In this way: it enables us to measure the length of a degree of latitude.

574. What this means will have already been gathered from what was said in Art. 159. As the Earth is round (or round enough for our explanation), if it were possible to walk along a meridian from the equator to either pole, the stars in our zenith would change; we should begin with a star of 0° declination over our head, and we should finish with a star of 90° declination over our head, having passed over 90° of latitude; and if it were possible to measure exactly how far we had walked, we should have the measure of a quarter of the Earth's circumference.

575. But this is impossible; what can be done is to measure the change in zenith distance of the same star, or the zenith distances of two stars the positions of which are accurately known, in countries which have been accurately triangulated and mapped. For instance, we can make such observations at the Observatories of Greenwich and Edinburgh, which are nearly on the same meridian, and determine the difference of the zenith distance of the same star observed at both. Now, thanks to the Ordnance Survey, the distance between the two Observatories is known to within a few yards, so we at once have the following proportion:—

$$\left\{\begin{array}{c}\text{Difference of zenith}\\ \text{distance}\end{array}\right\} : \left\{\begin{array}{c}\text{Distances between}\\ \text{observatories}\end{array}\right\} : : 1^\circ : \left\{\begin{array}{c}\text{Length of a}\\ \text{degree.}\end{array}\right.$$

and then if the Earth were round,

1° : 360° : : length of 1° : circumference of the Earth.

576. That the Earth is not quite round has been demonstrated by such surveys as the one we have referred to, made near the equator, and in higher northern latitudes than England. It has been found that the length of a degree in different latitudes varies as follows:—

	Mean Lat. °	Length of 1° in English feet.
India	12	362,956
,,	16	363,044
France	45	364,572
England	52	364,951
Russia	56	365,291
Sweden	66	365,744

It follows from these measurements, that near the equator we have to go a shorter distance to get a change of zenith distance of 1° than near the poles; consequently the Earth's surface is more curved at the equator and more flattened at the poles than it is in middle latitudes.

577. From these varying lengths of a degree we can determine not only the amount of polar compression of the Earth, but its circumference, and therefore its diameters, which are as follow:—

	English feet.
Equatorial diameter	41,852,404
Polar ,,	41,709,790

But this is not all. The most recent results of the various triangulations have taught us that the Earth is not quite truly represented by an orange—at all events, unless the orange be slightly squeezed; for the equatorial circumference is not a perfect circle, but an ellipse, the longer and shorter equatorial diameters being respectively 41,853,258 and 41,850,210 feet. That is to say, the equatorial diameter which pierces the Earth from long. 8° 15′ west to 188° 15′ west of Greenwich is 1,000 yards longer than that at right angles to it.*

578. Having now the exact form and dimensions of the Earth, it is easy for us to determine the distance between any two places the positions of which on the Earth's surface are accurately known.

579. We are, therefore, in a position to measure the distance of the Moon, if we find that, as seen from two places as far apart as possible, say Greenwich and the Cape of Good Hope, there is a sensible change in the position she apparently occupies on the background of the sky; for the line joining the two places may be used as a base line, and observations may be made on the Moon at each end of it, that is, at the two stations named, exactly as observations were made at each end of the base line at Lough Foyle.

580. As the two stations are not visible from each other, what is done in each case is to measure the polar distance of the Moon (north polar distance at Greenwich and south polar distance at the Cape), and it is clear that, in the case of a star, N. P. D. + S. P. D. would be equal to 180°.

This premised, in Fig. 68, in which a section of the Earth is shown, let *E* represent the centre of the Earth, *G* the observatory at Greenwich, and *C* that at the Cape of Good Hope, both situated nearly on the same meridian. As the stars are so distant that they appear in the same position viewed from all parts of the Earth—because, as seen from them, the diameter of the Earth is reduced to a point—the dotted parallel lines, *S G* and *S′ C* represent

---

* Clarke, "Geodesy," 1880.

the apparent positions of a star, *S*, as seen from Greenwich and the Cape. For the same reason the dotted lines, *G P* and *C P′*, parallel to the axis of the Earth, represent the apparent positions of the north and south poles of the heavens as seen from the places named. The angle *P G S* therefore represents the north polar distance of the star as seen from Greenwich; the angle *P′ C S* represents the south polar distance of the same star observed at the Cape: and these two angles will of course make up 180°.

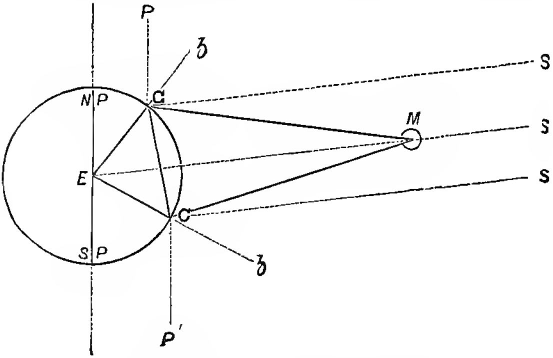


FIG. 68.—Measurement of the Moon's distance.

It is seen from the diagram that the north polar distance of the Moon as seen from Greenwich, which is observed, is greater than that of the star.

Similarly, the south polar distance as seen from the Cape, which is also observed, is greater than that of the star.

Therefore these two polar distances added together are greater than 180°, greater in fact by the angles *S G M* and *S C M*, which are equal to $GME + CME = GMC$.

The angle *GMC* is determined by observation to be about $1\frac{1}{2}^\circ$: therefore, as we know the length of the radii *GE* and *CE*, in addition to the two angles observed and the one deduced, plane trigonometry enables us easily to determine the lines *MG*, *MC* and *ME*, which are the distances of the Moon from Greenwich, the Cape, and the centre of the Earth respectively.

581. It also enables us to determine the angles *GME* and *CME*, which represent the *parallax* (Art. 543) of the Moon as observed at Greenwich and the Cape respectively. In this manner the mean equatorial horizontal parallax of the Moon has been determined to be nearly 57′ 2″.

LESSON XLVI.—*Determination of the Distances of Venus and Mars: of the Sun. Transit of Venus. The Transit of* 1882.

582. This method may be adopted to determine the distance of Venus when in conjunction with the Sun, and of Mars when in opposition; but it is only applicable in the former case when Venus is exactly between us and the Sun, or when she is said to transit or pass over his disc—when, in short, we have a **transit of Venus**; of which more hereafter.

583. In the case of Mars in opposition, there is, however, another method by which his distance may be determined by observations made at one observatory. In this method the base line is not dispensed with, but instead of using two different places on the Earth's surface, and determining the actual distance between them, we use observations made at the same place at an interval of twelve hours; in which time, of course, if we suppose them to be made on the equator, the same place would be at the two extremities of the same diameter, that is 8,000 miles apart: if the observations are not made actually on the equator, it is still easy, knowing exactly the shape and size of the Earth, to calculate the actual difference. Fig. 71, which represents a section of the Earth at the equator, will explain this method. *O* and *O′* represent the positions of the same observer at an interval of twelve hours, the Earth being in that time carried half round by its movement of rotation; *M* the planet Mars; and *S* a star of the same declination as the planet, the direction of the star being the same from all points of the surface as from the centre. At *O*, when Mars is rising at the place of observation, let the observer measure the distance the planet will appear to the east of the star; at *O′*, when Mars is setting at the place of observation, and therefore when the Earth's rotation has carried him to the other end of the same diameter, let him again measure the distance the planet will appear to the west of the star. He will thus determine, as in the case of the Moon, the angle the line joining the two places of observation subtends at the planet. In the case of observations made at the equator, the Earth's equatorial diameter forms the *base line*. The angle it subtends is determined by observation; and this can be accomplished, although both the Earth and Mars are moving in the interval between the two observations, as the motion of both can be taken into account. Here again then, when

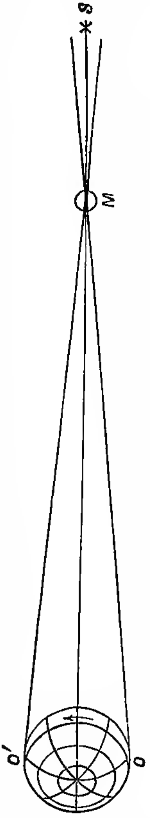


FIG. 69.—Determination of the distance of Mars by observations made at one place.

the size of the Earth is known, the distance of Mars can be determined by plane trigonometry.

584. As seen from the Sun, the Earth's diameter is so small that it is useless as a base line, and consequently the Sun's distance cannot be thus measured.

585. The Sun's distance can however be obtained indirectly by methods based upon the discovery of Kepler, that the distances of the orbits of the planets from the Sun and from each other are so linked together, that if we could determine any one of the distances, all the rest would follow. It was in this way that Dr. Gill, from observations of Mars made at the island of Ascension in 1877, fixed the Sun's distance at 93,080,000 miles. He used the plan of measurement just described in Art. 583, and known as the "diurnal method of parallaxes."

586. As we have seen, however, Mars does not come so near to us as Venus; but it happens that when Venus comes nearest to us, it comes between us and the Sun, and consequently its dark side is towards us, and we can only see it when it happens to be *exactly* between us and the Sun, when it passes over the Sun's disc as a dark spot, a phenomenon called a transit of Venus. These transits happen but rarely: the last happened in 1882; the next will not occur until the year 2004. But when they do happen, as the planet is projected on the Sun, the Sun serves the purpose of a micrometer, and great advantages (unfortunately not always realised in practice) are offered for observation. The measure of the Sun's distance—one of the noblest problems in astronomy, on which depends "every measure in astronomy beyond the Moon, the distance of and dimensions of the Sun and every planet and satellite, and the distances of those stars whose parallaxes are approximately known,"—is accomplished then by the following method, pointed out by Dr. Halley in 1716.

587. We have seen that when Venus crosses the Sun's disc during its transit it appears as a round black spot.

Let us suppose two observers placed at two different stations on the Earth, properly chosen for observations of the phenomenon ; one at a station *A* in the northern hemisphere, another at a station *B* in the southern one. When Venus is exactly between the Sun and the Earth, the observer at *A* will see her projected on the Sun, moving on the line *CD* in Fig. 70 ; the southern observer at *B* will, from his lower station, see the planet *V* projected higher on the disc, moving on the line *EF*. Now, what we require to know, in order to determine the Sun's distance, is the distance between these lines.

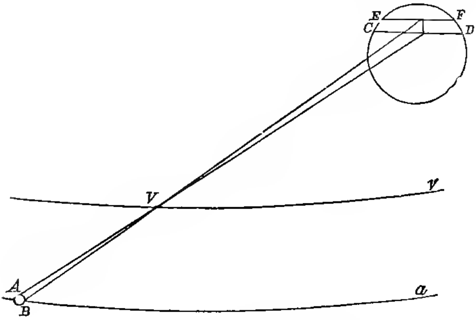


FIG. 70.—A Transit of Venus.

If the distance between the two stations is sufficiently great, the planet will not appear to enter on the Sun's disc at the same absolute moment at the two stations, and therefore the paths traversed, or the " chords," will be different. Speaking generally, the chords will be of unequal length, so that the time of transit at one station will be different from the time of transit at the other. This difference will enable us to determine the difference in the length of the chords described by the planet, and consequently their respective positions on the solar disc, and the angular amount of their separation. Now, this separation is what we want to know.

588. We already know the relative distances of Venus from the Earth and Sun; they are as 28 to 72 nearly; and whatever the absolute distances may be, the value of the separation of the two chords, in miles, will be the same. It is evident, for instance, that if the Sun were exactly as far from Venus on one side as we are on the other, and the observers occupied the two poles of the Earth, the separation would be equal to the Earth's diameter; but as the Sun is further from Venus than we are, in the proportion of 72 to 28, if the transit were observed from two stations, each chosen not too far from the Earth's poles, the separation of the two chords on the Sun would amount to 18,000 miles; and this proportion holds good whatever the distance.

589. At the two last transits of 1874 and 1882, photography was employed to determine the differences in apparent position of Venus on the Sun, as viewed from remote stations on the Earth. The problem seemed a very simple one. It was only to measure the amount of separation between the projected places of the planet, and the proportion of that amount to the whole diameter of the Sun. The value of the separation being already known in miles, this would give the real size of the Sun, whence its distance would at once follow. The results, however, showed marked discrepancies, not even the best photographs being sharply defined enough to bear measurement of the required minute accuracy.

590. We are accordingly thrown back upon eye-observations, and they take this form. The moments of ingress and egress are carefully noted at both stations, the differences in the length of the two chords showing us on what part of the Sun they lie; this known, it is easy to determine their separation in seconds of arc.

As the difference between the observed times of transit at the two stations is the quantity which determines the amount of separation, it is important to make this difference as great as possible, since then any error bears a smaller proportion to the observed amount.

591. This is accomplished by carefully choosing the stations, bearing the Earth's rotation well in mind. Let us introduce this consideration, and see, not only how it modifies the result, but also with what anxious foresight astronomers prepare for such phenomena, and why it was requisite in 1769, as well as in 1882, to go so far from home to observe them.

Let us take the transit of 1882. The instant and place (true perhaps to a second of time and arc) at which the planet would enter and leave the solar disc were calculated long beforehand; in other words, it was known exactly how the Earth would be hanging in space as seen from the Sun—how much the south pole would be tipped up—how the axis would exactly lie—how the Earth would be situated at the moments of ingress and egress. Fig. 71 shows how the planet appeared to cross the Sun as seen from the Earth. Fig. 72 shows the same circle with lines reversed, representing the points of ingress and egress, viewed in the same direction as the illuminated side of the Earth is viewed.

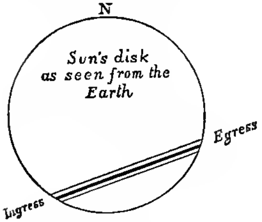


FIG. 71.

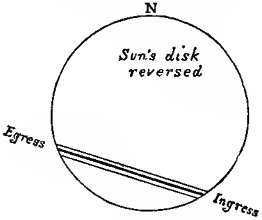


FIG. 72.

592. Now if we suppose two planes cutting the centre of the Earth and those parts of the Sun's limb at which the planet entered and quitted the solar disc, we shall see in a moment why it was that some parts of the Earth saw the planet enter the disc sooner than others. Some parts, on the other hand, saw it leave the disc later: in other words, according to the position of a place with reference to the plane of which we have spoken, both the ingress of the planet and its egress appeared to take place earlier or later, as the case might be.

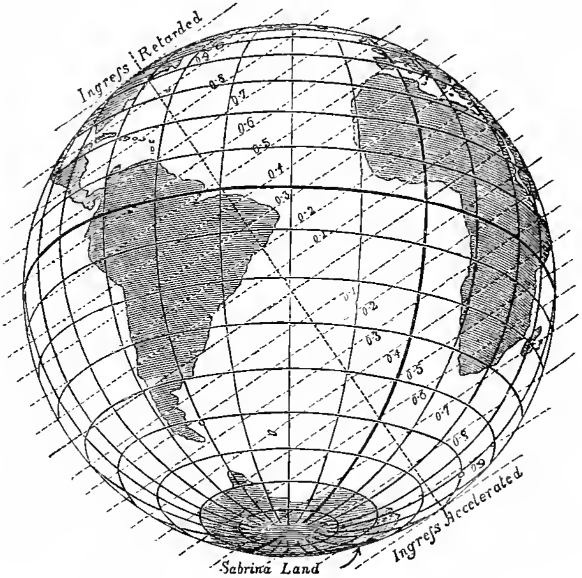


FIG. 73.—Illuminated side of the Earth at Ingress, Dec. 6d. 2h.

Now the object in selecting stations was to find a place where both the ingress was accelerated and the egress retarded, and another where the ingress was retarded and the egress accelerated, thus giving the greatest difference in the duration of the transit,—the greatest difference in the length of the chords, of which we have before spoken.

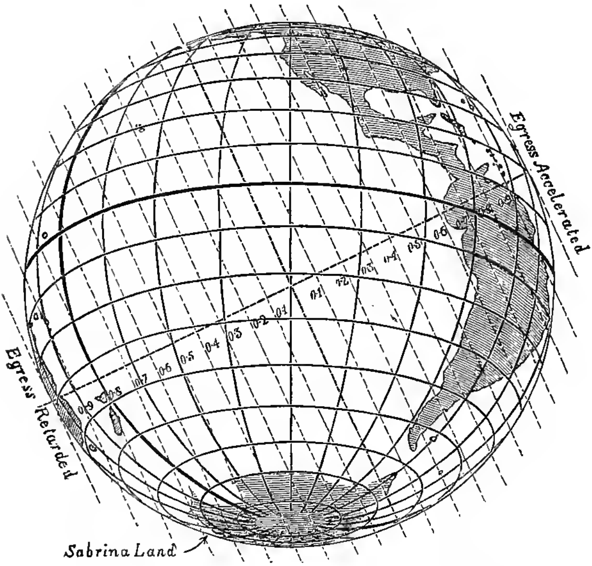


FIG. 74.—Illuminated side of the Earth at Egress, Dec. 6d. 8h.

For abridged duration, accordingly, Bermuda and Jamaica were fixed upon as stations; for lengthened duration, the Cape, New Zealand, and various points in New Zealand. The results have not yet been published; but their accuracy is known to have been impaired by atmospheric and optical phenomena tending to confuse determinations of the precise instants of contact between the limbs of Venus and of the Sun.

592 a. There is, however, another means of obtaining the Sun's distance quite independent of trigonometrical measurements. This is the method by the velocity of light. We have already stated (Art. 450), that the effect called "aberration," by which the stars seem to describe little ellipses about their true places, depends upon the relative velocity of light and of the Earth in its orbit. Hence, if we knew exactly how fast light travels we should also know how fast the Earth travels, consequently, the size of its orbit and its distance from the Sun. Now, within the last few years, experiments of very great nicety have been made with the view of finding this out. A series completed by Professor Newcomb at Washington in 1882, give as their result which can scarcely be in error more than eighteen miles either way, that light is transmitted through the ether of space at the rate of 186,828 miles a second. This gives for the mean distance of the Sun 92,965,020, or in round numbers, 93 million miles, which agrees very closely with Dr. Gill's determination from the opposition of Mars in 1877. So that we may fairly consider the problem of the Sun's distance as solved.

LESSON XLVII.—*Comparison of the Old and New Values of the Sun's Distance. Distance of the Stars. Determination of Real Sizes.*

593. The value of the Sun's distance obtained from observations of the transit of 1769 was about 95,000,000 miles. This is now known to have been about 2,000,000 of miles too large.

The old value of the parallax obtained by Encke from the transit of Venus was	8·578
The new value obtained by Hansen, from the Moon's parallactic equation	8·916
" " Winnecke, from observations of Mars	8·964
" " Stone	8·930
" " Foucault and Cornu, from the velocity of light	8·860
" " Leverrier, from the motions of Mars, Venus, and the Moon	8·866
" " Gill, from the opposition of Mars	8·780
" " Newcomb, from the velocity of light	8·794

The extreme difference between the old and new values, = two-fifths of a second of arc, amounts to no more than a correction to an observed angle represented by the apparent breadth of a human hair viewed at the distance of about 125 feet.

594. Having now obtained the Sun's distance, we can advance another step in our investigations :—I. We began with a measured base line in a field, and by it determined the distance of a tower we could not reach. II. Then the Earth was measured, and, with a base line between Greenwich and the Cape of Good Hope, the distance of the Moon was determined. III. Next, using the Earth's diameter (8,000 miles) as a base line, the distance of Mars was determined, then that of the Sun itself. IV. Having thus obtained the distance of the Sun, we are in possession of a base line of enormous dimensions, for it is clear that the positions successively occupied by our Earth in two opposite points of its orbit will be

186,000,000 miles apart. Are we then really here supplied with a base line sufficient to measure the distances of the stars? No; in the great majority of cases the parallax is so small that there is no apparent difference in the position as observed in January or July, February and August, &c. As seen from the fixed stars, that tremendous line is a point! Now an instrument such as is ordinarily used should show us a parallax of one second —that is, an angle of 1″ formed at the star by half the base line we are using—and a parallax of 1″ means that the object is 206,265 times further away than we are from the Sun, as the Sun's distance is the half of our new base line. Here then we get a limit. If the star's parallax is less than 1″, the stars must be further away than 93,000,000 miles multiplied by 206,265!

595. In the great majority of cases, however, the true zenith-distance of a star is the same all the year round; and as this true place results from the several corrections referred to in the last chapter being applied, it is very difficult when there is a slight variation, to ascribe it to parallax, since a slight error in the refraction, or the presence of proper motion in the star, would give rise to a greater difference in the places than the one due to parallax, which in no case amounts to 1″. Hence, as long as the problem was attacked in this manner, very little progress was made, the parallax of *a* Centauri alone being obtained by Henderson = 0″·9187 (since corrected to 0″·75).

Bessel, however, employed a method by which the various corrections were done away with, or nearly so. He chose a star having a decided proper motion, and compared its position, night after night, by means of the micrometer only, with other small stars lying near it which had no proper motion, and which therefore he assumed to be very much further away, and he found that the star with the proper motion did really change its position with regard to the more remote ones, as it was observed from different parts of the Earth's orbit. This method has since been pursued with great success: here are Tables showing some of the results:—

TABLE I.—*Parallaxes of Stars which have been determined in the Northern Heavens with considerable Accuracy.*

	Magnitude.	Proper motion.	Parallax.
		″	″
61 Cygni	5	5·14	0·50
Lalande 21185	7½	4·75	0·50
34 Groombridge	8	2·81	0·29
Lalande 21258	8	4·40	0·27
O.Mg. 17415	9	1·27	0·25
σ Draconis	—	1·87	0·25
Lyræ	1	0·35	0·20
p Ophiuchi	4½	1·0	0·17
α Bootis	1	2·43	0·13 ?
Groombridge 1830	7	7·05	0·09
Bradley, 3077	6	21·9	0·07
85 Pegasi	6	1·38	0·05

TABLE II.—*Results of Recent Researches on the Parallax of Stars in the Southern Hemisphere.*

Name of Star.	Observer.	Star's magnitude.	Annual proper motion in arc.	Parallax.	Star's distance in light units, or number of years in which light from star would reach the earth.	Velocity of star's motion in miles per second at right angles to line of sight.
			″	″		
α Centauri	G. and E.	1	3·67	0 75	4·36	14·4
Sirius	G. and E.	1	1 24	0·38	8·6	9·6
Lacaille 9352	G.	7½	6·95	0·28	11·6	73
ε Indi	G. and E.	5¼	4·68	0·22	15	63
o_2 Eridani	G.	4½	4·10	0·17	19	69
e Eridani	E.	4½	3·03	0·14	23	64
ζ Tucanæ	E.	—	2·05	0·06	54	101
Canopus	E.	1	0·00	Insensible.	—	—
β Centauri	G.	1	—	Insensible.	—	

The same principle was adopted in a series of researches lately carried out with great exactness by Drs. Gill and Elkin at the Cape of Good Hope. Fig. 75 shows on an enormously magnified scale the parallactic ellipse described by *a* Centauri, and the stars by comparison with which it was measured. Fig. 76 shows the annual fluctuations of apparent distance between *a* Centauri and the comparison stars.

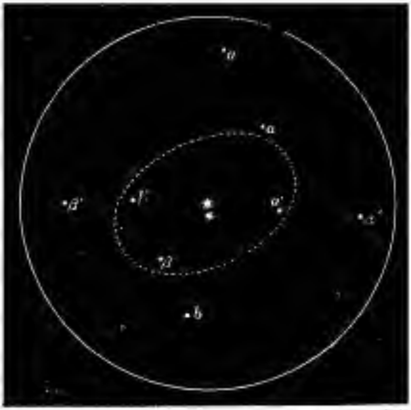


FIG. 75.—Showing comparison stars employed in determining the parallax of *a* Centauri.

596. So much for the measurement of distances. When the distance of a body is known, and also its angular measurement, its size is determined by a simple proportion, for the distance is, in fact, the radius of the circle on which the angle is measured.

There are 1,296,000 seconds in an entire circumference: there are therefore $\frac{1296000}{3{\cdot}1416}$ seconds in that part

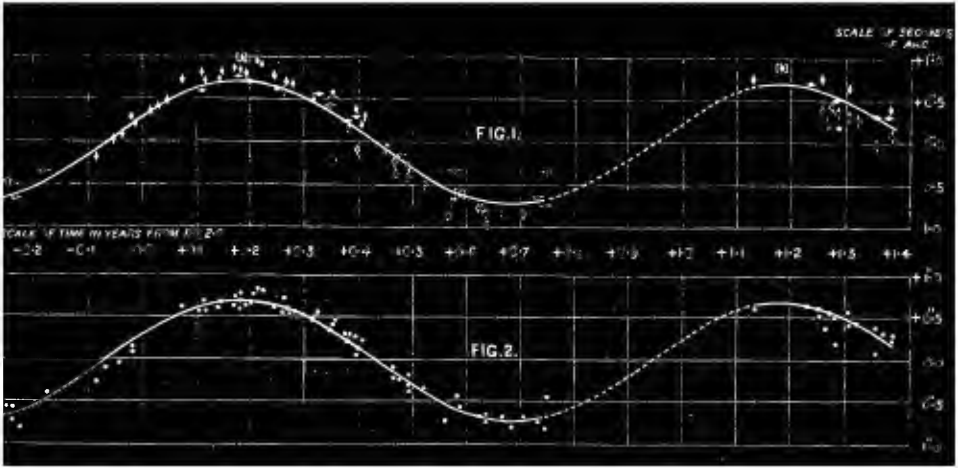


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FIG. 76.—Curves showing the results of the observations of α Centauri relative to the comparison stars α and β. Fig. 1 shows the apparent change of position relative to the star α, and Fig. 2 the change relative to β. The identity of the results in both cases leaves no doubt as to the reality of the change. The vertical scales in both figures represent the changes in declination in seconds of arc, and the horizontal scales represent time in years, dating from 1882.

of a circumference equal to the diameter, and $\frac{1296000}{3{\cdot}1416 \times 2}$ = 206265″ in that part of the circumference equal to the radius.

We have then

$$\left.\begin{array}{c}\text{The diameter}\\ \text{of the body}\\ \text{in miles}\end{array}\right\} : \left\{\begin{array}{c}\text{the distance}\\ \text{in miles}\end{array}\right\} :: \left\{\begin{array}{c}\text{the angular}\\ \text{diameter}\end{array}\right\} : \left\{\,206265''\right. ;$$

or, calling the real diameter *d*, and the distance *D*,

$$d = \frac{D \times \text{angular diameter}}{206265} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1).$$

597. For instance, the mean angular diameter of the Moon is 31′ 8″·8 = 1868″·8, and its distance is 237,640 miles. To determine its real diameter, we have

$$d = \frac{237640 \times 1868''{\cdot}8}{206265} = 2153 \text{ miles.}$$

In Table II. of the Appendix are given the greatest and least apparent angular diameters of the planets as seen from the Earth. The reader should, from these values and the distances given in Art. 377, determine the real diameters for himself.

598. Knowing the real and also the apparent angular diameter, we can at once determine the distance by transposing equation 1, as follows :—

$$D = \frac{206265 \times d}{\begin{array}{c}\text{angular diameter}\\ \text{in seconds.}\end{array}} \quad . \; . \; . \; . \; . \quad (2).$$

CHAPTER IX.

UNIVERSAL GRAVITATION.

LESSON XLVIII.—*Rest and Motion. Parallelogram of Forces. Law of Falling Bodies. Curvilinear Motion. Newton's Discovery. Fall of the Moon to the Earth. Kepler's Laws.*

599. IF a body at rest receive an impulse in any direction, it will move in that direction, and with a uniform motion, if it be not stopped. If *on the Earth* we so set a body in motion—a cricket-ball, for instance, along a field—it will in time be impeded by the grass. If we fire a cannon-ball in the air, the cannon-ball will in time be arrested by the resistance of the air; and, moreover, while its speed is slackening from this cause, it will fall, like everything else, to the Earth, and its path will be a curved line. If it were possible to fire a cannon in space where there is no air to resist, and if there were no body which would draw it to itself, as the Earth does, the projectile would for ever pursue a straight path, with an uniform rate of motion.

600. In fact, the moment a stone is thrown from the hand, or a projectile leaves the cannon, *on the Earth*, *there is superadded to the original velocity of projection an acceleration directed towards the Earth;* and the path actually described is what is called a **resultant** of these two velocities.

601. Let us make this clear with regard to motion in a straight line on the Earth's surface. Suppose that the cricket-ball *A*, in Fig. 77, receives an impulse which will send it to *B* in a certain time; it will move in the direction *AB*. Suppose, again, it receives an impulse that will send it to *C* in the same time; it will move in the direction *AC*, and more slowly, as it has a less distance to go. But suppose, again, that both these impulses are given at the same moment; it will neither go to *B* nor to *C*, but will move in a direction between those points. The exact direction, and the distance it will go, are determined by

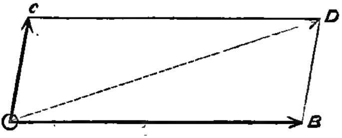

FIG. 77.—Parallelogram of Forces.

completing the parallelogram *ABCD*, and drawing the diagonal *AD*, which represents the direction and amount of the compound motion.

602. All bodies on the Earth fall to the Earth, as an apple from a tree, and it is from this tendency that the idea of **weight** is derived, and of the difference between a light body and a heavy one. This idea, however, is often incorrectly held, because the atmosphere plays such a large part in every-day life. For instance, if we drop a shilling and a feather, the feather will require more time to fall than the shilling: and it would at first appear that the tendency to fall, or the **gravity**, of the feather was different from that of the shilling. This, however, is not so; for if we place both in a long tube exhausted of air, we shall find that both will fall in the same time: and it is usual to measure gravity or attraction by the space through which bodies fall, in feet and inches, in one second of time. The difference in the time of fall in air, then, depends upon the unequal resistance of the air to the bodies.

603. Various machines have been invented at different times for measuring exactly the rate at which a body falls to the Earth, and it has been found that the rate of fall goes on increasing with the distance fallen through. Thus a body falls in one second through a distance of $16\frac{1}{12}$ feet, and has then acquired a velocity of $32\frac{1}{6}$ feet per second, and so on: so that, generally, the space fallen through in any given number of seconds is equal to $16\frac{1}{12}$ feet multiplied by the square of the time. If we represent the space fallen through by S, the velocity acquired after a fall of one second by G, and the time by t, we have

$$S = \frac{G}{2} t^2.$$

604. Now if a cannon-ball were left unsupported at the mouth of the gun, it would fall to the Earth in a certain time: when fired from the gun it has superadded to its tendency to fall a motion which carries it to the target, but in its flight its gravity is always at work, and the law referred to in Art. 601, holds good in this case also, which is one of curvilinear motion: and as the cannon-ball is pulled out of its straight course towards the target by the action of the Earth upon it, pulling it down, so in all cases of curvilinear motion there is a something deflecting the moving body from the rectilinear course.

605. Sir Isaac Newton was the first to see that the Moon's curved path was similar to the curved path of a projectile, and that both were due to the same cause as the fall of an apple, namely, the **attraction of the Earth.** He saw that on the Earth's surface the tendency of bodies to fall was universal, and that the Earth acted, as it were, like a magnet, drawing everything free to move to it, even on the highest mountains; why not then at the distance of the Moon? And he immediately applied the knowledge derived from observation on falling bodies on the Earth to test the accuracy of his idea.

606. Newton's discovery of the law of gravitation teaches us that the force of gravity is common to all kinds of matter. Its law of action may be stated thus:—The force with which two material particles attract each other is directly proportional to the product of their masses, and inversely proportional to the square of the distances between their centres. Now the intensity of a force is measured by the **momentum,** or joint product of velocity and mass, produced in one second in a body subjected to this force, and this measure of force must be remembered in discussing the above law of gravity.

607. Thus, if our unit of mass be one pound, and if this pound be allowed to fall towards the Earth, at the end of one second it will be moving with the velocity of $32\frac{1}{6}$ feet per second. Now let the mass be a ten-pound weight; it might be thought that, since the Earth attracts each pound of this weight, and therefore attracts the whole weight with ten times the force (see above definition) with which it attracts one pound, we should have a much greater velocity produced in one second. The old schoolmen thought so, but Galileo showed that a ten-pound weight will fall to the ground with the same velocity as a one-pound weight. A little consideration will show us that this is quite consistent with our definition of gravity and our definition of force. Undoubtedly the ten-pound weight is attracted with ten times the force, but then there is ten times the mass to move, so that even although the velocity produced in one second is no greater than in the one-pound weight, yet if we multiply this velocity by the mass the momentum produced is ten times as great.

608. Now, since it is each individual atom of the Earth that attracts each individual atom of the weight, we might expect, from our definition of gravity as well as from the well-known law that every action has a reaction, that the Earth, when the weight is dropped, at the end of one second rises upwards to the weight with the same momentum that the weight moves downwards to the Earth. No doubt it does; but as the Earth is a very large mass, this momentum represents a velocity infinitesimally small.

609. Again, were the Earth twice as large as it is, it would produce in one second of time a double velocity, or $64\frac{1}{3}$ feet per second; and were it only half as large, we should have only half the velocity, or $16\frac{1}{12}$ feet per second produced.

610. Hence we see that at the surface of the Moon the gravity is very small, whereas at the surface of the Sun it is enormous. There remains to consider the element of distance.

A body at the surface of the Earth, or 4,000 miles from its centre, acquires, as we have seen, by virtue of the Earth's attraction, the velocity of $32\frac{1}{6}$ feet per second at the end of one second. During this one second it has not, however, fallen $32\frac{1}{6}$ feet; for, as it started with no velocity at all, and only acquired the velocity of $32\frac{1}{6}$ feet at the end, it will have gone through the first second with the mean velocity of $16\frac{1}{12}$ feet; it will, in fact, have fallen $16\frac{1}{12}$ feet from rest in one second. Now this body, at the distance of the Moon, or sixty times as far off, would only fall in one second towards the Earth a distance of $\frac{16\frac{1}{12}}{60\times 60}$ or $\frac{16\frac{1}{12}}{3600}$ of a foot. Let us look into this a little closer.

611. Experiment shows, as we have seen, that attraction, or gravity, at the Earth's surface causes a body to fall $16\frac{1}{12}$ feet in the first second of fall, after which it has acquired a velocity of $2\times 16\frac{1}{12}=32\frac{1}{6}$ feet during the second

second, and so on, according to the square of the time (Art. 603). Thus

			feet.		feet.
Fall in 1 second	=	1 ×	$16\frac{1}{12}$	=	$16\frac{1}{12}$
" 2 seconds	=	4 ×	$16\frac{1}{12}$	=	$64\frac{4}{12}$
" 3 "	=	9 ×	$16\frac{1}{12}$	=	$144\frac{9}{12}$
" 4 "	=	16 ×	$16\frac{1}{12}$	=	$257\frac{4}{12}$
" 5 "	=	25 ×	$16\frac{1}{12}$	=	$402\frac{1}{12}$

612. The Moon's curved path is an exact representation of what the path of our cannon-ball (Art. 604) would be at the Moon's distance from the Earth ; in fact, the Moon's path *MM'*, in Fig. 78, is compounded of an *original impulse* in the direction at right angles to *EM*, and therefore in the direction *MB*, and a *constant pull* towards the Earth—the amount of pull being represented for any arc by the line *MA* (Fig. 78). To find the value of *MA*, let us take the arc described by the Moon in one minute, the length of which is found by the following proportion :—

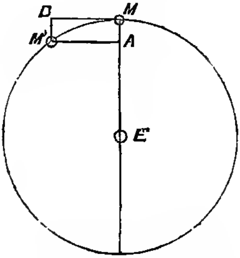

FIG. 78.—Action of Gravity on the Moon's path.

27d. 7h. 43m. : 1m. : : 360° : 33″ nearly = *MM'*.

From this value of the arc, the length of the line *MA* is found to be $16\frac{1}{12}$ feet when *ME* = 240,000 miles. That is, a body at the moon's distance falls as far in one minute as it would do on the Earth's surface in one second—that is, it falls a distance 60 times less. A body on the Earth's surface is 4,000 miles from the Earth's centre, whereas the Moon lies at a distance of 240,000 from that centre—that is, exactly (or exactly enough for our present purpose) 60 times more distant.

613. It is found, therefore, that the deflection produced in the Moon's orbit from the tangent to its path in one second is precisely of $\frac{16\frac{1}{12}}{3600}$ a foot. Here we see that, as the Moon is sixty times further from the Earth's centre than a stone at the Earth's surface, it is attracted to the Earth 60 × 60, or 3600 times less. In fact, the force is seen experimentally *to vary inversely as the square of the distance* of the falling body from the surface. It was this calculation that revealed to Newton the law of universal gravitation.

614. Long before Newton's discovery, Kepler, from observations of the planets merely, had detected certain laws of their motion, which bear his name. They are as follows :—

I. Each planet describes round the Sun an orbit of elliptic form, and the centre of the Sun occupies one of the foci.

II. The areas described by the radius-vector of a planet are proportional to the time taken in describing them.

III. If the squares of the times of revolution of the planets round the Sun be divided by the cubes of their mean distances, the quotient will be the same for all the planets.

615. We have already in many places referred to the first law : II. and III. require special explanation, which we will give in this place. We stated in Art. 293 that the planets moved faster as they approached the Sun; II. tells how much faster. The **radius-vector** of a planet is the line joining the planet and the Sun. If the planet were always at the same distance from the Sun, the radius-vector would not vary in length; but in elliptic orbits its length varies; and the shorter it becomes, the more rapidly does the planet progress. This law gives the exact measure of the increase or decrease of the rapidity.

616. In Fig. 79 are given the orbit of a planet and the Sun situated in one of the foci, the ellipticity of the

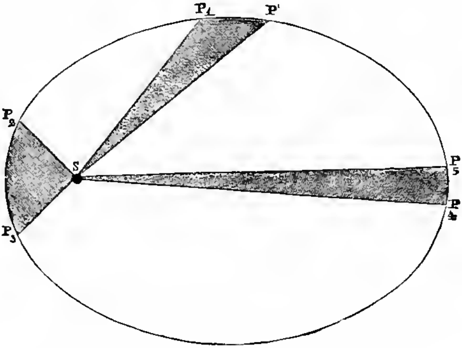

FIG. 79.—Explanation of Kepler's second law.

planet's orbit being exaggerated to make the explanation clearer. The areas of the three shaded portions are equal to each other. It is readily seen that where the radius-vector is longest, the path of the planet intercepted is shortest, and *vice versâ.* This, of course, is necessary to produce the equal areas. In the figure, the arcs $P\,P_1$, $P_2\,P_3$, and P_4P_5, are those described at mean distances perihelion and aphelion respectively, in equal times; therefore, as a greater distance has to be got over at perihelion and a less one at aphelion than when the planet is situated at its mean distance, the motion in the former case must be more rapid, and in the latter case slower, than in other parts of the orbit.

617. The third law shows that the periodic time of a planet and its distance from the Sun are in some way bound together, so that if we represent the Earth's distance and periodic time by 1, we can at once determine the distance of, say, Jupiter from the Sun, by a simple proportion; thus—

$$\left.\begin{array}{c}\text{Square of}\\\text{Earth's}\\\text{period}\\1\times1\end{array}\right\} : \left\{\begin{array}{c}\text{Square of}\\\text{Jupiter's}\\\text{period.}\\11{\cdot}86\times11{\cdot}86\end{array}\right\} :: \left\{\begin{array}{c}\text{Cube of}\\\text{Earth's}\\\text{distance}\\1\times1\times1\end{array}\right. : \left\{\begin{array}{c}\text{Cube of}\\\text{Jupiter's}\\\text{distance}\\=\\140{\cdot}559.\end{array}\right.$$

That is, whatever the distance of the Earth from the Sun may be, the distance of Jupiter is $\sqrt[3]{140}$ times greater.

618. The following table shows the truth of the law we are considering:—

	Periodic Time.	Mean distance. Earth = 1.	Time squared. / Distance cubed.
Mercury	87·97	0·3871	133,421
Venus	227·70	0·7233	133,413
Earth	365·25	1·0000	133,408
Mars	686·98	1·5237	133,410
Jupiter	4332·58	5·2028	133,294
Saturn	10759.22	9·5388	133,401
Uranus	30688·30	19·1834	133,404
Neptune	60180·86	30·0544	133,411

LESSON XLIX.—*Kepler's Second Law proved. Centrifugal Tendency. Centripetal Force. Kepler's Third Law proved. The Conic Sections. Movement in an Ellipse.*

619. As these laws were given to the world by Kepler, they simply represented facts; for, owing to the backward state of the mechanical and mathematical sciences in his time, he was unable to see their hidden meaning. This was reserved for the genius of Sir Isaac Newton, after Kepler's time.

620. Newton showed that all these laws established the truth of the law of gravitation, and flowed naturally from it. In Fig. 80, let S represent the centre of the Sun, and P a planet, at a given moment. During a very short time this planet will describe a part of its orbit PP', and its radius-vector will have swept over the area PSP'. If no new force intervene, in another similar interval the planet will have reached P'', the area $P'SP''$ being equal to

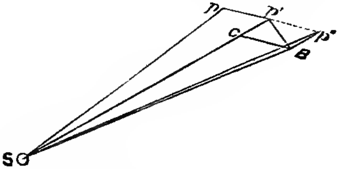

FIG. 80.—Proof of Kepler's second law.

PSP' according to Kepler's second law. But the planet will really describe the arc $P'B$, and the area $P'SB$ will be equal to $P'SP''$; as the triangles are equal, and on the same base, the line $P''B$ will be parallel to $P'S$; and completing the parallelogram $P'P''BC$, we see that the planet at P' was acted upon by two forces, measured by $P'P''$ and $P'C$—that is, by its initial velocity and a force directed to the Sun. Hence Kepler's second law shows that this force is directed towards the Sun.

621. A good idea of the tendency of bodies to keep in the direction of their original motion may be gained by attaching a small bucket, nearly filled with water, to a rope, and by swinging it round gently; the tendency of the water to fly off will prevent its falling out of the bucket; and it will be found that the more rapidly the bucket is whirled round, the greater will be this tendency, and therefore the tighter will be the rope.

622. The circular movement of the bucket is represented in Fig. 81. A represents the bucket, OA the rope; let us suppose that the bucket receives an impulse which in the absence of the rope, would have sent it in the direction AB with an uniform motion. In a very short time, being held by the rope, it will arrive at c, and $A\,d$ measures the force applied by the rope. Call this force f, we have

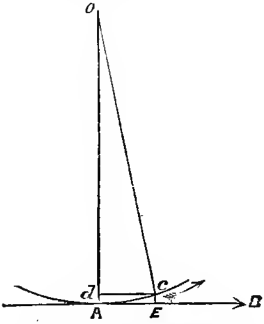

FIG. 81.—Circular Motion.

$$A\,d = \tfrac{1}{2} f\, t^2 \quad . \quad . \quad . \quad . \quad (1).$$

Further, the distance traversed—that is, $A\,c$—is determined by the velocity (v) of the bucket, and the time taken (t), so we have $Ac = v\,t$; and the arc $A\,c$ being taken equal to its chord, we have, representing the radius by R,

$$A\,c^2 = 2R \times A\,d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

But $A\,c = vt$, and $A\,d = \tfrac{1}{2}ft^2$; therefore,

$$v^2t^2 = 2R \times \tfrac{1}{2}ft^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

$$\text{and } f = \frac{v^2}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

This gives the acceleration in feet independently of the mass m of the bucket; if the force is sought in pounds, m must be introduced, and the equation becomes

$$f = \frac{mv^2}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

This measures, in the instance we have quoted, the amount of pull on the rope, the rope holding the bucket by a force $\frac{mv^2}{R}$ equal in amount and opposite. The first is called the **centrifugal tendency**; the second the **centripetal** force.

As the entire circumference $2\pi R$ (where ν π 3·1416 and R = radius) is traversed at the velocity ν in the time t, we have

$$2\pi R = \nu t,$$

$$\text{that is, } \nu = \frac{2\pi R}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6).$$

Substituting this in equation 4, we get

$$f = \frac{4\pi^2 R}{t^2} \text{ or } = 4\pi^2 \frac{R}{t^2} \quad . \quad\quad . \quad . \quad (7).$$

623. Now if for a moment the orbits of the planets be treated as circles, this formula gives the acceleration of their motion—that is, the force of attraction on a unit of mass at the planet's distance, as attraction does exactly for the planet what the rope does for the bucket.

Let it next be supposed that several planets at different distances from the Sun represented by $R\,R'\,R''$ . . . . are revolving round him in different times, $T\,T'\,T''$ . . . . we shall have in each case

$$f = 4\pi^2 \frac{R}{T^2} \qquad f' = 4\pi^2 \frac{R'}{T'^2} \qquad f'' = 4\pi^2 \frac{R''}{T'^2}$$

But, by Kepler's third law, in each case the squares of the times of revolution T^2 T'^2 T''^2 are proportional to the cubes of the distance from the Sun R, R', &c. Calling this law L, we have in each case

$$L = \frac{R^3}{T^2} \quad L = \frac{R'^3}{T'^2} \quad L = \frac{R''^3}{T''^2}.$$

Dividing the former equations by these, we get

$$f = 4\pi^2 \frac{L}{R^2} \quad f' = 4\pi^2 \frac{L}{R'^2} \quad f'' = 4\pi^2 \frac{L}{R''^2};$$

that is, in each case f, or the attraction on the unit of mass, varies in the inverse ratio of the square of the distances.

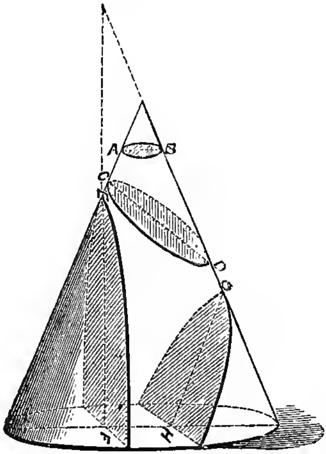

FIG. 82.—The Conic Sections: $A\,B$ the circle; $C\,D$ the eclipse; $E\,F$ the hyperbola; $G\,H$ the parabola.

624. Newton also showed, in a similar manner, that the attraction is proportional to the product of the masses of the bodies; and that if we take two bodies, the Sun and our Earth, for instance, we may imagine all the gravitating energies of each to be concentrated at their centres, and that if the smaller one receives an impulse neither exactly towards nor from the larger one, it will describe an orbit round the larger one, the orbit being one of the conic sections—that is, either a circle, ellipse, hyperbola, or parabola. Which of these it will be depends in each case upon the direction and force of the original impulse, which, as the movements of the heavenly bodies are not arrested as bodies in movement on the Earth's surface are, is still at work, and suffices for their present movements. Were the attraction of the central body to cease, the revolving body, obeying its original impulse, would leave its orbit, in consequence of the centrifugal tendency it acquired at its original start: were the centrifugal tendency to cease, the centripetal force would be uncontrolled, and the body would fall upon the attracting mass.

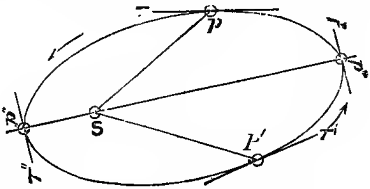

FIG. 83.—Diagram showing how the varying velocities of a body revolving in an orbit are caused and controlled.

625. Next let us inquire how it is that equal areas are swept over in equal times. This is easily understood in a circle, and may be explained as follows in the ellipse:—In a circle the motion is always at a right angle to the line joining the two bodies; this condition of things occurs only at two points in an ellipse, *i.e.* at the **apses**, or extremities of the major axis—the aphelion and perihelion points.

626. In Fig. 83 the planet P is moving in the direction PT, the tangent to the ellipse at the place it occupies, and this direction is far from being at right angles to the Sun, so that the attractive force of the Sun helps the planet along. At P' it is equally evident that the attractive force is pulling the planet back. At P'' the attractive force is strong, but the planet is enabled to overcome it by the increased velocity it has acquired from being acted upon at P; while at P''' the attractive force is weak, but the planet is not able to overcome it, on account of its velocity having been enfeebled from being acted upon as at P'.

LESSON L.—*Attracting and Attracted Bodies considered separately. Centre of Gravity. Determination of the Weight of the Earth; of the Sun; of the Satellites.*

627. As every particle of matter attracts every other particle, the smaller bodies attract the larger ones; so that, to speak of the Sun and Earth as examples, the Earth attracts the Sun as well as the Sun the Earth.

628. Now, it must here be remarked that, at the same distance, the attraction of one body on another is quite independent of the mass of the *attracted* body. If we take the Earth as the attracting body, for instance, and the Sun and Jupiter when equally distant from the Earth as the attracted bodies, leaving for the present mutual attractions out of the question, the Earth's attractive power over both is equal, and is the same as it would be on a pea or on a mass larger even than the Sun, at the same distance. That is, if we had the Sun, Jupiter, a pea, and a mass larger than the Sun, at the same distance from the Earth, the Earth's attraction would pull them through the same number of feet and inches in one second of time.

629. Secondly, still dealing with attracted bodies at the same distance from the attracting body, not only will the attraction be the same for all, but it will depend upon, and vary with, the mass of the attracting body.

630. Thirdly, if the attracted bodies be at different distances, the power of the attracting body over them varies inversely as the square of its distance from them.

631. If we consider the mutual attractions, then the attraction of a body with, say, one unit of mass will be 1,000 times less than that of a body with 1,000 units of mass—this proportion being, of course, kept up at all distances. If in the case of two bodies, such as the Earth and Sun, all the attraction were contained, say, in the Sun, then the Earth would revolve round the Sun, the Sun's centre being the centre of motion ; but as the Earth pulls the Sun, as well as the Sun the Earth, a consequence of this is, that both Earth and Sun revolve round a point in a line joining the two, called the **centre of gravity**. The centre of gravity would be found if we could join the two bodies by a bar, and find out the point of the bar by which they could be suspended, scale fashion. It is clear that if the two bodies were of the same mass, such a point of suspension would be half-way between the two ; if one be heavier than the other, the point of suspension will approach the heavier body in the ratio of its greater weight. In the case of the Sun and Earth, for

FIG. 84.—Centre of Gravity and Motion in the case of *equal* masses. *A* and *B*, two equal masses ; *c*, the centre of gravity and motion.

instance, the centre of gravity of the two lies within the Sun's surface.

632. It follows from what has been stated, that the masses of the Sun, and of those planets which have satellites, can be determined, if the mass of our own Earth and the various distances of the attracted bodies from their centres of motion are known: for, knowing the mass of our Earth, we can compare all *attracting* bodies with it, as their attractions are independent of the masses of the *attracted* bodies (Art. 628), and the law that attraction varies inversely as the square of the distance is established (Art. 606); so that we can exactly weigh them against the Earth. Thus we can weigh the Sun, because the planets revolve round him; and from the curvature of their paths we can determine his pull, and contrast it with the Earth's pull. We can similarly weigh Jupiter, Saturn, Uranus, Neptune, and the double stars whose distances and orbits are known.

FIG. 85.—Centre of Gravity and Motion in the case of *unequal* masses. *A* and *B*, two unequal masses; *c*, the centre of gravity and motion.

633. Further, attraction is not only a *controlling force* keeping each planet and satellite in its orbit with regard to the central body, but it is a *disturbing* or *perturbating force*, seeing that every body attracts every other body: hence its effects are of the most complicated kind, as will be seen presently. By carefully watching the perturbating effects of our Moon on the Earth; and of those planets which have no satellites, and of the satellites of Jupiter, Saturn, Uranus, and Neptune upon each other;

their masses, in terms of the Earth's mass, have also been determined. Let us see how this has been done.

634. It is not sufficient to determine the Earth's bulk or volume, because it might be light, like a gas, or heavy, like lead. The mean density, or specific gravity, of its materials—that is, how much the materials weigh, bulk for bulk, compared with some well-known substance such as water—must be determined.

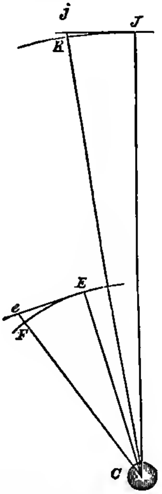

FIG. 86.—Showing the differences in the curvature of the orbits of Jupiter and the Earth. *J K* and *E F*, the fall towards the Sun.

635. The following methods have been used to determine the density of the Earth:—

I. By comparing the attractive force of a large ball of metal with that of the Earth.

II. By determining the degree by which a large mountain will deflect, or pull out of the upright towards it, a plumb-line.

III. By determining the rate of vibration of the same pendulum—
   (*a*) on the top and at the bottom of a mountain.
   (*b*) at the bottom of a mine, and at the Earth's surface.

636. It will be sufficient here to describe the first mentioned method, which was adopted by Cavendish in 1798, and called the *Cavendish experiment.* The weight of anything is a measure of the Earth's attraction. Cavendish, therefore, took two small leaden balls of known weight, and fixed them at the two ends of a slender wooden rod six feet long, the rod being suspended by a fine wire. When the rod was perfectly at rest, he brought two large leaden balls, one on either side of the small

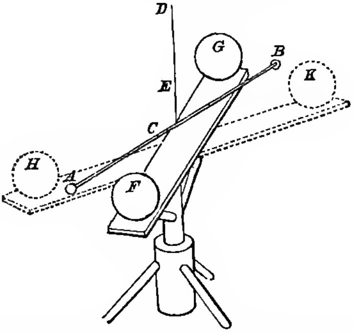

FIG. 87.—*The Cavendish Experiment.* *A B,* the small leaden balls on the rod *C.* *D E,* the suspending wire. *F G,* the large leaden balls on one side of the small ones. *H K,* the large leaden balls in a position on the other side.

ones. If the large balls exerted any appreciable attractive influence on the smaller ones, the wire would twist, allowing each small ball to approach the large one near it; and a telescope was arranged to mark the deviation.

637. Cavendish found there was a deviation. This enabled him to calculate how large it would have been had each large ball been as large as the Earth. He then had the attraction of the Earth, measured by the weight of the small balls, and the attraction of a mass of lead as large as the Earth, as the result of his experiment. The density of the Earth then was to the density of lead as the attraction of the Earth to the attractive force of a leaden ball as large as the earth. This proportion gave a density for the Earth of 5·45 (corrected later to 5·55) as compared with water, the density of lead being 11·35 compared with water. With this density, the weight or mass of the whole Earth can readily be determined; it amounts in round numbers to

6,000,000,000,000,000,000,000 tons:

but this number is not needed in Astronomy; the relative masses indicated in Art. 147 are sufficient.

638. Then as to the mass of the Sun. The question is, how many times is the mass of the Sun greater than the mass of the Earth? We shall evidently get an answer if we can compare the action of the Earth and Sun upon the same body. Now, on the Earth's surface, *i.e.*, at 4,000 miles from its centre, a body falls $16\frac{1}{12}$ feet in a second. Can we determine how far it would fall at 4,000 miles from the centre of the Sun? This is easy since we can determine as in the case of the Moon (Art. 612) how far the Earth falls to the Sun in a second: it is found to be ·0099 feet. But this is at a distance of 92,965,000 miles from the Sun's centre. We must bring this to 4,000 miles from the Sun's centre, or 23,241 times nearer. Now as attraction varies inversely as the square of the distance, we must multiply the square of 23,241 by ·0099 to represent the fall of the body in one second at 4,000 miles from the Sun's surface. The result is 5,337,427 feet. Then

$$\overset{\text{ft.}}{16\tfrac{1}{12}} \ : \ \overset{\text{ft.}}{5{,}337{,}427} \ :: \ 1 \ : \ 331{,}867$$

The mass of the Sun therefore is roughly 331,867 times greater than that of the Earth. The correct mass is stated in Table IV. of the Appendix.

639. Similarly from the orbit of any one of the satellites we determine its rate of fall at 4,000 miles from the centre of any of the planets, and then compare it with the $16\frac{1}{12}$ feet fall on the Earth's surface.

640. Or we may determine the Sun's mass from equation 7 (Art. 622) in this way:—

The centrifugal tendency of the Earth in her orbit $=4\pi^2\frac{R}{T^2}$; and this equally measures the Sun's attraction, which is proportional to his mass, and inversely as the square of the distance; so that we have

$$\frac{\text{Sun's mass}}{R^2} = 4\,\pi^2\frac{R}{T^2} \quad . \ . \ . \ . \ . \quad (1)$$

Or

$$\text{Sun's mass} = 4\pi^2\frac{R^3}{T^2} \quad . \quad . \ . \quad (2)$$

Again, we may take $4\pi^2\ \frac{r}{t^2}$ to represent the Earth's attraction on the Moon; so that

$$\text{Earth's mass } 4\pi^2\frac{r^3}{t^2} \quad . \ . \ . \quad . \ . \ (3).$$

Dividing the Sun's mass by the Earth's mass (that is, dividing equation 2 by equation 3), we get—

$$\frac{\text{Sun's mass}}{\text{Earth's mass}} = \frac{R^3}{T^2} \times \frac{t^2}{r^3} \quad . \ . \ . \quad . \ (4).$$

We next substitute values :—

$R_{\odot}$ = the Sun's distance from the earth = 11,744 Earth diameters.
T = the Earth's year . = 365·265 days.
r = the Earth's distance from the Moon . = 29·982 Earth diameters.
t = the Moon's period. . = 27·321 days.

So equation 4 becomes :

$$\frac{\text{Sun's mass}}{\text{Earth's mass}} = \frac{11{,}744^3 \times 27{\cdot}321^2}{365{\cdot}265^2 \times 29{\cdot}982^3}.$$

This should be worked out.

In the same way we may determine the mass of Jupiter, Saturn, Uranus, or Neptune.

641. The force of gravity on the surface of the Sun or a planet, compared to that on our Earth, may be determined in the following manner:

Let us take the case of the Sun. If we take the Earth's radius, mass, and gravity, each as 1, then the gravity on the Sun's surface compared to that on the Earth's will be —

$$\frac{\text{Sun's mass}}{\text{Square of distance}} = \frac{330{\cdot}000}{109{\cdot}3^2} = 27{\cdot}6.$$

LESSON LI.—*General Effect of Attraction. Precession of the Equinoxes; how caused. Nutation. Motions of the Earth's Axis. The Tides. Semi-diurnal, Spring, and Neap Tides. Cause of the Tides. Their probable Effect on the Earth's Rotation.*

642. What has gone before will show that it is the attraction of gravitation which causes the planets and satellites to pursue their paths round the central body; that their motion is similar to that of a projectile fired on the Earth's surface, if we leave out of consideration the resistance of the air; and that Newton's law enables us to determine the masses of the Sun and of the other bodies from their motions, when the mass of the Earth itself is known.

643. Moreover, the orbit which each body would describe round the Sun or round its primary, if itself and the Sun or primary were the only bodies in the system, is liable to variations in consequence of the existence of the other planets and satellites, since these attract the body as the Sun or primary attracts it, the attractions varying according to the constantly changing distances between the bodies. These irregular attractions, so to speak, are called **perturbations,** and the resulting changes in the motions of the bodies are called **inequalities** if the disturbances are large, and **secular inequalities** if they are of such a nature that they require a long period of time to render them sensible.

644. These perturbations, and their results on the orbits of the various bodies, are among the most difficult subjects in the whole domain of astronomy, and a sufficient statement and explanation of them would carry us beyond the limits of this little book. We will conclude this chapter, therefore, with a reference to two additional effects of attraction of a somewhat different kind, and of the utmost importance, on the Earth itself. One results from the attractions of the Sun and Moon on the equatorial protuberance, and is called **the precession of the equinoxes;** the other is due to the attractions of the Sun and Moon on the water on the Earth's surface, whence result **the tides.**

645. Let the equatorial protuberance of the Earth be represented by a ring, supported by two points at the extremities of a diameter on a horizontal concentric ring, and inclined to its support as the Earth's equator is inclined to the ecliptic. Let a long string be attached to the highest portion of the ring, and let the string be pulled horizontally, at right angles to the two points of suspension, and away from the centre of the ring. This pull will represent the Sun's attraction on the protuberance. The effect on the ring will be that it will at once take up a horizontal position; the highest part of the ring will fall as if it were pulled from below, the lowest part will rise as if pulled from above.

646. The Sun's attraction on the equatorial protuberance in certain parts of the orbit is exactly similar to the action of the string on the ring, but the problem is complicated by the two motions of the Earth. In the first place—in virtue of the yearly motion round the Sun—the protuberance is presented to the Sun differently at different times, so that twice a year (at the solstices) the action is greatest, and twice a year (at the equinoxes) the action is *nil;* and, in the second place, the Earth's rotation is constantly varying that part of the equator subjected to the attraction.

647. If the Earth were at rest, the equatorial protuberance would soon settle down into the plane of the ecliptic; in consequence, however, of its two motions, this result is prevented, and the attraction of the Sun on a particle situated in it is limited to causing that particle to meet the plane of the ecliptic earlier than it otherwise would do if the Sun had not this special action on the protuberance. If we take the presentation of the Earth to the Sun at the winter solstice (Fig. 18), and bear in mind that the Earth's rotation is from left to right in the diagram, it will be clear, that while the particle is mounting the equator, the Sun's attraction is pulling it down; so that the path of the particle is really less steep than the equator is represented in the diagram: towards the east the particle descends from this less height more rapidly than it would otherwise do, as the Sun's attraction is still exercised: the final compound result therefore is, that it meets the plane of the ecliptic sooner than it otherwise would have done.

648. What happens with one particle in the protuberance happens with all; one half of it, therefore, tends to fall, the other half tends to rise, and the whole Earth meets the strain by rolling on its axis: the inclination of the protuberance to the plane of the ecliptic is not altered, but, in consequence of the rolling motion, the places in which it crosses that plane precede those at which the equator would cross it were the Earth a perfect sphere: hence the term **precession.**

649. In what has gone before the sphere inclosed in the equatorial protuberance has been neglected, as the action of the Sun on the spherical portion is constant: it plays an important part, however, in averaging the precessional motion of the entire planet during the year, acting as a break at the solstices, when the Sun's action on the equatorial protuberance is most powerful, and continuing the motion at the equinoxes, when, as before stated, the Sun's action is *nil.*

650. Also, for the sake of greater clearness, we have omitted to consider the Moon, although our satellite plays the greatest part in precession, for the following reason: The action referred to does not depend upon the actual attractions of the Sun and Moon upon the Earth as a whole, which are in the proportion of 120 to 1, but upon the difference of the attraction of each upon the various portions of the Earth. As the Sun's distance is so great compared with the diameter of the Earth, the differential effect of the Sun's action is small; but as the Moon is so near, the differential effect is so considerable that her precessional action is three times that of the Sun.

651. An important result of the motion of the protuberance has now to be considered. The change in the position of the equator, which follows from the rolling motion, is necessarily connected with a change in the Earth's axis.

652. In Fig. 88, let ab represent the plane of the ecliptic, CQ a line perpendicular to it, hfe the position of the equator at any time at which it intersects the plane of the ecliptic in *e*. The position of the Earth's axis is in the direction *Cp*. When, by virtue of the precessional movements, the equator has taken up the position *lkg*, crossing the plane of the ecliptic in *g*, the Earth's axis will occupy the position *Cp'*.

653. The lines *Cp* and *Cp'* have both the same inclination to *CQ*. It follows, therefore, that the motion of the Earth's axis due to precession consists in a slow revolution round the axis of the celestial sphere, perpendicular to the plane of the ecliptic.

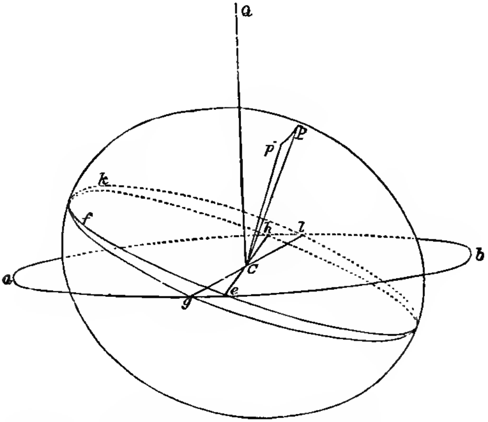

FIG. 88.—Showing the effects of Precession on the position of the Earth's axis.

654. Superadded to the general effect of the Sun and Moon in causing the precession of the equinoxes, or luni-solar precession, is an additional one due to the Moon alone, termed **nutation**.

655. The Moon's nodes perform a complete revolution in nineteen years (Art. 244); consequently for half this period the Moon's orbit is inclined to the ecliptic in the same way as the Earth's equator is, though in a less degree (*m n*, Fig. 89, *a b* representing the mean inclination). During the other half the orbit is inclined so that its divergence from the plane of the Earth's equator, *E Q*, is very considerable (*p q*).

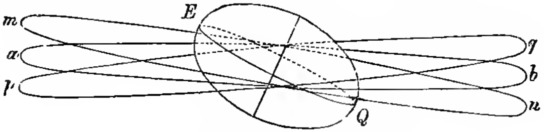

FIG. 89.—Explanation of Nutation.

656. It follows, from what we have already seen in the case of the Sun, that in the former position, *m n*, the precessional effect will be small, while in the latter position, *p q*, it will be great.

657. Hence the circular movement of the axis which causes the precession of the equinoxes is not the only one; there is another due to the **nutation.** Were the pole at rest, we should have from this latter cause a small ellipse described every nineteen years; but since it is in motion, as we have seen in Art. 653, the two motions are

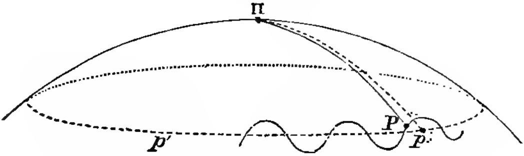

FIG. 90.—Apparent motion of the Pole of the Equator, *P*, round the Pole of the heavens (or Ecliptic), Π.

compounded so that the motion of the pole of the equator round the pole of the ecliptic, instead of being circular, is *waved.*

658. The effect of these motions of the Earth's axis on the apparent position of the heavenly bodies, and the corrections which are thereby rendered necessary, have already been referred to at length in Lesson XLIII.

We next come to the **tides.**

659. The waters of the ocean rise and fall at intervals of 12 hours and 25 minutes—that is, they rise and fall twice in a lunar day (Art. 423). When the tide is highest, we have **high water,** or flood ; after this the tide **ebbs,** or goes down, till we have **low water,** or ebb : and after this the water **flows,** or increases again to the next high water, and so on.

660. We not only have two tides in a lunar day, but twice in the lunar month—about three days after new and full Moon—the tides are higher than usual : these are the **spring** tides. Twice also, three days after the Moon is in her quadratures, they are lower than usual: these are the **neap** tides. It will be gathered from the foregoing that the tides have something to do with the Moon ; in fact, these phenomena are due to the attraction of the Sun and Moon on the fluid envelope of the Earth, and, as in the case of luni-solar precession, not only is it to the differential action of these bodies, and not to their absolute action, that the effect is due, but the two periods correspond with the lunar day and the lunar month, because the Moon's differential attraction is far greater than that of the Sun.

661. If we take the Sun's distance as 23,482 terrestrial radii, and its mass as 330,000 times that of the Earth, the Earth's action on a particle of water at its surface being represented by 1, then $\frac{330,000}{23,481^2}$ and $\frac{330,000}{23,483^2}$ will represent the Sun's attraction on a particle on the sides of the Earth adjacent to it and turned away from it respectively.

In the case of the Moon we shall have, similarly, $\frac{\cdot 0123}{59^2}$ and $\frac{\cdot 0123}{61^2}$; it is readily seen that the differential attraction, therefore, in the case of the Moon is much greater than in the case of the Sun.

662. It may be stated generally, that the semi-diurnal tides are caused by the Moon (although there is really a smaller daily tide caused by the Sun), that the semi-monthly variation in their amount is due to the Sun's tide being added to that of the Moon when she is new and full—that is, when the Sun and Moon are pulling together; and subtracted from it when at the first and last quarters they are pulling crosswise, or at right angles to each other.

663. The double daily tide arises from the action of the Moon on both the water and the Earth itself. On the side under the Moon the water is pulled from the Earth, piled up under the Moon, as the Moon's action on the surface water is greater than its action on the Earth's centre; but, for the same reason, the Moon's attraction on the Earth's centre is greater than its attraction on the water on the opposite side of the Earth, so that in this case, as the solid earth must move with its centre, the Earth is pulled from the water. There are, therefore, always two tides on the Earth's surface; and it is to the motion of rotation of the Earth under this double tide—which is a state of the water merely without progressive motion—nearly at rest under the Moon, and under which the Earth (as it were) slips round—that the occurrence of two tides a day instead of one is due. There is, in fact, an ellipsoid of water inclosing the Earth, which always remains with its longer axis pointing to the Moon.

664. The existence of a state of high water under, or nearly under, the Moon, does not depend merely upon the direct attraction of our satellite upon the particles immediately underneath it, but upon its action upon all the particles of water on the side of the Earth turned to it, all of which tend to *close up* under the Moon. The force acting upon these particles is called the tangential component of the attraction ; and this is by far the most powerful cause of the tides, as it acts at right angles to the Earth's gravity, whereas the direct attraction of the Moon acts in opposition to it.

665. The spring and neap tides, which, as we have seen, depend upon the combined or opposed action of the Sun and Moon in longitude, are also influenced by the difference of latitude between the two bodies. Of course, that spring tide will be highest which occurs when the Moon is nearest her node, or in the ecliptic. The apex of the semi-diurnal tide also follows the Moon throughout her various declinations.

666. The phenomena of the tides are greatly complicated by the irregular distribution of land. The time of high water at any one place occurs at the same interval from the Moon's passage over the meridian ; this period is different for different places. The interval at new or full Moon between the times of the Moon's meridian passage and high water is termed the **establishment of the port.**

667. Although in the open ocean the velocity of the tidal undulation may be 500 or even 900 miles an hour, in shallow waters the undulation is retarded to even seven miles at the same time that its height is increased. The average height of the tide round the islands in the Atlantic and Pacific Oceans is but 3½ feet ; whereas at the head of the Bay of Fundy it is 70 feet. As the tidal undulation does not move so rapidly as the Earth does, since it is regulated by the Moon, it appears to move westward while the Earth is moving eastward ; and it has been suggested that this apparent backward movement *acts as a break* on the Earth's rotation, and that, owing to the effects of tidal action, the diurnal rotation is, and has been, constantly decreasing in velocity to an extremely minute extent. At all events, if the sidereal day be assumed to be invariable, it is impossible to represent the Moon's true place at intervals 2,000 years apart by the theory of gravitation. On this assumption the Moon, looked upon as a time-piece, is *too fast* by 6″ or 12s. (nearly) at the end of each century. This may be due to the fact that our standard of measurement of the sidereal day is *too slow*; and it has been calculated that this part of the apparent acceleration of the Moon's mean motion may be accounted for by supposing that the sidereal day is shortening, in consequence of tidal action, at the rate of $\frac{1}{66}$th part of a second in 2,500 years.

APPENDIX.

APPENDIX.

TABLE I.

EXPLANATION OF ASTRONOMICAL SYMBOLS AND ABBREVIATIONS.

Signs of the Zodiac.

			°				
0.	♈	Aries	0	VI.	♎	Libra . . .	180
I.	♉	Taurus . .	30	VII.	♏	Scorpio . .	210
II.	♊	Gemini	60	VIII.	♐	Sagittarius.	240
III.	♋	Cancer . . .	90	IX.	♑	Capricornus	270
IV.	♌	Leo . .	120	X.	♒	Aquarius .	300
V.	♍	Virgo . .	150	XI.	♓	Pisces . . .	330

The Sun.
☉

The Moon.
☾

Major Planets.

☿ Mercury.
♀ Venus.
⊕ or ♁ The Earth.
♂ Mars.

♃ Jupiter.
♄ Saturn.
♅ Uranus.
♆ Neptune.

A Comet.
☄

A Star.
✳

☌ Conjunction.
□ Quadrature.
☍ Opposition.
☊ Ascending Node.
☋ Descending Node.
⚹ Sextile.
h Hours.
m Minutes of Time.
s Seconds of Time.

° Degrees.
′ Minutes of Arc.
″ Seconds of Arc.
R.A. or Æ. or α., Right Ascension.
Decl. or D. or δ., Declination.
N.P.D., North Polar Distance.

Minor Planets.

① Ceres.
② Pallas.
③ Juno.
④ Vesta.

⑤ Astræa.
⑥ Hebe.
⑦ Iris.
⑧ Flora.

⑨ Metis.
⑩ Hygeia.
⑪ Parthenope.
⑫ Victoria.

Minor Planets—continued.

⑬ Egeria.
⑭ Irene.
⑮ Eunomia.
⑯ Psyche.
⑰ Thetis.
⑱ Melpomene.
⑲ Fortuna.
⑳ Massalia.
㉑ Lutetia.
㉒ Calliope.
㉓ Thalia.
㉔ Themis.
㉕ Phocæa.
㉖ Proserpine.
㉗ Euterpe.
㉘ Bellona.
㉙ Amphitrite.
㉚ Urania.
㉛ Euphrosyne.
㉜ Pomona.
㉝ Polyhymnia.
㉞ Circe.
㉟ Leucothea.
㊱ Atalanta.
㊲ Fides.
㊳ Leda.
㊴ Lætitia.
㊵ Harmonia.
㊶ Daphne.
㊷ Isis.
㊸ Ariadne.
㊹ Nysa.
㊺ Eugenia.
㊻ Hestia.
㊼ Aglaia.
㊽ Doris.
㊾ Pales.
㊿ Virginia.
(51) Nemausa.
(52) Europa.
(53) Calypso.
(54) Alexandra.
(55) Pandora.
(56) Melete.
(57) Mnemosyne.
(58) Concordia.
(59) Olympia.
(60) Echo.
(61) Danaë.
(62) Erato.
(63) Ausonia.
(64) Angelina.
(65) Maximiliana.
(66) Maia.
(67) Asia.
(68) Leto.
(69) Hesperia.
(70) Panopæa.
(71) Niobe.
(72) Feronia.
(73) Clytie.
(74) Galatea.
(75) Eurydice.
(76) Freia.
(77) Frigga.
(78) Diana.
(79) Eurynome.
(80) Sappho.
(81) Terpsichore.
(82) Alcmene
(83) Beatrix.
(84) Clio.
(85) Io.
(86) Semele.
(87) Sylvia.
(88) Thisbe.
(89) Julia.
(90) Antiope.
(91) Ægina.
(92) Undina.
(93) Minerva.
(94) Aurora.
(95) Arethusa.
(96) Ægle.
(97) Clotho.
(98) Ianthe.
(99) Dike.
(100) Hecate.
(101) Helena.
(102) Miriam.
(103) Hera.
(104) Clymene.
(105) Artemis.
(106) Dione.
(107) Camilla.
(108) Hecuba.
(109) Felicitas.
(110) Lydia.
(111) Ate.

Minor Planets—continued.

(112) Iphigenia.
(113) Amalthea.
(114) Cassandra.
(115) Thyra.
(116) Sirona.
(117) Lomia.
(118) Peitho.
(119) Althæa.
(120) Lachesis.
(121) Hermione.
(122) Gerda.
(123) Brunhilda.
(124) Alcestis.
(125) Liberatrix.
(126) Velleda.
(127) Johanna.
(128) Nemesis.
(129) Antigone.
(130) Electra.
(131) Vala.
(132) Æthra.
(133) Cyrene.
(134) Sophrosyne.
(135) Hertha.
(136) Austria.
(137) Melibæa.
(138) Tolosa.
(139) Juewa.
(140) Siwa.
(141) Lumen.
(142) Polana.
(143) Adria.
(144) Vibilia.
(145) Adeona.
(146) Lucina.
(147) Protogeneia.
(148) Gallia.
(149) Medusa.
(150) Nuwa.
(151) Abundantia.
(152) Atala.
(153) Hilda.
(154) Bertha.
(155) Scylla.
(156) Xantippe.
(157) Dejanira.
(158) Coronis.
(159) Æmilia.
(160) Una.
(161) Athor.
(162) Laurentia.
(163) Érigone.
(164) Eva.
(165) Loreley.
(166) Rhodope.
(167) Urda.
(168) Sibylla.
(169) Zelia.
(170) Maria.
(171) Ophelia.
(172) Baucis.
(173) Ino.
(174) Phædra.
(175) Andromache.
(176) Idunna.
(177) Irma.
(178) Belisana.
(179) Clytemnestra.
(180) Garumna.
(181) Eucharis.
(182) Elsa.
(183) Istria.
(184) Deiopeia.
(185) Eunike.
(186) Celuta.
(187) Lamberta.
(188) Menippe.
(189) Phthia.
(190) Ismene.
(191) Colga.
(192) Nausicaa.
(193) Ambrosia.
(194) Procne.
(195) Eurycleia.
(196) Philomela.
(197) Arete.
(198) Ampella.
(199) Byblis.
(200) Dynamene.
(201) Penelope.
(202) Chryseïs.
(203) Pompeïa.
(204) Callisto.
(205) Martha.
(206) Hersilia.
(207) Hedda.
(208) Lachrymosa.
(209) Dido.
(210) Isabella.

Minor Planets—continued.

(211)	Isolda.
(212)	Medea.
(213)	Lilæa.
(214)	Aschera.
(215)	Œnone.
(216)	Cleopatra.
(217)	Eudora.
(218)	Bianca.
(219)	Thusnelda.
(220)	Stephania.
(221)	Eos.
(222)	Lucia.
(223)	Rosa.
(224)	Oceana.
(225)	Henrietta.
(226)	Weringia.
(227)	Philosophia.
(228)	Agathe.
(229)	Adelinda.
(230)	Athamantis
(231)	Vindobona.
(232)	Russia.
(233)	Asterope.
(234)	Barbara.
(235)	Carolina.
(236)	Honoria.
(237)	Cælestina.
(238)	Hypatia.
(239)	Adrastea.
(240)	Vanadis.
(241)	Germania.
(242)	Kriemhilda.
(243)	Ida.
(244)	Sita.
(245)	Vera.
(246)	Asporina.
(247)	Eukrate.
(248)	Lameia.
(249)	Ilse.
(250)	Bettina.
(251)	Sophia.
(252)	Clementina.
(253)	Mathilde.
(254)	Augusta.
(255)	Oppavia.
(256)	Walpurga.
(257)	Silesia.
(258)	Tyche.
(259)	Aletheia.
(260)	Huberta.
(261)	Prymus.
(262)	Valda.
(263)	Dresda.
(264)	Libussa.
(265)	Anna.
(266)	Aline.
(267)	Tirza.
(268)	Adorea.
(269)	(Palisa.)
(270)	Anahita.
(271)	Penthesilea.
(272)	(Charlois.)

TABLE II.—ELEMENTS OF THE PLANETS.

[For this and the following Tables the Author is largely indebted to "Chambers' Astronomy," and Proctor's "Saturn and his System."]

Symbol.	Distance from the Sun.			Distance from the Earth.		Time of Revolution Round the Sun.	Synodic Revolution.
	Mean.	Greatest.	Least.	Greatest.	Least.		
	Miles.	Miles.	Miles.	Miles.	Miles.	Mean Solar Days.	Mean Solar Days.
☿	35.987,000	43,386,000	28,588,000	137,910,000	48,020,000	87·9692	115·877
♀	67,245,000	67,705,000	66,787,000	162,229,000	23,701,000	224·7007	583·920
♁ or ⊕	92,965,000	94,524,000	91,406,000	……	……	365·2563	……
♂	141,650,000	154,860,000	128,440,000	249,384,000	33,916,000	686·9796	779·936
♃	483,678,000	507,016,000	460,340,000	601,540,000	365,816.000	4332·5848	398·867
♄	886,779,000	936,388,000	837,170,000	1,030,912,000	742,646,000	10759·2198	378·090
♅	1,783,383,000	1,866.059,000	1,700,707,000	1,960,583,000	1,606.183,000	30688·30	369·656
♆	2,794,000,000	2,819,120,000	2,768,881.000	2,913,644,000	2,674,357,000	60180·86	367·487

Symbol.	Time of Rotation on Axis.			Inclination of the Planet's Equator to its Orbit.			Ascending Node of Equator on Orbit.		Equatorial Diameter.	Planet's Mass, Earth's = 1.	Bodies Fall in 1 Second	Density, Earth's = 1.	Volume, Earth's = 1.	Apparent Diameter as seen from the Earth.	
														Greatest.	Least.
	h.	m.	s.	°	′	″	°	′	Miles.		Feet.			″	″
☿	24	5	28	20	?		?		2,957	0·065	6·95	1·21	0·044	11·5	4·5
♀	23	16	19	53	11	26	56	30	7,919	0·769	15·80	0·85	0·905	62·0	9·5
♁ or ⊕	23	56	4	23	27	24	0	0	7,927	1·000	16·09	1·00	1·000	...	...
♂	24	37	23	24	52	0	79	1	4,185	0·110	6·23	0·74	0·148	25·5	3·3
♃	9	55	28	3	4	0	313	22	87,680	311·868	45·02	0·24	1299·450	46·0	30·0
♄	10	14	24	26	49	0	171	43	73,713	93·328	18·36	0·13	717·907	20·5	14·6
♅	10	0	0	60	20	0	?		33,563	14·460	11·52	0·23	62·870	4·3	3·5
♆		?			?		?		36,620	16·863	12·17	0·20	84·316	2·7	2·6

TABLE III.—ELEMENTS OF THE SATELLITES.

Primary.	No.	Name of Satellite.	Distance from Primary.	Sidereal Revolution.			Inclination of Orbit to Plane of Ecliptic.			Diameter.	Apparent Star Magnitude.	Name of Discoverer.
			Miles.	d.	h.	m.	°	′	″	Miles.		
Earth.	1	Moon.										
Mars.	1	Phobos.	5,820	0	7	39	26	6	0	11	12	Hall.
	2	Deimos.	14,600	1	6	18	26	6	0	9	12	
Jupiter.	1	Io.	267,380	1	18	27	3	4	6	2,252	7	Galileo.
	2	Europa.	425,160	3	13	14	3	5	5	2,099	7	
	3	Ganymede.	678,390	7	3	43	3	9	2	3,436	6	
	4	Callisto.	1,192,820	16	16	32	3	28	0	2,929	7	
Saturn.	1	Mimas.	120,800	0	22	37	28	0	0	1,000	16	Sir W. Herschel.
	2	Enceladus.	155,000	1	8	53	28	0	0	?	15	"
	3	Tethys.	191,000	1	21	18	28	10	0	500	13	Cassini.
	4	Dione.,	246,000	2	17	41	28	10	0	500	12	"
	5	Rhea.	343,000	4	12	25	28	11	0	1.200	11	"
	6	Titan.	796,000	15	22	41	27	34	0	3,300	9	Huygens.
	7	Hyperion.	1,007,000	21	7	8	28	0	0	?	17	Bond and Lassell.
	8	Japetus.	2,314,000	79	7	55	18	44	0	1,800	11	Cassini.
Uranus. [Motion of Satellites retrograde.]	1	Ariel.	123,000	2	12	28	98	0	0	?	16	Lassell.
	2	Umbriel.	171,000	4	3	27	Ascending			?	16	"
	3	Titania.	281,000	8	16	55	Node			?	13	Sir W. Herschel.
	4	Oberon.	376,000	13	11	6	165° 30′			?	14	"
Neptune. [Motion possibly retrograde.]	1	……	220,000	5	21	8	145	7		…	14	Lassell.

TABLE IV.—THE SUN.

		Old Value.	New Value.
Equatorial horizontal parallax		8′·5776	8″·794
Mean distance from the Earth		95,274,000	92,965,000
Time of rotation	Variable with the latitude. The rotation in 24 hours of mean solar time is expressed by the formula, 865′ ± 165′ *sin* $\frac{7}{4}l$.		
Diameter in miles		888,646	867,000
Mass	Earth's as 1 =	354,936	330,000
Density		0·250	
Volume		1,415,225	1,305,000
Force of gravity at Equator		28·7	27·6
Inclination of Axis to plane of ecliptic		82° 45′	for 1850
Longitude of Node		73 40	
Apparent diameter as seen from the Earth—			
Maximum			32′36″·41
Minimum			31 32·0

TABLE V.

ADDITIONAL ELEMENTS OF THE MOON.

Mean Horizontal Parallax =	57′ 2″·70
Mean Angular Telescopic Semi-diameter	15′ 33·36
Ascending Node of Orbit	13° 53′ 17″
Mean Synodic Period	29·530588715 days
Time of Rotation	27·321661418 „
Inclination of Equator to the Ecliptic	1° 32′ 9″
Longitude of Pole	?
Daily Geocentric Motion	13 10 35
Mean Revolution of Nodes	6793^{d}·39108
„ „ Apogee or Apsides	3232·37543

Density, Earth as 1	=	0·60736
Volume, „	=	0·02033
Force of Gravity at Surface, Earth as 1	=	$\frac{1}{6}$
Bodies fall in One Second		2·6 feet

TABLE VI.—TIME.

I.—THE YEAR.

	Mean Solar Days. d.	h.	m.	s.
The Mean Sidereal Year	365	6	9	9·6
The Mean Solar or Tropical Year	365	5	48	46·054440
The Mean Anomalistic Year	365	6	13	49·3

II.—THE MONTH.

	d.	h.	m.	s.
Lunar or Synodic Month	29	12	44	2·84
Tropical Month	27	7	43	4·71
Sidereal „	27	7	43	11·54
Anomalistic „	27	13	18	37·40
Nodical „	27	5	5	35·60

III.—THE DAY.

The Apparent Solar Day, or interval between two transits of the Sun over the meridian	*variable.*		
The Mean Solar Day, or interval between two transits of the Mean Sun over the meridian	24	0	0

(Astronomers reckon this day from noon to noon, through the 24 hours.)

The Sidereal Day	23	56	4·09
The Mean Lunar Day	24	54	0

TABLE VII.

For converting Intervals of SIDEREAL Time into Equivalent Intervals of MEAN SOLAR TIME.

HOURS.		MINUTES.		SECONDS.		FRACTIONS OF A SECOND.	
Sidereal Time.	Equivalents in Mean Time.	Sidereal Time.	Equivalents in Mean Time.	Sidereal Time.	Equivalents in Mean Time.	Sidereal Time.	Equivalents in Mean Time.
h.	h. m. s.	m.	m. s.	s.	s.	s.	s.
1	0 59 50·170	1	0 59·8362	1	0·9973	0·01	0·0099
2	1 59 40·340	3	2 59·5085	3	2·9918	0·04	0·0399
3	2 59 30·511	5	4 59·1809	5	4·9864	0·07	0·0698
4	3 59 20·681	7	6 58·8532	7	6·9809	0·10	0·0997
5	4 59 10·852	9	8 58·5256	9	8·9754	0·13	0·1296
6	5 59 1·022	10	9 58·3617	10	9·9727	0·16	0·1596
7	6 58 51·193	11	10 58·1979	11	10·9700	0·19	0·1895
8	7 58 41·363	13	12 57·8703	13	12·9645	0·22	0·2194
9	8 58 31·534	15	14 57·5426	15	14·9591	0·25	0·2493
10	9 58 21·704	17	16 57·2150	17	16·9536	0·28	0·2792
11	10 58 11·874	19	18 56·8873	19	18·9481	0·30	0·2991
12	11 58 2·045	20	19 56·7235	20	19·9454	0·31	0·3092
13	12 57 52·215	21	20 56·5597	21	20·9427	0·34	0·3391
14	13 57 42·386	23	22 56·2320	23	22·9372	0·37	0·3690
15	14 57 32·556	25	24 55·9044	25	24·9318	0·40	0·3989
16	15 57 22·727	27	26 55·5767	27	26·9263	0·43	0·4288
17	16 57 12·897	29	28 55·2490	29	28·9208	0·46	0·4587
18	17 57 3·067	30	29 55·0852	30	29·9181	0·49	0·4887
19	18 56 53·238	31	30 54·9214	31	30·9154	0·50	0·4986
20	19 56 43·409	33	32 54·5937	33	32·9099	0·52	0·5186
21	20 56 33·579	35	34 54·2661	35	34·9045	0·55	0·5485
22	21 56 23·749	37	36 53·9384	37	36·8990	0·58	0·5784
23	22 56 13·920	39	38 53·6108	39	38·8935	0·61	0·6083
24	23 56 4·090	40	39 53·4470	40	39·8908	0·64	0·6382
		41	40 53·2831	41	40·8881	0·67	0·6682
		43	42 52·9555	43	42·8826	0·70	0·6981
		45	44 52·6278	45	44·8772	0·73	0·7280
		47	46 52·3002	47	46·8717	0·76	0·7579
		49	48 51·9725	49	48·8662	0·79	0·7878
		50	49 51·8087	50	49·8635	0·82	0·8178
		51	50 51·6449	51	50·8608	0·85	0·8477
		53	52 51·3172	53	52·8553	0·88	0·8776
		55	54 50·9896	55	54·8499	0·90	0·8975
		57	56 50·6619	57	56·8444	0·91	0·9075
		59	58 50·3343	59	58·8389	0·94	0·9374
		60	59 50·1704	60	59·8362	0·97	0·9673

TABLE VIII.

For converting Intervals of MEAN SOLAR Time into Equivalent Intervals of SIDEREAL Time.

HOURS.		MINUTES.		SECONDS.		FRACTIONS OF A SECOND.	
Mean Time.	Equivalents in Sidereal Time	Mean Time.	Equivalents in Sidereal Time.	Mean Time.	Equivalents in Sidereal Time.	Mean Time.	Equivalents in Sidereal Time.
h.	h. m. s.	m.	m. s.	s.	s.	s.	s.
1	1 0 9·856	1	1 0·1643	1	1·0027	0·01	0·0100
		3	3 0·4928	3	3·0082	0·04	0·0401
2	2 0 19·713	5	5 0·8214	5	5·0137	0·07	0·0702
3	3 0 29·569	7	7 1·1499	7	7·0192	0·10	0·1003
		9	9 1·4785	9	9·0246	0·13	0·1303
4	4 0 39·425	10	10 1·6428	10	10·0274	0·16	0·1604
5	5 0 49·282	11	11 1·8070	11	11·0301	0·19	0·1905
		13	13 2·1356	13	13·0356	0·22	0·2206
6	6 0 59·138	15	15 2·4641	15	15·0411	0·25	0·2507
7	7 1 8·995	17	17 2·7927	17	17·0465	0·28	0·2808
		19	19 3·1212	19	19·0520	0·30	0·3008
8	8 1 18·851	20	20 3·2855	20	20·0548	0·31	0·3108
9	9 1 28·708	21	21 3·4498	21	21·0575	0·34	0·3409
		23	23 3·7783	23	23·0630	0·37	0·3710
10	10 1 38·564	25	25 4·1069	25	25·0685	0·40	0·4011
11	11 1 48·421	27	27 4·4354	27	27·0739	0·43	0·4312
		29	29 4·7640	29	29·0794	0·46	0·4613
12	12 1 58·277	30	30 4·9282	30	30·0821	0·49	0·4913
13	13 2 8·134	31	31 5·0925	31	31·0849	0·50	0·5014
		33	33 5·4211	33	33·0904	0·52	0·5214
14	14 2 17·990	35	35 5·7496	35	35·0958	0·55	0·5515
15	15 2 27·847	37	37 6·0782	37	37·1013	0·58	0·5816
		39	39 6·4067	39	39·1068	0·61	0·6167
16	16 2 37·703	40	40 6·5710	40	40·1095	0·64	0·6417
17	17 2 47·560	41	41 6·7353	41	41·1123	0·67	0·6718
		43	43 7·0638	43	43·1177	0·70	0·7019
18	18 2 57·416	45	45 7·3924	45	45·1232	0·73	0·7320
19	19 3 7·273	47	47 7·7209	47	47·1287	0·76	0·7621
		49	49 8·0495	49	49·1342	0·79	0·7922
20	20 3 17·129	50	50 8·2137	50	50·1369	0·82	0·8222
21	21 3 26·985	51	51 8·3780	51	51·1396	0·85	0·8523
		53	53 8·7066	53	53·1451	0·88	0·8824
22	22 3 36·842	55	55 9·0351	55	55·1506	0·90	0·9025
23	23 3 46·698	57	57 9·3637	57	57·1561	0·91	0·9125
		59	59 9·6922	59	59·1615	0·94	0·9426
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