The elements of natural or experimental philosophy

https://hdl.handle.net/1874/359589

THE

ELEMENTS

OF

NATURAL OR EXPERIMENTAL PHILOSOPHY.

BY

TIBERIUS CAVALLO, F.R.S. &c.

ILLUSTRATED WITH COPPER PLATES.

IN FOUR VOLUMES.

VOL. IV.

LONDON:
Printed by Luke Hansard,
FOR T. CADELL AND W. DAVIES, IN THE STRAND.

1803.

Luke Hansard, Printer,
Great Turnſtile, Lincoln's-Inn Fields.

ELEMENTS OF

NATURAL PHILOSOPHY.

PART IV.

ASTRONOMY.

THE nature of the luminous objects that are ſeen in the heavens, and of which the moon is the neareſt to us; their number, their diſtances, their movements, with the appearances which ariſe therefrom, and the uſeful purpoſes to which the human ſpecies has applied the knowledge of thoſe particulars, form the ſcience of *aſtronomy*.

To the vulgar eye the heavenly bodies offer an unprofitable, confuſed, but pleaſing, ſpectacle. The leaſt obſervation ſhews that the ſeaſons, the lengths of days and nights, the viciſſitudes of heat and cold, &c. are connected with particular ſituations of the celeſtial bodies. Farther obſervations point out the entire dependance of the former upon the latter, as alſo the periodical returns of the ſame circumſtances.

The periods of the moſt remarkable phenomena have been aſcertained from time immemorial; and when we conſider the accuracy of certain obſervations, the ſcarcity of opportunities, and the want of the teleſcope as well as of other inſtruments, we are forced to acknowledge and to applaud the ingenuity of our forefathers.

Every age has added ſomething to the ſtock of aſtronomical knowledge; but, ſince the ſixteenth century, the advancement has been much more rapid than the ſimple proportion of the times; and we may with ſatisfaction boaſt of the aſtronomical diſcoveries which have been made within the laſt 30 years.

The preſent knowledge of this moſt noble ſcience can aſſign a proper reaſon for almoſt every particular phenomenon; it ſubjects them to ſtrict, to unanſwerable, calculation; and deduces eſſential benefits from the reſults.

The vulgar, whoſe minds ſeldom connect more than two ideas, may laugh at the employment of examining with unwearied toil, what is ſo far removed from us; and they may wonder that aſtronomers ſhould be ſo anxious to aſcertain not only the day or the hour, but even the very moment when a certain celeſtial appearance is to take place, or when a ſtar, which is hardly viſible, will come within a certain diſtance of the ſun, or of the moon.

But whoever endeavours to trace the influence, whether immediate or remote, of thoſe peculiar accuracies upon ſcience in general, and upon the various human affairs; whoever conſiders that they afford the means, and the only accurate means, by which the mariner can navigate the oceans, and can find his exact ſituation at ſea; which afford the accurate meaſurement of time; by which the real diſtances of places upon the ſurface of the earth can be determined; which furniſh ſtandards of weights and meaſures, &c. whoever, I ſay, conſiders this various and extenſive influence, will undoubtedly find abundant reaſons for admiring and for encouraging the utmoſt diligence and the moſt ſcrupulous accuracy in the ſtudy of aſtronomy.

Were the motions of the celeſtial objects uniform and regular, the calculation of their aſpects would be accompliſhed with facility. But the apparent irregularities of thoſe objects, render the inveſtigation of their movements, and the calculations for their appearances, extremely intricate; nor could the ſcience have attained the preſent much improved ſtate, had it not been aſſiſted by all the ſublimeſt branches of mathematics, and by the admirable mechanical improvements of later times; ſuch as time-keepers, teleſcopes, quadrants, and other inſtruments.

Before we enter into the particular ſtatement of the number, the order, the motions, and the mutual dependence of the celeſtial objects; as alſo before we endeavour to determine their real from their apparent motions and ſituations, it will be neceſſary to ſtate certain principles, which, though obviouſly true, will however much aſſiſt the beginner in the comprehenſion of the ſcience, as alſo will render the ſubſequent chapters more perſpicuous and conciſe.

CHAPTER I.

PRELIMINARY PRINCIPLES.

IT has been ſhewn in the principles of optics, (vol. III.) that our ſight judges of the diſtances of objects of unknown ſizes and ſhapes, only by the converging of the optical axis, and by the parts of thoſe objects appearing more or leſs diſtinct; but when the object is beyond a certain limit, which hardly exceeds a few miles, the inclination of the optical axis of our eyes becomes unalterable, and diſtinct viſion becomes doubtful. Therefore thoſe objects which are at immenſe diſtances from us, as the celeſtial bodies, appear as if they were ſituated on the internal ſurface of an hollow ſphere, and we might eaſily be led to believe that they are equally diſtant from us, had we not other moſt concluſive proofs of their being variouſly removed from us, as well as from each other.

It is almoſt uſeleſs to obſerve that the angular diſtances of objects are quite different from their linear or true diſtances. The angular diſtance relates to a particular point as a centre, and is meaſured by the arc of a circle which has that point for centre. Thus,

Thus, to a ſpectator at A, fig. 1. Plate XXVI. the angular diſtance of the two objects, B and C, is meaſured by the arc FG, of the circle HFG, whoſe centre is A; and it is immaterial whether this circle be large or ſmall; for the arc which is intercepted by the lines AB, AC, (whoſe inclination BAC is the angular diſtance between the objects B and C) bears always the ſame proportion to the whole circle of which it is a part; viz. FG is ſuch a part of the circle HFG, as *fg* is of the circle *hfg*.

The arc FG may happen to be a tenth or a thirtieth, or, in ſhort, any other part of the whole circle; but for the conveniency of expreſſing this part, the whole circle is divided, or is ſuppoſed to be divided, into 360 equal parts called *degrees*, each degree is ſubdivided into 60 equal parts called *minutes*, each minute is divided into 60 equal parts called *ſeconds*; each ſecond is likewiſe divided into 60 equal parts called *thirds*, and ſo on; but diviſions, ſmaller than a ſecond, are more commonly expreſſed in decimals of a ſecond; then if the arc FG be the tenth part of the circle, it is ſaid to be equal to 36 degrees; becauſe 36 is the tenth part of 360; if it be the 30th part of the circle, it is ſaid to be equal to 12 degrees, becauſe 12 is the 30th part of 360; and ſo forth.

Inſtead of the word *degrees*, a ſmall ° is more commonly placed on the right hand ſide of the number, and a little above it; inſtead of the word *minutes* a little ſtroke is more commonly annexed to the

the number; and two ſuch ſtrokes denote ſeconds, &c.: thus, the expreſſion $24^\circ, 13', 22'',5$, means 24 degrees, 13 minutes, 22 ſeconds, and half a ſecond, or 5-tenths of a ſecond.

It is evident that in fig. 1, to a ſpectator at A, the objects B and C; or D and C, or D and E, or B and E, have exactly the ſame angular diſtance, though their real diſtances from each other are ſo evidently various. Hence it follows, that the movements of a diſtant body cannot be known, except by the change of the angular diſtance between that and ſome other body which is either fixed or moving in a determinate way. When a body moves in a ſtraight line, either directly towards us or from us, we judge of its approaching to, or of its receding from, us, by the apparent enlargement or contraction of its dimenſions; as is ſhewn by the plaineſt propoſitions of trigonometry; and from the meaſurements of thoſe dimenſions, and one or two more data, we can frequently determine the real ſize of the body.—That the ſame body in motion will appear to move either regularly or irregularly, or even to ſtand ſtill, according to the different ſituations of the ſpectator, will be illuſtrated by the following example:

Let a body A, fig. 2, Plate XXVI. move regularly along the circumference of the circle ABCD, viz. ſuppoſe it to deſcribe equal arcs in equal times; then it is clear that to a ſpectator ſituated at E, which is the centre of the circle, the body A will appear to move equably and regularly one way; but if the ſpectator be ſituated at any other point within the circle, as for inſtance at H, then the ſame body A, will appear to move at different rates, according as it comes nearer to, or goes farther from, the obſerver; for, ſuppoſe the arcs A F, G C, to be equal, and of courſe to be deſcribed in equal times; then the angle A H F, being ſmaller than the angle G H C, the revolving body will appear to move ſlower from A to F, than from C to G. Yet it muſt be obſerved that the body A will always appear to move one way, and not to go back or to ſtand ſtill during any quantity of time; as is the caſe when the ſpectator himſelf is in motion, or when he is ſituated out of the circle, but in the ſame plane. Let, for inſtance, a body move equably along the circumference of the circle A B D F P, fig. 3, Plate XXVI.; viz. to deſcribe the equal arcs A B, B D, D E, E F, &c. in equal times; and ſuppoſe the ſpectator to be ſituated at O in the ſame plane in which the circle is, but out of its circumference; then when the body moves from A to B, its apparent motion is meaſured by the angle A O B, or by the arc H L, which it will appear to deſcribe. In an equal portion of time the body deſcribes the arc B D (equal to A B), and this apparent motion is meaſured by the angle B O D, or by the arc L M, which is ſmaller than the arc H L; and of courſe the body will appear to have ſlacked its motion.—In another equal portion of time the body goes from

from D to E; but as this arc DE, nearly coincides with the line D M O, the body will appear to be almoſt ſtationary during that time. It then proceeds from E to F, in another equal portion of time, but now the body will appear to go back from M to I; viz. to be *retrograde*, and this retrograde motion will continue until the body reaches the arc QP, where it will again appear to be almoſt ſtationary; then it will appear to go again from the left towards the right, &c.

This *optical inequality* (as the aſtronomers call it), muſt evidently be various, according as the ſpectator is ſituated near to or farther from the circular path; hence thoſe, who are ſufficiently ſkilled in the mathematics, may from the obſervations of thoſe unequal movements, often determine the diſtance of ſuch a moving body from the place of obſervation; and from the appearance of its motions, as ſeen from a certain place, they may determine what appearance its motions muſt have from ſome other given place.

If, inſtead of being in the ſame plane, the ſpectator be ſituated above the plane of the circular path, the motion of the body muſt likewiſe appear unequal; excepting however when the ſpectator is in ſome point of the ſtraight line which paſſes through the centre, C, of the circle, and is perpendicular to its plane.

If, inſtead of moving in a circular, the body moved in an elliptical, orbit; ſimilar apparent inequalities

qualities muſt evidently take place. Hitherto the ſpectator has been ſuppoſed to remain immoveable, either within or without the circular path of the moving body. But when the place of the obſerver is itſelf alſo in motion, then the appearances will be very different, as may be eaſily conceived by reflecting on the apparent motion of bodies to perſons on a ſailing ſhip; or as it may be deduced from what has been ſaid with reſpect to relative motion in the firſt volume of theſe Elements.—In this caſe not only the regularly moving body may appear to move irregularly, but quick motions may appear ſlow, and ſlow motions may appear quick; bodies at reſt may appear to move, and moving bodies may appear to be at reſt; or their movements may appear to be quite contrary to what they really are.

Before we conclude this chapter, and before we begin to examine what belongs to the celeſtial objects, it will be neceſſary to remove ſome erroneous ideas, which are pretty commonly entertained by uninſtructed perſons concerning the earth which we inhabit.

The ſhortneſs of our ſight enables us to behold but a very ſmall portion of the ſurface of the earth at one time, and that portion appears to be an immenſe plain with ſome accidental elevations, called mountains, hills, &c. and ſome depreſſions moſtly filled with water, ſuch as ſeas, lakes, &c.

A variety of eaſy but conſtant obſervations prove beyond

beyond a doubt, that what, at firſt ſight, appears to be a vaſt flat, or plain, is, in truth, a convex ſurface; and upon a ſtricter inquiry, it appears to be the ſurface of an oblate ſpheroid, viz. of a globe a little compreſſed on two oppoſite ſides.—Some of the obſervations which prove the reality of this figure, are hereto briefly ſubjoined. Others of a nicer nature will be found in other chapters of this part.

It is conſtantly obſerved by all mariners, that as they ſail from any high objects, ſuch as mountains, rocks, ſteeples of churches, &c. they firſt begin to loſe ſight of the lower parts of thoſe objects, and then gradually loſe ſight of their higher parts. Alſo perſons on the ſhore firſt diſcover the upper parts of the maſts of approaching veſſels, and then by degrees ſee the lower parts in proportion as the veſſel comes nearer to the ſhore. In the ſame manner, when ſailors approach a country, they firſt diſcover the higheſt parts of that country from the tops of the maſts, and then ſee the loweſt parts, or ſee the ſame parts from the deck of the ſhip.

In all thoſe caſes, the obſtruction to the ſight ariſes from the intervening curvature of the earth; and in this reſpect no aſſiſtance can be derived from the uſe of the teleſcope; for the teleſcope will only enable the obſerver to ſee more diſtinctly that part of the object which is not behind the convexity of the earth. Thus in fig. 4, Plate XXVI. the loweſt part of the object A cannot be ſeen by the veſſel at B, on account of the intervening curvature of the earth.

earth T. The veſſel E will be able to ſee a ſmaller part of the ſame object A, becauſe a greater quantity of curvature is between that object and the veſſel E. When the veſſel ſails farther off, as at F, the object A diſappears entirely.

So far the obſervations prove that the ſurface of the earth is convex; but that this curvature returns into itſelf, viz. is continued all round without any interruption, is proved by this; namely, that various navigators have ſailed all round the earth, and at laſt have returned to the very ſame place from which they originally ſailed. They have not indeed ſailed in an exact circle, for that is prevented by the ſituation of the lands; but by going in and out according as the coaſts happened to lie, they have kept on the ſame courſe upon the whole, and have arrived to the ſame place from another ſide.

Thoſe who level grounds for the purpoſe of forming canals, &c. ſoon perceive that the real level is not a ſtraight line, but a curve, whoſe centre is the ſame as the centre of the earth. The ſurface of water, which is level, follows the ſame curvature.

Were the earth a perfect ſphere, the curvature would be the ſame in every part of its ſurface; but the moſt accurate obſervations and meaſurements which have been made with the niceſt inſtruments, ſhew that this curvature differs a little in different parts, and from thoſe differences, according to the lateſt meaſurements, it has been calculated, 1ſt, that the real figure is not much different from that of a ſpheroid generated by the motion of a ſemi-ellipſis, about its minor axis; 2dly, that its axis or ſhorteſt diameter, viz. a line ſuppoſed to be drawn through its centre, from one of its flatteſt parts to the other, is nearly equal to 7893,5 Engliſh miles, and its longeſt diameter, viz. a line drawn through the centre from one moſt protuberant part of its ſurface to the other, is equal to 7928 Engliſh miles. The whole circumference is equal to 24855,43 Engliſh miles *. Since the figure of the earth differs ſo little from a ſphere, therefore, for the purpoſes of aſtronomy, the earth is conſidered as a perfect ſphere.

When we ſpeak of the ſurface of the earth, we take no notice of mountains, hills, ſeas, &c. but we conſider the whole as an uniform ſurface; for, in fact, the mountains and other elevations are to the ſurface of the earth, no more than grains of ſand are to the ſurface of a globe of 8 or 10 feet in diameter. When the diſtance of the ſurface of the earth from its centre is mentioned in general, it is always meant of the ſurface near the level of the ſea. All places above that level, viz. more diſtant from

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* The French, according to their lateſt determination of their meaſures, ſuppoſe this whole circumference to be divided into 40 millions of parts, which they call *metres*. From the moſt accurate admeaſurements, it appears, that, at the temperature of 62° Fahrenheit's Thermometer, the French ſtandard metre is equal to 39,371 Engliſh inches.

the centre, are called *elevations*; below that level, are called *depreſſions*.

The ſurface of the terraqueous globe is irregularly ſpotted with lands and water. The greater part (viz. almoſt three quarters) of its ſurface is occupied by the latter. The ſhape and extent of thoſe ſpots are uſually delineated upon a globe, which of courſe repreſents the earth, and is called the *terreſtrial globe* *.

When the ſurface of the terreſtrial globe with the ſhape of the lands, the coaſts, &c. is delineated, either entirely or in part, upon a flat ſurface; ſuch a delineation is called a *map* or *chart*. A complete ſet of ſuch maps, has been called a *terreſtrial atlas*.

The navigators of all ſeas and of all times; the travellers, and the inhabitants of all countries, ſee the ſame expanſe of heaven over their heads, the ſame ſun, moon, &c. which proves that the terraqueous globe is not attached to any other body, but that it exiſts by itſelf perfectly inſulated in the unfathomable expanſe of the Univerſe.

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* Dr. Long endeavoured to determine what proportion the land bears to the ſea by the following ingenious method. He took the ſlips of paper which are made for covering the ſurface of a terreſtrial globe, and, by means of a pair of ſciſſars, he ſeparated that part which repreſents the land from that which repreſents the ſea. He then weighed thoſe two parcels of paper ſeparately, and found that the papers which repreſented the land weighed 124 grains; the others weighed 349 grains. See his Aſtronomy, page 168.

It is a conſequence of this uncontrovertible theory, that all the inhabitants of the earth, being directed with their feet towards the centre of it, muſt be variouſly inclined to one another, like the ſpokes of a wheel; and the inhabitants of thoſe countries, which are diametrically oppoſite, muſt have their feet directly oppoſite. Such people are called *antipodes* reſpectively, viz. thoſe of one country are the antipodes of thoſe of the other country.

Hence alſo it appears, that, with reſpect to the Univerſe, there is no real up or down; for what is upper or over the head of one perſon, is poſited otherwiſe with reſpect to another perſon. But in relation to the globe we inhabit, the words up or down, above or below, mean the ſituations nearer to, or farther from the centre of the earth, than we, or than other given objects, are.

It is the general attraction of the matter of the whole terraqueous globe (as has been already explained *) that keeps us, and every particle of matter, tending towards the centre of it.—We ſhall preſently ſee that this ſame power acts univerſally throughout, at leaſt, the ſolar ſyſtem; and that every phenomenon of aſtronomy, as far as can be traced, is regulated by the laws of motion, and by thoſe of univerſal attraction.

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* See Chap. V. of the firſt part of theſe Elements.

With reſpect to the heavenly ſpace which ſurrounds the earth, the ſtudent of natural philoſophy muſt relinquiſh ſeveral incoherent ideas, which he may have imbibed from common prejudices, and from allegorical, poetical, or ſuperſtitious, expreſſions. The canopy of heaven, the ſtarry firmament, the celeſtial ſpheres, the cryſtalline ſphere, the empyreal regions, the vaulted heaven, the *primum mobile*, and ſuch like expreſſions, have no real and determinate meaning. They are fictitious, hypothetical, allegorical, and, upon the whole, uſeleſs words, which can only miſlead and confuſe the underſtanding.

What we perceive beyond our atmoſphere is the ſun, the moon, and a number of lucid and apparently ſmall bodies, called ſtars, planets, and comets; and thoſe are demonſtratively at different diſtances from us as well as from each other; but of the immenſe ſpace in which they exiſt and move, we have not the ſmalleſt knowledge either from reaſoning or from experience. We ſee no boundary, no ſhell, no arch, no vault, no limit.—The blue ſky, as is commonly called, is the colour of, or the reflection from, our atmoſphere, which extends not many miles above the ſurface of the earth [*]. For, beſides other reaſons, when the moon is not full, viz. when only a portion of it is illumined, the other portion

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[*] See vol. II. chap. VIII. of theſe Elements. Alſo Prieſtley's Hiſtory of Viſion, Light, and Colours. Period VI. Sect. III. Chap. IV.

of

of it appears blue, or of the colour of the ſky, which would not be the caſe if the blue colour proceeded from ſome thing beyond the moon.

Since to our eyes the celeſtial bodies appear as if they were all equally diſtant from us; therefore, in order to aſſiſt the underſtanding, or to inſtruct the ſtudents of aſtronomy, the ſtars and other celeſtial bodies are commonly repreſented upon a convex, and ſometimes upon a concave, ſpherical ſurface of a few inches, or a few feet, in diameter. Such artificial repreſentation of the celeſtial bodies is uſually called a *celeſtial globe.* When all the ſtars or part of them only is delineated upon a flat ſurface, ſuch delineation is called a *celeſtial planiſphere*, or *map*, or *plate*, and a complete ſet of ſuch plates has been called a *celeſtial atlas.*

CHAP. II.

OF THE APPARENT SYSTEM OF THE WORLD, AND THE DEFINITION OF THE TERMS PRINCIPALLY USED IN ASTRONOMY.

THE incomparably ſuperior ſplendor of the ſun in the day time, renders all the other celeſtial bodies inviſible to our naked eyes, excepting the moon, which ſometimes may be barely diſtinguiſhed; and two or three much ſmaller bodies, which in ſome favourable circumſtances may be juſt diſcerned, whilſt the ſun is viſible yet *.

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* In the day time, the refraction and reflection of the ſun's light from the atmoſphere renders the ſtars inviſible to us even when we turn our backs to the ſun; but if we look at the heavens through a very long tube in the day time, the abovementioned reflected light will not penetrate a great way within the cavity of the tube; and therefore the ſtars may be perceived through it. A tube ſufficiently long to anſwer this purpoſe is difficultly conſtructed and managed; but deep pits, and deep wells, are in fact long tubes; hence, from the bottoms of thoſe places the ſtars may be ſeen in the day time.—A good teleſcope will alſo ſhew the ſtars in the day time.

At night, viz. during the abſence of the ſun, the moon frequently affords more light than all the other celeſtial objects. The other numerous bright bodies, which we perceive beſides the moon, are in general called *ſtars*. They appear to differ much in magnitude, but they ſeem to be vaſtly ſmaller than the moon. Eight of them are called *planets*; the reſt are called *fixed ſtars*, for reaſons which will be mentioned preſently. The *comets* are luminous bodies, which are ſeen not very frequently, nor at certain or determinable times.

Theſe, in ſhort, are all the objects which we perceive in the heavens; the aſpects and the motions of thoſe objects form the whole ſubject of aſtronomy. And here we may obſerve, once for all, that the circles, the curves, the lines, axes, poles, points, and the figures of the conſtellations, of which frequent mention is made in aſtronomy, are not viſible things; but they only exiſt in our imagination, and they have been adopted, and are uſed, for the neceſſary purpoſe of communicating our ideas to other perſons, or for expreſſing meaſures, ſituations, motions, &c.

When an obſerver is ſituated on a large extended plane, or in an open ſea, he will find his ſight circumſcribed by a great circle, which divides the viſible part of the heavens from that which is hid in conſequence of the opacity of the earth; or where the ſurface of the globe we inhabit ſeems to meet the heavens. That circle is called the *ſenſible horizon*.

rizon. The *rational horizon* is a circle in the heavens, ſuppoſed to be formed by the interſection of a plane, which paſſes through the centre of the earth, and is parallel to the ſenſible horizon. The planes of thoſe two horizons are diſtant from each other by the ſemidiameter of the earth; but with reſpect to the heavens, they may be ſafely ſuppoſed to coincide; for the diſtance of the fixed ſtars from us is ſo immenſe, that the diameter of the earth is a mere nothing with reſpect to it. Hence the horizon divides the heavens into two equal parts; viz. the viſible, which is above it, from the inviſible which is below it.

With reſpect to the earth; viz. if by the horizon we mean the boundary of that part of the earth's ſurface which is ſeen by the ſpectator, then it is evident that the horizon is more extended in proportion as the ſituation of the obſerver is more elevated; for inſtance, if the obſerver be ſituated cloſe to the ſurface of the earth, G D E F, fig. 5, Plate XXVI. as at *a*, he will ſee a very ſmall portion of its ſurface; becauſe the viſual line is a tangent, (or nearly a tangent) to the ſurface of the earth at that point;—if he be ſituated at *b*, then the viſual line *b* E will touch the earth at E, and of courſe the horizon will be the circle, which is denoted by the line DE.—If the ſpectator be ſituated at *c*, his horizon will be GF; and if the ſpectator ſtood at an immenſe diſtance, then his horizon would be equal to the circumference of the earth; viz. to

O I;

O I; ſo that he would ſee the half of its ſurface *.

It is evident, that every ſpectator has a different horizon; therefore, ſtrictly ſpeaking, the half of the heavens which is ſeen by any one ſpectator, is not preciſely the ſame half that is ſeen by another ſpectator at the ſame time.

To us Europeans the ſun, the moon, the planets, and moſt of the ſtars, appear to go continually round the earth, and to perform each revolution in about 24 hours. I ſay *about* 24 hours; for ſome of the celeſtial objects perform it ſlower than others. They riſe on one ſide of the horizon, which is called the *eaſtern ſide*, paſs obliquely over it, and deſcend on the oppoſite ſide, which is called the *weſtern ſide* of the horizon; then they riſe again, &c.

If a perſon will obſerve the heavens in the night time, he will find that the ſtars ſeem to perform, or to move along, different circles; ſome larger, others ſmaller; gradually diminiſhing towards a certain part of the heavens, until ſome of them per-

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* The greateſt diſtance *b* E, from which an eye ſituated any where above the ſurface of the earth, as at *b*, will perceive an object E on the ſurface of the earth, is one ſide of a plane triangle *b* E C, right-angled at E. Its other two ſides are the radius EC of the earth, and C *b*, which is the ſum of the radius and height *a b*.—When *a b* is known, the diſtance *b* E is found by the following rule:— Add the height *a b* to the *diameter* of the earth; multiply the ſum by the height *a b*; then the ſquare root of the product is the diſtance *b* E. This rule depends on Prop. 47th, B. I.; and on Prop. 6th, B. II. of Euclid's Elements.

form circles ſo ſmall as not to be diſcerned without proper inſtruments. In ſhort, the whole apparent ſphere ſeems to move round an axis, and of courſe there are two points in the heavens, which, being the extremities of that axis, do not ſeem to move at all. Thoſe points are called the *poles of the world*; one being called the *arctic*, or the *north*, *pole*; and the other the *antarctic*, or *ſouth*, *pole*. The axis itſelf, or the line which joins thoſe poles, is called *the axis of the world*.

In this metropolis we can perceive one pole only, namely, the north pole, which is elevated above the horizon at an angle of 51° 31″. In truth, we cannot perceive the pole itſelf; (which is an imaginary point) but we may determine the ſituation, or the angular altitude, of that immoveable point, by examining the ſtars, which, being near it, revolve without ever going below the horizon; for by taking a mean of the leaſt, and greateſt, obſerved altitudes of any one of thoſe ſtars, we have the altitude of the pole itſelf; it being evident that in its circular revolution each ſtar muſt riſe as much above the pole as it deſcends below it.

A pretty large ſtar, called the *north polar ſtar*, is ſituated near the north pole, and to the naked eye it appears to be quite ſtationary; but when examined by means of a fixed teleſcope, or of other aſtronomical inſtruments, it is found to deſcribe a ſmall circle, which proves that it is not quite at the pole.

Beſides the poles, there are ſeveral other remarkable points, determined and conſtantly uſed by the aſtronomers, which are therefore neceſſary to be deſcribed. One of thoſe points is called the *zenith*, and is the higheſt point of the heavens, or that which is exactly over our heads. The oppoſite or loweſt point of the heavens, which is directly under our feet, is called the *nadir*. If a plummet be freely ſuſpended, and if it be ſuppoſed to be infinitely extended both upwards and downwards, its thread will paſs through the zenith and nadir. Thoſe points are alſo called the *poles of the horizon* *. All circles, drawn through the zenith and nadir, which of courſe muſt be perpendicular to the horizon, are called *vertical circles*, or *azimuths*. Two of the innumerable circles, which may be deſcribed through thoſe points, are peculiarly remarkable; viz. that which paſſes through them, and at the ſame time through the poles of the world, is called the *meridian*. This circle divides the ſphere into two equal parts, one of which is the *eaſtern*, and the other the *weſtern*, *hemiſphere*. When the celeſtial bodies in their daily courſe arrive at that part of the meridian which is above the horizon, then they are ſaid to *culminate*; viz. to be at their greateſt elevation; for beyond the meridian they deſcend towards the horizon; and when they are at that part of the meridian, which is below the horizon, then they are ſaid to be at their greateſt depreſſion; for beyond that limit they again

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* In ſpherics every circle of the ſphere has two poles, which are the points on the ſurface of the ſphere, where a ſtraight line, paſſing through the centre of the circle and perpendicular to the plane of it, meets the ſurface.

riſe towards the horizon. Therefore the meridian divides the time of the celeſtial bodies courſe above the horizon, into two equal parts, and it alſo divides into two equal parts the period of their courſe below the horizon; hence, when the ſun is at the meridian in the day time, it is *noon* or *midday* (whence the meridian has derived its name); and when the ſun is at the meridian below the horizon; viz. at night, it is then ſaid to be *midnight.*

The other remarkable circle amongſt the azimuths, is that which is perpendicular to the meridian, and is called the *prime vertical.* This circle divides the eaſtern and weſtern ſides of the horizon, each into two equal parts. Thoſe points of interſection are called the true *eaſt* and *weſt* points; ſo that the meridian and the prime vertical divide the horizon into four equal parts, and the points of diviſion, viz. the *north*, the *eaſt*, the *ſouth*, and the *weſt*, have been called the *principal*, or *cardinal*, *points* of the horizon; for each quarter of the horizon is ſubdivided into eight parts; ſo that the whole horizon is divided into 32 parts, which are called the *rhumbs*, or the *points of the compaſs*, from their being generally marked upon the cards of the mariner's compaſſes.

The ſituation of the above-mentioned points is ſo commonly underſtood, that it will be almoſt ſuperfluous to obſerve, that if we turn our backs towards the north pole, we ſhall then have the ſouth exactly before us, the eaſt on the left, the weſt on the right hand

hand ſide, the zenith over our heads, the nadir under our feet, the meridian paſſing over our heads, and under our feet, viz. through the north, the zenith, the ſouth, and the nadir; and the prime vertical paſſing over our heads, and from our right to our left hand, through the eaſt, zenith, weſt, and nadir.

It is evident upon the leaſt reflection, that as the horizon is different for every ſpectator, or for every point of the ſurface of the earth, ſo the cardinal points, and the rhumbs in general, which are the diviſions of the horizon, muſt be different for every ſpectator; and ſo muſt alſo be the zenith and the nadir, which are the poles of the horizon; but for a fixed obſervatory, or for a given ſpot, thoſe circles and points are fixed and immoveable. The meridian is the ſame, and the prime vertical is different for all thoſe obſervers or ſpots which are in the ſame line, but only north or ſouth of each other; whereas the prime vertical is the ſame, and the meridian is different for all thoſe obſervers or ſpots, which are only eaſt and weſt of each other.

That arc of the horizon of any particular place, which is intercepted between the meridian and azimuth circle that paſſes through a particular celeſtial object at any given time, is called the *azimuth of that celeſtial object.* The arc of the horizon which is intercepted between the prime vertical (viz. the eaſt or weſt points of the horizon) and the azimuth circle, which paſſes through the celeſtial object, is called the *amplitude* of that object.

Another very remarkable, but fixed, circle of the ſphere,

ſphere, is called the *equator* or *equinoctial*, which divides the ſphere into two equal parts, and is perpendicular to the axis of the world, as alſo to the plane of the meridian. In this metropolis, when we place ourſelves with our backs to the north, as has been mentioned above, the equator ſtands obliquely before us, viz. it paſſes through the eaſt and weſt points of the horizon, and croſſes the meridian at a point which makes an angle of 38°, 29′ with the horizon. To thoſe who are ſituated ſouth of us, the interſection of the equator with the meridian is higher up, and to thoſe who are north of us, that interſection is lower down. The poles of the world are the poles of the equator.

Now, if we ſuppoſe the planes of various meridians, as well as of the equator, and of the rational horizon, to cut the ſurface of the earth, then the ſame circles which are ſuppoſed to exiſt in the heavens, may likewiſe be conceived to exiſt on the ſurface of the earth. Alſo that point of the ſurface of the earth, which is exactly under the north pole of the world, is called the *north pole of the earth*; and the ſame thing muſt be underſtood of the ſouth pole.

The uſe which is made of thoſe points and circles on the ſurface of our globe, will be ſhewn hereafter; but we ſhall obſerve for the preſent, that the ſituation of the equator with its axis and its poles, which are the ſame as the axis and the poles of the world, appears differently ſituated to the different inhabitants

inhabitants of the earth. Thoſe different ſituations may be reduced to three ſpecies, and theſe have obtained peculiar appellations; viz. to thoſe perſons who live exactly under the equator, the poles of the world muſt appear in the horizon, and the equator muſt be perpendicular to the horizon, viz. muſt cut it at right angles; hence that ſituation is called the *right poſition of the ſphere.* To thoſe who live under either of the poles of the earth, one of the poles of the world muſt be over their heads, and the equator muſt coincide with, or be parallel to, the horizon; hence that ſituation is called *a parallel ſphere.* And laſtly, to all the other inhabitants of the earth the ſphere is ſaid to be in an *oblique poſition,* becauſe the equator is neither perpendicular nor parallel, but oblique, to the horizon. Thus in fig. 6. Plate XXVI. NEHS repreſents the celeſtial ſphere, or a meridian; *a c b* repreſents the earth, N and S are the poles of the world, N S is its axis, and E E is the equator. Now to us at *a*, who are neither under the equator at *c*, nor under the poles at *b*, the ſphere is ſaid to be oblique, becauſe the equator E E is neither perpendicular, nor parallel, but oblique, to our horizon H H. To thoſe who live at *c*, viz. under the equator, the ſphere is ſaid to be right, becauſe the equator E E is perpendicular to their horizon, which is N S. And to thoſe who live at *b*, viz. under the poles, the ſphere is ſaid to be parallel, becauſe the equator E E coincides with, or is the ſame as, their horizon.

The apparent movements of the ſtars, which are performed in circles parallel to the equator, muſt, of courſe, appear to be performed in circles perpendicular to the horizon to thoſe who live under the equator at *c*, and to them (who likewiſe ſee the poles of the world in their horizon) all the ſtars muſt appear to riſe and to ſet in every revolution, and in every revolution they ſee all the ſtars ſucceſſively. But to thoſe who live under the poles at *b*, the ſtars move in circles parallel to the horizon, ſo that they never riſe or ſet, and conſequently thoſe people can only ſee half the ſtars, viz. one hemiſphere, whilſt the other is never ſeen by them, it remaining conſtantly below their horizon. To thoſe who live neither under the equator, nor under the poles, the ſtars appear to move in circles oblique to the horizon, and they ſee a greater or a ſmaller number of the ſtars paſs in ſucceſſion, according as they are ſituated nearer to the equator or nearer to the poles. Thus to us ſituated at *a*, all the ſtars which are ſituated within the portion PEH, OEH, are ſeen ſucceſſively; but thoſe which are about the ſouth pole S, viz. in the portion HSO, are never ſeen by us, becauſe, as the ſphere revolves round the axis NS, the portion HSO, never riſes above our horizon HH. And the ſtars, which are in the portion HNP, about the north pole N, are always within our ſight, becauſe that portion HNP, of the ſphere, never goes below our horizon HH.

The circle HP, parallel to the equator, which limits

limits the part HNP, that never goes below the horizon of any given place, is called the circle of *perpetual apparition.* The circle HO, parallel to the equator, which limits the part HSO, that never riſes above the horizon of any given place, is called the circle of *perpetual occultation.*

Not all the celeſtial objects appear to a ſpectator in a fixed place, to riſe conſtantly from, or to ſet at, the ſame reſpective points of the horizon; or, in ſhort, to move conſtantly along the ſame circles.

The fixed ſtars properly ſo called, (which comprehend all the celeſtial objects, excepting the ſun, the moon, eight planets, and ſome comets, which appear now and then) do move with that uniformity, viz. they move along the ſame tracks or circles, and preſerve the ſame diſtances from each other; hence they have been denominated *fixed ſtars*; and therefore the aſtronomers uſe them as fixed points with which, and by which, the motions of the other celeſtial objects are compared and expreſſed. The whole ſphere, or all the fixed ſtars, perform their revolution; viz. go from the meridian of a given place, and return to the ſame place, conſtantly in the ſpace of 23 hours, 56 minutes, and 4 ſeconds.

The ſun riſes and ſets every day at different points of the horizon, and it alſo croſſes the meridian of any place every day at a different point; but it never goes farther from the equator than about

23° 28′, either towards the north or towards the ſouth of it. The time of its riſing, ſetting, and of croſſing the meridian, is not always the ſame; it being ſometimes later, and at other times ſooner, than on the preceding day. The difference is progreſſively increaſing and decreaſing. Upon the whole it amounts only to a few minutes; and, at a mean, its revolution (which is called the ſun's daily revolution from its producing the viciſſitudes of day and night) employs 24 hours, viz. 3′, 56″ longer than the revolution of the fixed ſtars; or rather, we divide the mean time of the ſun's daily revolution, into 24 parts, which we call *hours*. The ſixtieth part of an hour is called a *minute* of time, and the ſixtieth part of a minute is called a *ſecond* of time.

If the very great ſplendor of the ſun did not prevent our ſeeing the ſtars in the day time, we ſhould find that the ſun (which, as has been ſaid above, moves ſlower than the ſtars) is left conſtantly behind; viz. every day more towards the eaſt, and likewiſe a little more towards the north, or towards the ſouth. In ſhort, if every day at noon, when the ſun croſſes the meridian of a given place, we marked the exact place of its centre in the heavens among the ſtars, and if when the ſun has returned to the ſame point of the heavens, all which period takes up 365 days, 5 hours, 48′, 49″, and is called the *mean ſolar year*, we drew a line along all thoſe marked

marked points, that line would be found to be a great circle of the ſphere.

This circle interſects the equator at two oppoſite points, and its plane forms an angle of about 23° 28′, with the plane of the equator. This circle, which is the annual path of the ſun, is called the *ecliptic*; the angle, which it forms with the equator, is called the *obliquity of the ecliptic*; and the points where it interſects the equator are called the *equinoxes*, or the *equinoctial points*.

A broad portion of the heavens, which ſtretches about 8° on each ſide of the ecliptic, and of courſe follows its direction all round the heavens, is called the *zodiac*.

Since the ecliptic is a fixed circle, and every day the ſun is found in a different point of it; therefore every day the ſun ſeems to perform its revolution in a circle parallel to the equator, but which recedes farther and farther from it, until it reaches its greateſt diſtance; which, as has been ſaid above, is about 23° 28′ from it towards the north; after which the daily courſe of the ſun is performed in a circle, which approaches the equator gradually until it coincides with the equator, then it begins again to recede from it towards the ſouth, until it reaches its greateſt ſouthern diſtance, which is likewiſe equal to about 23° 28′; then it approaches the equator anew, and ſo forth.

Now when the ſun is at its greateſt diſtances from the equator, the circles parallel to the equator which it it nearly deſcribes at thoſe two points, are called the *tropics*, and that which is towards the north is called the *tropic of Cancer*, whilſt that which is towards the ſouth is called the *tropic of Capricorn*. The diſtance of the ſun, as well as of any other celeſtial object, from the equator, is called the *declination* of that object, and it is *north* or *ſouth declination*, according as the object is on the north, or the ſouth of the equator.

It has been ſaid above, that if the ſplendor of the ſun did not prevent our ſeeing the ſtars which are near it, we ſhould find it every day near a different ſtar. But though we cannot ſee the ſtars that happen to be near the ſun; yet, by means of proper inſtruments, we can obtain the reſult exactly in the ſame manner as if we ſaw them; for knowing the time of the revolution of the ſtars, and likewiſe knowing their reſpective ſituations, the aſtronomers, by examining the time of the ſun's paſſage over the meridian, which differs a little in different days, as alſo by examining its daily altitude, when it croſſes the meridian at noon, can determine with great preciſion which ſtar muſt croſs the meridian at the ſame time, and through the ſame point, or within a certain diſtance of it.

The moon appears to riſe from, and to ſet every day at, different points of the horizon, and likewiſe to croſs the meridian at different points; but with much more irregularity than the ſun. It alſo moves much ſlower than the ſun; ſo that if one night it be found near a certain ſtar, on the following night it will be ſeen much to the eaſt of that ſtar; viz. about 13°, or rather more; on the following night it will be found about as much more backward, and ſo on. It likewiſe advances at the ſame time towards the north or towards the ſouth. Indeed, ſo rapid is its motion, that if any attentive perſon will watch its courſe amongſt the ſtars during a few hours only, he will plainly perceive her change of place. All this retrogradation, which is called the *proper movement of the moon*, viz. from the time that it is ſeen near a certain ſtar, and until it comes near it again, takes up about 27 or 28 days.

The different appearances (or as they are more commonly called the *phaſes*) of the moon, are the phenomena which are more particularly ſtriking and more generally remarked in the heavens, even by the rudeſt nations of the earth. During the 27 or 28 days of her proper movement, we perceive the moon affording more or leſs light, or ſhewing a ſmaller or larger part of its illuminated diſc. For about three days out of the 27, the moon is almoſt inviſible; then we begin to ſee it in the evening towards the weſt, ſomewhat like a luminous arch with pointed extremities, properly called *cuſps* or *horns*. In that ſtate it is denominated a *creſcent*: for its luminous part increaſes gradually until it appears after ſeven days, like a ſemicircle. It is then at the apparent diſtance of 90° from the ſun, and we ſay that it is in *its firſt quarter*. It ſtill continues to increaſe until ſeven or eight days after, it gets quite oppoſite to the ſun, and ſhines with its entire circular diſc, in which ſtate we call it the *full moon.* After that period the luminous part of the moon begins to decreaſe, and when it comes again within 90° of the ſun, but on the other ſide, we ſay it is at its *laſt quarter.* It laſtly gets too near the ſun, where we loſe ſight of it for a ſhort time, and the moment it paſſes beyond the meridian of the ſun's centre, we call it the *new moon*; for, a day or two after this, we begin to ſee it again towards the weſt; and ſo forth. The convex part of the moon's illuminated portion, or the more convex of its two ſides, is always turned towards the ſun *.

Amongſt the ſtars there are, as we have already noticed, eight luminous bodies, which the naked eye can hardly diſtinguiſh from the fixed ſtars; but which, when viewed through a teleſcope, have very different aſpects; and when examined with reſpect to their motions, are found to be quite different from the fixed ſtars; for though they appear to move like the other celeſtial bodies, from eaſt to weſt, yet each of them performs that apparent revo-

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* The period of each of the four remarkable phaſes of the moon which is performed in the ſpace of ſeven or eight days, and likewiſe the whole lunation or the period of its entire revolution which is performed in about 28 days, ſeems to have ſuggeſted the general cuſtom of counting by months and weeks. See de la Lande's Aſtronomy.

lution in a different time: hence they all change their mutual diſtances, as well as their ſituations with reſpect to the fixed ſtars; for inſtance, one evening one of them will be ſeen near a certain ſtar, the next evening it will be found near ſome other ſtar, which is to the eaſt of the former; on the following evening it will be found ſtill more eaſterly, and ſo on for a number of nights; then perhaps it will appear to be ſtationary; viz. it will remain near the ſame ſtar during ſome nights; after which it will move towards the weſt of that ſtar, &c.

From ſuch irregular or wandering movements, thoſe eight celeſtial objects have been denominated *Planets.* The aſtronomers have given them peculiar names; and for the conveniency of expreſſing them upon globes, tables, &c. they are often denoted by peculiar characters. Here follow their names and characters.

Mercury ☿; *Venus* ♀; *Mars* ♂; *Ceres Ferdinandea*; *Pallas*; *Jupiter* ♃; *Saturn* ♄; and the *Georgium Sidus*, or *Georgian Planet*, which, by ſome, has alſo been called either *Uranius*, or *Herſchel* ♅ *.

Since

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* Mercury, Venus, Mars, Jupiter, and Saturn, have been known from time immemorial; the Georgian planet was diſcovered by Dr. Herſchel about 20 years ago. The Ceres was diſcovered by Mr. Piozzi, an Italian aſtronomer, on the 1ſt of January 1801, or the firſt day of the preſent century. The laſt, or Pallas, was diſcovered by Dr. Olbers of

Since the ſtars properly ſo called, are conſidered as fixed points in the celeſtial ſphere, which ſerve to denote the movements peculiar to the ſun, the moon, the planets, and the comets; and whoſe ſituations are likewiſe uſeful for other purpoſes; therefore aſtronomers have laboured with great aſſiduity to determine, with the utmoſt accuracy, their ſituations in the heavens, or their diſtances from each other; and ſuch diſtances are laid down in books, or catalogues, or tables. This however has been more particularly the cuſtom of latter times; for the obſervers of very remote antiquity parcelled the whole into irregular aſſemblages, to which they gave the names of men, of birds, of fiſhes, &c. according to ſome faint or diſtant reſemblance, which that particular arrangement ſeemed to indicate. Then, in order to ſpecify any particular ſtar of a certain arrangement or imaginary figure, they ſpoke, for inſtance, of the ſtar on the ſhoulder of Orion, or on the tail of the fiſh, &c. And ſuch is the aſſiſtance which thoſe imaginary figures afford to the memory, that this cuſtom is ſtill continued, viz. of expreſſing the ſtars by their ſituations in thoſe imaginary figures of men, fiſhes, birds, &c. which are called *aſteriſms* or *conſtellations*. The modern more accurate aſtronomers uſe thoſe conſtellations for the purpoſe of in-

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of Bremen, on the 28th of March 1802.—I do not know that any particular characters have as yet been appropriated to the two laſt diſcovered planets.

dicating the general aſſemblage of ſtars in a certain portion of the heavens; but they diſtinguiſh each particular ſtar by a Greek letter, or by the figures of numbers, as 1, 2, 3, &c. and mark its true place by mentioning its diſtances from particular points.

Some of the principal fixed ſtars have peculiar names, ſuch as Aldebaran, Sirius, Regulus, &c.— We ſhall treat of the conſtellations, as alſo of the particular ſtars which are contained in them, in another chapter of this part; but for the preſent it will be neceſſary juſt to mention that the zodiac is occupied by twelve conſtellations, whoſe names and characters are as follow:

Aries ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra* ♎, *Scorpio* ♏, *Sagittarius* ♐, *Capricornus* ♑, *Aquarius* ♒, and *Piſces* ♓. Thoſe conſtellations are ſuppoſed to divide the zodiac, or the ecliptic, into 12 equal parts; therefore 30 degrees are aſſigned to each of them; 12 times 30 making 360°, or the whole circle. They are ſituated in the order in which they are mentioned above from the weſt towards the eaſt.

Having thus given a general or ſuperficial view of the number and movements of the principal celeſtial bodies, as well as of the moſt remarkable circles and points that are uſed in the ſcience of aſtronomy; it will be neceſſary to indicate ſome of the moſt ſtriking effects that are produced by thoſe movements, and likewiſe to ſhew the uſe of the

the abovementioned circles and points, in determining diſtances and poſitions; but to this I ſhall briefly prefix a few of the more remarkable properties of the circles of a ſphere, by way of refreſhing the memory of the ſtudents, who are ſuppoſed to have previouſly ſtudied ſpherical geometry, trigonometry, &c.

If a plane cut a ſpherical ſurface, the ſection will be a circle. If the plane paſs through the centre of the ſphere, the ſection is called a *great circle of the ſphere*; it being the largeſt circle that can be drawn upon the ſphere; but if the cutting plane do not paſs through the centre of the ſphere, then the ſection will be a *leſſer circle.* Therefore all great circles of the ſphere have the ſame common centre, and cut one another as well as the ſphere, into two equal parts. But leſſer circles have not the ſame centre with the ſphere, and they may be cut unequally by a great circle, or by another leſſer circle.

Parallel circles are thoſe whoſe planes are parallel.

A *ſpheric angle* is the inclination of two great circles, and is meaſured by an arc of a great circle intercepted between the legs of that angle, at 90° diſtance from the angular point. When two circles interſect one another, the oppoſite angles are equal.

A *ſpheric triangle* is a figure formed on the ſurface of the ſphere by the mutual interſections of three great circles.

The *poles of a circle* are thoſe two points on the ſurface of the ſphere, where a ſtraight line paſſing through the centre of the circle, and perpendicular to its plane, meets that ſurface.

Both the poles of a great circle are equidiſtant from it; but thoſe of a leſſer circle are not equidiſtant. When two great circles are perpendicular to each other, they muſt paſs through each other's poles; and then either of them is called *ſecondary* to the other. Thus the meridians are ſaid to be ſecondaries to the equator, and the azimuths are ſecondaries to the horizon.

A great circle perpendicular to a leſſer circle, muſt paſs through the poles of the latter; but the reverſe is not true.

The *projection* of the ſphere is the repreſentation of its circles, points, &c. upon a flat ſurface; and thoſe repreſentations of circles may be either ſtraight lines, or circles, or ellipſes, or other curves, according as the circles lie in the direction of the eye of the obſerver, or perpendicular, or oblique to it; and likewiſe according to the nature of the projection, of which there are ſeveral ſorts.

We may now return to the aſtronomical circles, and ſhall, in the firſt place, ſhew their principal uſe upon the ſurface of the earth.

The equator on the earth, which is juſt under the celeſtial equator, is a great circle which divides the earth into two equal parts, namely, the northern and the ſouthern hemiſpheres. This imaginary circle paſſes through the continent of Africa, croſſes the Indian ocean, as alſo the iſlands of Sumatra and Borneo; it paſſes along the whole extent of the Pacific ocean, and the continent of South America. This circle is commonly called ſimply the *line*, and when navigators go from one ſide of it to the other, they commonly ſay that they have *croſſed the line.*

The ſhorteſt diſtance of a place on the ſurface of the earth from the equator, is called the *latitude* of that place, and is ſaid to be *north* or *ſouth latitude*, according as the place is ſituated on the northern or ſouthern hemiſphere. This latitude is meaſured by an arc of the meridian of that place; thus the latitude of London is ſaid to be 51° 31′ north; the latitude of Liſbon is 38° 42′ north; the latitude of the Cape of Goodhope is 34° 29′ ſouth, &c. Places that are exactly under the equator, have no latitude; and the latitude of thoſe, which are exactly under the poles, is 90° north or ſouth*.

A leſſer circle paſſing through any place, parallel to the equator, is called a *parallel of latitude*; and, of courſe, all places through which that circle paſſes, have the ſame latitude.

The *longitude* of one place from another on the ſurface of the earth, or what is, more properly, called their *difference of longitude*, is the diſtance of their meridians

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* The latitude of a place is equal to the elevation of the pole of the ſame denomination, above the horizon of that place.

meridians from one another; which is meaſured by the arc of the equator, that is intercepted by thoſe meridians; and is expreſſed in degrees, minutes, &c. In general, the longitude is reckoned from a certain meridian, and is called *eaſt* or *weſt* longitude, according as the places lie eaſt or weſt of that meridian.

Now the equator being a fixed and immutable circle, the latitude muſt unavoidably be reckoned from that line; but ſince there is no fixed and general meridian; therefore the longitude may be reckoned from the meridian of any place at pleaſure. For a long time it has been the general cuſtom to reckon the longitude from the meridian of Teneriffe, one of the Canary Iſlands; that iſland being for many years the moſt weſtern land known. But at preſent the moſt prevailing cuſtom is for every principal nation to reckon the longitude from the meridian of its capital. Thus the Engliſh begin to reckon from, or conſider as, the firſt meridian, that which paſſes through London, or rather through the Royal Obſervatory at Greenwich. The French begin to count the longitude from the Obſervatory of Paris. Therefore, according to the French reckoning, the longitude of Greenwich is 2° 25′ weſt; and, according to the Engliſh reckoning, the longitude of Paris is 2° 25′ eaſt.

Then, in order to ſtate the ſituation of places upon the ſurface of the earth, it is neceſſary to ſpecify

ſpecify both their latitudes and their longitudes, and ſuch ſtatements are always ſound annexed to the names of towns, capes, &c. in geographical dictionaries, and other works on the ſubject of geography.

In order to eſtimate real diſtances in miles from the ſtatement of the latitudes and longitudes of any two places, the reader muſt obſerve, 1ſt, That when the two places are under the ſame meridian, or have the ſame longitude, and differ only in latitude, then their difference of latitude converted into miles, at the rate of 69,043 Engliſh miles per degree, will give their real diſtance in miles *. 2dly, That when the places have the ſame latitude, and differ in longitude only, then their real diſtance cannot be had by converting their difference of longitude into miles, according to the above-mentioned rate, unleſs the two places are both under the equator; for ſince the meridians approach each other, according as they recede from the equator, and at laſt do all meet at the poles; therefore the diſtance between two places, which have the ſame difference of longi-

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* A degree of latitude, or of longitude at the equator in nautical affairs, is generally reckoned equal to 60 miles, commonly called *geographical miles*; but ſince it appears from the lateſt meaſurements that the whole circumference of the earth is equal to 24855,43 Engliſh miles; therefore dividing this number by 360°, we have the length of one degree equal to 69,043 Engliſh miles.

tude, diminiſhes in proportion as their latitude increaſes, viz. according as they recede from the equator; the diminution being in the ratio of radius to the coſine of the latitude; viz. the length of a degree of longitude at the equator is to the length of a degree of longitude at a given latitude, as radius is to the coſine of that latitude. Therefore, when two places have the ſame latitude, convert their difference of longitude into miles, at the rate of 69,043 miles per degree; then ſay, as radius is to the coſine of the latitude of the two places, ſo is the number of miles juſt found, to a fourth proportional, which is the real diſtance in miles between the two places. 3dly, When the places differ in longitude as well as in latitude, then their real diſtance in miles muſt be found by the reſolution of a right-angled ſpherical triangle, according to the rules of trigonometry; or it may be found mechanically, and with tolerable accuracy, upon a terreſtrial globe, the uſe of which will be ſhewn hereafter.

In the heavens the diſtance of the ſun, moon, and other objects from the equator, is called their *declination*, which is north or ſouth, according as the object is north or ſouth of the equator; and it is evident that the declination cannot be more than 90°. The fixed ſtars, being diſperſed all over the heavens, are to be found in every degree of declination; but the declination of the ſun never exceeds 23° 28′.

Great circles drawn through the poles of the equator,

equator, or the ſecondaries to the celeſtial equator, are alſo called *circles of declination*, or *meridians*, becauſe upon them the declination is meaſured. Twenty-four of thoſe ſecondaries, that are at 15° diſtance one from the other, and which, of courſe, divide the equator into 24 equal parts (for 360°, divided by 15°, quotes 24), are called *hour circles*; becauſe the ſun, in its apparent diurnal motion, paſſes over 15° in every hour.

The *right aſcenſion* of a celeſtial body, is an arc of the equator interſected between one of the equinoctial points, called the firſt point of Aries, and a declination circle paſſing through that body. This arc is meaſured according to the order of the ſun's apparent motion *. The *oblique aſcenſion* of a celeſtial body is an arc of the equator, intercepted between the firſt point of Aries, and that point of the equator, which riſes with that body in an oblique ſphere. The *aſcenſional difference* is the difference between the right and oblique aſcenſion.

Thus it appears that the diſtance from the equator, and the diſtance from a given meridian, which, for places upon the ſurface of the earth, are called the *latitude* and *longitude*; for celeſtial objects are called the *declination* and *right aſcenſion*.

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* It is called right aſcenſion, becauſe in a right ſphere the declination-circle, which paſſes through the given body, riſes with that body above the horizon.

The *latitude* and *longitude* of a celeſtial object, are its diſtance from the ecliptic, meaſured upon a ſecondary of the ecliptic (hence ſecondaries to the ecliptic are alſo called circles of celeſtial latitude); and its diſtance from a ſecondary of the ecliptic that paſſes through the firſt point of Aries (viz. where the ecliptic interſects the equator), or an arc of the ecliptic interſected by two of its ſecondaries, viz. one which paſſes through the firſt point of Aries, and the other which paſſes through the given body. If the celeſtial body be ſuppoſed to be ſeen from the centre of the earth, its longitude is called *geocentric longitude*. If it be ſuppoſed to be ſeen from the centre of the ſun, it is then called *heliocentric longitude*. And the ſame thing muſt be underſtood of the latitude of the celeſtial bodies; viz. it may be *geocentric*, or *heliocentric*.

Let us now return to the courſe of the ſun, and let us endeavour to explain the lengths of days and nights, the ſeaſons, and other things which depend upon it. As the ſun moves in the period of one year all along the ecliptic, from weſt to eaſt, and as the ecliptic croſſes the equator in two points, and is inclined to it at an angle of about 23° 28′; therefore the ſun, twice in the year, muſt be in the equator, at which time its declination is 0°; and twice in the year muſt be fartheſt from the equator, when its declination is about 23° 28′; once on the north ſide of the equator, and once on the ſouth ſide of it. The former two of thoſe points are called the

the *equinoctial points*, (becauſe when the ſun is at thoſe points, the days are equal to the nights) otherwiſe called the firſt point of *Aries*, and firſt point of *Libra*. A great circle, or a ſecondary to the equator, paſſing through thoſe points, is called the *equinoctial colure*. The latter two points are called the *ſolſtitial points*, becauſe thoſe points (which are the firſt point of *Cancer*, and the firſt point of *Capricorn*) are the laſt ſtations of the ſun, after which it begins again to draw near to the equator. It is at thoſe two points that the tropics touch the ecliptic. A ſecondary to the equator, paſſing through the ſolſtitial points, is called the *ſolſtitial colure*.

In fig. 7, Plate XXVI. *nahsb* repreſents the earth; NCSE repreſents the apparent celeſtial ſphere, or our meridian, as ſituated with reſpect to our latitude, viz. 51° 31′ north; EE is the equator, CD the ecliptic, which interſects the equator at an angle COE of 23° 28′. CT is the tropic of Cancer, which is parallel to the equator, and touches the ecliptic at its moſt northerly point C, which is the firſt point of Cancer. RD is the tropic of Capricorn, likewiſe parallel to the equator, and touching the ecliptic at its moſt ſoutherly point D, which is the firſt point of Capricorn. HH is our horizon, London being at *z*, and our zenith at Z. NS is the axis of the world, of which N is the north, and S the ſouth, pole*.

O is

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* For the ſake of perſpicuity the ſphere in this figure is projected orthographically, and the meridian NCHSDT is the

O is one interſection of the ecliptic with the equator, or the firſt point of Aries. The other interſection, or the firſt point of Libra, being on the oppoſite ſide. C is one ſolſtitial point; namely, the firſt point of Cancer; and D is the other ſolſtitial point; namely, the firſt point of Capricorn.

Now, on the 20th of March the ſun will be found at O, viz. where the ecliptic interſects the equator; therefore it will appear to move round the earth, together with the whole ſphere, in about 24 hours, and its path will coincide with the equator. On the following day the ſun will be found, not at O, but in another point of the ecliptic a little eaſtward of O, as, for inſtance, at P, and, with the whole ſphere, will appear to turn round the earth in a circle parallel to the equator, for inſtance, along the dotted circle 1, 2, the arc E 1 being its declination for that day. On the enſuing day the ſun will be found farther from O, as for inſtance at Q; and, moving with the whole ſphere, will appear to turn in a circle parallel to, but a little farther from, the equator, and ſo on; until in about three months time, viz. on the 21ſt of June, it will reach the ſolſtitial point C of the ecliptic; and on that day it will appear to turn with the tropic C T; its north

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the primitive circle; therefore all the circles, whoſe planes are perpendicular to the primitive, ſuch as the equator, the tropics, the ecliptic, &c. are repreſented by right lines.

declination CE being an arch of about 23° 28′. After this, the ſun will continue to move on the ecliptic, and after about three months longer, viz. on the 23d of September it will reach the other interſection of the ecliptic with the equator. Proceeding ſtill farther, in about three months more, viz. on the 22d of December, it will reach the other ſolſtitial point D of the ecliptic, at which time it will appear to move along the tropic DR. Near three months after, it will reach again the equinoctial point O; having performed the whole courſe of the ecliptic from the weſt towards the eaſt, in the compaſs of 12 months; after which it begins to perform a ſecond and ſimilar revolution, &c.—This motion of the ſun being once underſtood, the following conſequences will be readily comprehended.

I. When the ſun is at the point O of the ecliptic, and appears to move along the equator EE; then, ſince EE is a great circle, and the horizon HH is likewiſe a great circle; therefore they muſt cut each other into two equal parts; hence, at that time, half the apparent daily courſe of the ſun is performed above the horizon, and the other half is performed below it; or, in other words, the day is equal to the night. When the ſun is in any other point of the ecliptic, between O and C, its daily courſe will be performed in *leſſer* circles parallel to the equator; which leſſer circles are cut into two *unequal* parts by the horizon, becauſe they are not

perpendicular

perpendicular to the horizon; thus the circle C T is cut by the horizon H H, into two unequal parts, whereof C 3 is the largeſt, and 3 T the ſhorteſt; for ſince C T is cut at 5, into two equal parts by the great circle N O S; therefore C 3, being longer than the half C 5, muſt be much longer than the ſegment T 3. Of any one of thoſe circles, along which the ſun appears to perform each daily revolution, that portion, which is above the horizon, is called the *diurnal arch*, and that which is below the horizon, is called the *nocturnal arch*; the halves of which, viz. from the horizon to the meridian as 3 C, and 3 T; or as 1 *y*, and 2 *y*, are reſpectively called the *ſemidiurnal*, and the *ſeminocturnal, arches*. Therefore, from the 20th of March, at which time the ſun is at the point O, until the 21ſt of June, at which time the ſun is at the point C of the ecliptic; the diurnal arches, or the days, grow continually longer than the nocturnal arches, or the nights. After that, the days begin to ſhorten, and the nights to lengthen, in proportion as the ſun draws nearer to the autumnal equinox, and on the 23d of September, when the ſun is exactly at that point, the day becomes equal to the night. Proceeding ſtill farther towards the ſouthern part of the ecliptic, the ſun again performs its daily courſe in leſſer circles, which are unequally divided by the horizon; with this difference, however, that now the *nocturnal* are longer than the *diurnal* arches; viz. the nights grow continually longer than the days, until the ſun reaches,

reaches, on the 22d of December, the point D of the ecliptic, at which time the ſemi-diurnal arch R 4, or the day is the ſhorteſt, and the ſeminocturnal arch D 4, or the night is the longeſt. Then the days begin to lengthen again, &c.

In ſhort, during the 12 months, four remarkable changes, or periods, or ſeaſons, may be diſtinguiſhed, viz. 1ſt. From the vernal equinox, on the 20th of March, when the ſun is at O in the ecliptic, until the ſummer ſolſtice, on the 21ſt of June, when the ſun is at C. 2dly, From the laſt-mentioned time, until the ſun reaches the autumnal equinox on the 23d of September. 3dly, From the 23d of September, until the 22d of December, when the ſun reaches the winter ſolſtice. 4thly, and laſtly, From the laſt-mentioned time until the ſun reaches again the point O, on the 20th of March; thoſe periods form the four ſeaſons of the year, which are attended with different degrees of temperature, different fertility of the ground, &c. Thoſe differences ariſe from the following three cauſes, that is, 1ſt, becauſe when the ſun is longer above the horizon (as in ſummer) than below it, the ground, by being longer expoſed to its rays, acquires more heat than when the ſun remains a ſhort portion of the 24 hours above the horizon; 2dly, becauſe, when the ſun gets nearer to our zenith, its rays, coming leſs obliquely, fall upon a given ſpot in greater quantity than when they are more oblique; and 3dly, becauſe when the ſun is nearer to the zenith, its rays go a ſhorter way through

through the atmoſphere, and, of courſe, are leſs obſtructed by it, than when they are more oblique *.

II. The effects, which we have juſt deſcribed, are ſuch as take place in our latitude; but in other latitudes they differ conſiderably, as will be eaſily comprehended by attending to fig. 7; and, by obſerving that when the ſun is advancing towards the northern hemiſphere, it muſt recede from the ſouthern hemiſphere; and therefore whilſt the days are growing longer to us, and the nights ſhorter; the reverſe muſt take place with reſpect to the inhabitants of the ſouthern hemiſphere; viz. the days muſt be diminiſhing and the nights muſt be growing longer, therefore, when it is ſummer to us, it muſt be winter to them, and *vice verſa.* But when the ſun is at the equinoctial points, the days are equal to the nights all over the earth, becauſe the ſun then moves along the equator, which, being a great circle, is cut into two equal parts by the horizon of every place.

III. Excepting when the ſun is at the equinoctial points, the length of the ſame day, viz. of the ſun's continuance above the horizon, is different according

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* The diſc of the ſun appears, from meaſurement, to be a little larger in winter than in ſummer; therefore we infer that the ſun is a little nearer to us in winter than in ſummer. But the difference is ſo ſmall, that the effect which might ariſe therefrom, is vaſtly overpowered by the above-mentioned three cauſes.

ing to the difference of latitude; for in that proportion the parallels of declination are more or leſs inclined to the horizon; and, of courſe, are more or leſs unequally divided by the horizon of each particular place. Thus, for inſtance, on the 4th of May we have about 20 hours of day light, and about four hours of darkneſs; but on the ſame 4th of May thoſe, whoſe latitude is farther north, have a longer continuance of day light, and a ſhorter of darkneſs; whereas thoſe who live nearer to the equator than we do, have a ſhorter continuance of day light, and a longer of darkneſs. In ſhort, to thoſe who live under the equator, the days are always equal to the nights, becauſe every parallel of declination, or every apparent revolution of the ſun is divided into two equal parts by their horizon. But the horizons of other places cut the parallels of declination more and more unequally, in proportion as thoſe places are more and more diſtant from the equator; whence the difference between the days and the nights increaſes accordingly. But to thoſe whoſe latitude exceeds 66° 32′, either ſouth or north, the ſun remains above the horizon during ſeveral days ſucceſſively in ſummer, and remains quite inviſible during ſeveral days ſucceſſively in winter.

In order to underſtand the reaſon of this phenomenon, it muſt be previouſly conſidered, that when an opaque globe, like the earth, is expoſed to a very diſtant luminous object, like the ſun, it can have not more

more than half its ſurface illuminated at the ſame time, and the boundary of that illuminated part round the ſphere, forms a great circle, the axis of which, if produced, will paſs through the luminous object. Now when the ſun is at the ſolſtitial point C, it is then vertical to that part of the earth (viz. to the ſpot *i*), the latitude of which is about 23° 28′ north; for ſuch is the angle COE. Now ſince the circle *b b*, which forms the boundary of light, being a great circle, is 90° diſtant from its pole *i*; and ſince the arch *e n* is likewiſe 90°; therefore the diſtance *bn* of the boundary of light from the pole *n*, muſt be equal to *i e*, viz. 23° 28′; ſo that at that time the portion *anb* of the earth muſt be conſtantly illuminated; that is, the ſun muſt appear to go round and round for ſeveral days, without ever ſetting. It is alſo evident that an equal portion *bsf* of the earth, round the ſouth pole *s*, muſt remain as long in an uninterrupted darkneſs. The circles *b a*, and *b f*, which limit thoſe ſpots, and which are about 23° 28′ diſtant from the poles (viz. as much as the tropics are from the equator), are called the *polar circles*, *b a* being the *north*, and *b f* the *ſouth*, *polar circles*, otherwiſe called the *arctic*, and the *antarctic circles*. When the ſun, after the ſolſtice, draws nearer to the equator, the boundary of light muſt of courſe approach the poles; hence a ſmaller portion of the earth, round the north pole, will have conſtant day light, and an equal portion round the ſouth pole will have conſtant darkneſs. But when the

the ſun, having croſſed the equator, advances towards the ſouthern hemiſphere, then the boundary of light recedes from the north pole *n*; that is, a larger and larger portion of the earth round that pole, will be left in continual darkneſs, whilſt an equal ſpot round the ſouth pole *s* will enjoy conſtant day light, and ſo on. Therefore the inhabitants of the north pole (ſuppoſing that ſome may live there) muſt ſee the ſun above their horizon (which coincides with the equator) moving parallel to it during ſix months of the year; viz. from the vernal equinox to the autumnal equinox; and muſt altogether loſe ſight of it during the other ſix months; whereas the inhabitants of the ſouth pole muſt have a conſtant night during the former ſix months, and a conſtant day light during the latter ſix months.

IV. As the ſun moves from one tropic to the other, and back again to the former tropic in the courſe of every year, and as the tropics are about 23° 28′ diſtant from the equator; therefore the ſun is vertical to, or paſſes over the zenith of, different places on the ſurface of the earth, provided the latitudes of thoſe places do not go beyond 23° 28′ north or ſouth of the equator. That portion or zone of the earth which is within thoſe two latitudes, or which is between the tropics, is called the *torrid zone*, from the great heat to which it is expoſed. The portions *b n a*, and *f s b*, which are limited by the polar circles, are called the *north* and the *ſouth frigid zones*; the remaining parts of the earth, which

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are between the tropics and the polar circles, are called the *temperate zones*. Thus the ſurface of the earth is ſuppoſed to be divided into five zones*.

After the above mentioned conſequences of the ſun's daily and annual courſe, it will be neceſſary to mention ſome irregularities reſpecting it, the cauſe of which will be explained hereafter; as alſo the length of the year, both ſolar and aſtral.

If we count the time from the vernal equinox to the autumnal equinox, and likewiſe the time from the autumnal equinox to the next vernal equinox, we ſhall find that the former period exceeds the latter by about eight days, which ſhows that the ſun re-

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* The following uſeleſs diſtinction reſpecting the ſhadows which are caſt by the different inhabitants of the earth, is generally mentioned by the writers on aſtronomy. The inhabitants of the torrid zone are called *Amphiſcii*, becauſe, at different times of the year, their meridian ſhadows are directed towards both poles, but when the ſun is over their heads, then their ſhadow falls under their feet, or rather they form no ſhadow ſimilar to the human body, and at that time they are called *Aſcii*, or ſhadowleſs. Thoſe who live in the temperate zones, are called *Heteroſcii*, becauſe their meridian ſhadows are projected towards one pole only at any time of the year. Laſtly, the inhabitants of the frigid zones are called *Periſcii*, becauſe when the ſun is conſtantly above their horizons, their ſhadows are ſucceſſively directed towards all the points of the compaſs in 24 hours.

mains about eight days longer on the northern half of the ecliptic than on the other half of it.

Aſtronomers conſider the year under two diſtinctions; viz. the *ſolar* and the *aſtral.* The *tropical* or *ſolar year*, upon which the ſeaſons depend, is the exact time in which the ſun moves all round from one equinox to the ſame again, and which period has been found to be equal to 365 days, 5 hours, 48′ 49″. The *aſtral year* is the time that the ſun employs in going from one fixed part of the heavens, viz. from a given fixed ſtar, all round, and again to the ſame preciſe point of the heavens; and this period or aſtral year is a little longer than that of the ſolar year, viz. it is equal to 365 days, 6 hours, 9′, 12″, which is longer than the ſolar year by 20′, 23″, of time; or to an arc of 50″,25 (for, in 20′, 23″ of time, the ſun percurs an arch of 50″,25[*]); ſo that the ſun, as ſeen from the earth, arrives at the equinoctial point, viz. at the equator, a little before it arrives at that ſame preciſe point of the heavens, with which it coincided, when it croſſed the equator on the preceding year. This difference between the period of the ſun's going from one equinox to the ſame, and the period of its going from a given ſtar,

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[*] This is eaſily determined by means of the common rule of proportion; for ſince the ſun's apparent daily motion performs an entire circle in 24 hours; therefore we ſay as 24 hours are to 360 degrees, ſo are 20′ 23″ to a fourth proportional.

or part of the heavens, to the ſame again, is called the *preceſſion of the equinoxes.* This preceſſion in one year is very trifling, but the accumulation of it after a number of years, produces a conſiderable difference, which can by no means be paſſed unnoticed; thus, in a hundred years (which is called the *ſecular preceſſion*) it amounts to 1°, 23′, 45″; and the difference, which it has produced ſince the ſtars were firſt obſerved, and their poſitions were delineated, is very ſtriking.

Novices in aſtronomy do not, in general, readily comprehend the real meaning of the preceſſion of the equinoxes; therefore it will be neceſſary to explain it in a more particular manner.

How can the ſun return to the ſame equinox at the end of every year, without returning to the ſame ſpot in the heavens, or to the ſame fixed ſtar? is the uſual difficulty. In order to clear this difficulty the reader muſt recollect that the equator is a circle which, being equidiſtant from the poles, divides the celeſtial ſphere into two equal portions. Now, if the poles were ſtationary, viz. coincided conſtantly with the ſame ſpots in the heavens, then the equator would likewiſe paſs conſtantly over the ſame fixed ſtars, and would cut the ecliptic conſtantly at the ſame points; for the ecliptic is an invariable circle, viz. it paſſes always over the ſame ſtars. But it has been obſerved, that the poles are ſubject to a conſtant, though very ſmall, movement; ſo that if at at one time any one of the two points in the heavens, which do not revolve with the daily revolution of the reſt of the ſphere, and which we, for that reaſon, call the poles, be near a certain ſtar, ſome years after it will be found near ſome other ſtar; or in other words, the polar ſtar is not always the ſame. It appears from the reſult of calculations eſtabliſhed upon the obſervations made during ſeveral centuries, that the path of either of the poles is a circle, the pole of which coincides with the pole of the ecliptic, and that the pole will move along that circle ſo very ſlowly, as to accompliſh the whole revolution in 25791 years nearly. The diameter of this circle is equal to twice the inclination of the ecliptic to the equator, viz. to about 27°.

Now, as the ecliptic is a fixed circle in the heavens; but the equator, which muſt be equidiſtant from the poles, moves with the poles; therefore the equator muſt be conſtantly changing its interſection with the ecliptic. And from the beſt obſervations it appears that the equator cuts the ecliptic every year $50'',25$ more to the weſtwards, than it did the year before: hence the ſun's arrival at the equinoctial point *precedes* its arrival at the ſame fixed ſpot of the heavens every year by $20'\ 23''$ of time, or by an arc of $50'',25$. Thus, by little and little, theſe equinoctial points will cut the ecliptic more and more to the weſtward, until, after the long period of 25791 years, they will cut it again at the ſame point preciſely.

The 12 conſtellations, which, as has been mentioned in the preceding pages, occupy the whole zodiac, have given their names to 12 equal portions of the ecliptic, each portion conſiſting of 30°, and each portion was marked by the ſign, mark, or character, peculiar to the conſtellation to which it belonged, or with which it coincided when the conſtellations were firſt noticed, at which time the vernal equinox took place in the conſtellation of Aries, the ſummer ſolſtice in that of Cancer, &c. but on account of the preceſſion of the equinoxes, the conſtellations no longer coincide with thoſe points; for inſtance, the vernal equinox is in the conſtellation of Piſces, and the conſtellation of Aries is now conſiderably removed from it, and is gone nearer to the ſummer ſolſtice; and ſo are all the other conſtellations removed; yet their characters have been left to denote the ſame parts of the ecliptic; thus the vernal equinox is called the firſt point of Aries, and is marked ♈; and ſo of the reſt.

From what has been ſaid above, it appears that not only the equinoctial points, but alſo the ſoliſtitial points, muſt change accordingly.

It is now neceſſary to explain the *civil* or common way of reckoning the year.—It has been ſaid above, that the length of the aſtral year is 365 days, 6 hours, 9′, 12″, and that the length of the mean tropical or ſolar year is 365 days, 5 hours,

48′,

48′, 49″. Then, ſince the ſeaſons and the lengths of days and nights depend upon the latter, it is therefore natural to uſe the laſt, viz. the ſolar year, for the purpoſes of civil ſociety. Now as the period of that year does not conſiſt of a number of entire days; therefore, beginning to reckon from any day, one year after that, or the new year, ought to begin when 365 days, 5 hours, 48′, 49″, are elapſed; and the next year ought to begin when twice that period, or when 730 days, 11 hours, 37′, 38″, are elapſed; which would make an enormous confuſion: on the other hand, if the 5 hours, 48′, 49″, be neglected, the accumulation of ſo many neglected 5 hours, &c. after a number of years, would produce a conſiderable difference between the ſolar and the civil year, and the ſeaſons would not fall conſtantly on the ſame months.

It is eaſy to obſerve that the 5 hours, 48′, 49″, will amount to nearly 24 hours, viz. to a whole day at the end of every four years. Therefore Julius Cæſar, willing to remedy this irregularity, ordered that every fourth year ſhould have an *intercolary day*, viz. ſhould conſiſt of 366 days; whereas every one of the other three years conſiſts of 365 days; and this mode of reckoning, which has prevailed ever ſince, has thence been called the Julian method; and that every fourth or Julian year, has been univerſally called *Biſſextile year*; in England, *leap year*. The additional day which that year has above every one of the three preceding, or of the three ſucceed-

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ing years, was by the ancient Romans added to the 23d of February; ſo that in a leap year they reckoned the 23d of February twice over, viz. according to their way of reckoning, in that year they had two ſixth days preceding the calends of March. Hence (viz. from *bis ſextus*) that year was called a *biſſextile year*. At preſent we add the intercolary day at the end of February; ſo that the month of February has 28 days during three ſucceſſive years; but every fourth, or leap, year, it has 29 days.

Thus the compenſation would be ſufficient, if the ſolar year conſiſted of 365 days and 6 hours, becauſe the ſix hours of all the four years, amounting to 24 hours, would be exactly equal to the additional day, which is allowed to every fourth year. But ſince the odd time amounts to 5 hours, 48′, 49″ which is 11′, 11″, ſhort of 6 hours; and the accumulation of thoſe 11′, 11″, amounts to one complete day in about 130 years; therefore, the addition of one day every four years is evidently too much, by 4 times 11′, 11″; viz. by 44′, 44″, or by about one day in 130 years. In fact, at the council of Nice (A. D. 325.) the vernal equinox fell on the 21ſt March; but the equinox continually falling back, it appeared at the time of Pope Gregory the 13th, that the ſun came to the vernal equinox on the 11th of March, therefore the difference between the ſolar and the civil years, amounted to 10 whole days; in conſequence of which the above-mentioned

Pope ordered that the calendar ſhould be corrected, by taking 10 whole days out of it; and accordingly, in the year of our Lord 1582, the day following the 4th of October, inſtead of being called the 5th, was called the 15th; by means of which alteration the real equinox was reſtored to the 21ſt of March: and in order to prevent, as much as poſſible, the like irregularity in future, the ſame pope ordained, that every 100th year, which according to the Julian mode was to be a biſſextile year, ſhould be a common year, viz. of 365 days; but becauſe that was too much, every 400th year was to remain biſſextile. In other words, to leave out a biſſextile-day in February at the end of every century of years not diviſible by four, reckoning them common years of 365 days each; ſuch as the 17th century, or the year 1700, the 18th century, or the year 1800, &c. and to retain the biſſextile day in February at the end of thoſe centuries, which are diviſible by 4, ſuch as the 16th, 20th, 24th centuries, &c. or the years 1600, 2000, 2400, &c. Thus the preſent year 1802 is ſaid to be the ſixth year after the leap year, for the year 1800, viz. the 18th century, being not diviſible by 4, was reckoned a common year.

This new form of reckoning, viz. with the juſt and neceſſary correction which was ordained by Pope Gregory, is called the *Gregorian*, or the *new, ſtyle*, and has been adopted by almoſt all the enlightened nations of the world. There are ſome, however,

however, who ſtill reckon according to the old ſtyle, viz. as if no alteration had been made by Pope Gregory.

What has been ſaid above, concerning the deviation of the true vernal equinoctial point from its uſual day in March, muſt be likewiſe underſtood of the other equinoctial point, as alſo of the ſolſtitial points; for according as one of them deviates from its uſual day, ſo muſt the others evidently deviate from their uſual days.

CHAP. III.

OF THE TRUE SYSTEM OF THE WORLD, OR OF THE SOLAR SYSTEM.

THE apparent movements of the celeſtial bodies have been deſcribed in the preceding chapter, ſufficiently to give a general and comprehenſive idea of the whole. With this view, as alſo for the purpoſe of avoiding confuſion of ideas, the moſt minute particulars, together with the practical methods of taking and calculating the ſame, have been reſerved for future chapters. In that view ſeveral apparent irregularities have been pointed out, which, together with various other conſiderations, prove that the celeſtial bodies muſt move in paths different from what they appear to perform.

We have ſhewn in the firſt chapter of the preſent part, that regular movements may appear to be very irregular; as alſo that bodies actually in motion may appear to be at reſt; or, *vice verſa*, that bodies at reſt may appear to be in motion, according to the ſituation of the ſpectator.

The evidence of our ſenſes, frequently fallacious, and hardly ever correct, muſt be ſubmitted to the ſuperiority of reaſon and demonſtration. When the ſame appearances may be produced by various different cauſes; that cauſe muſt be admitted, believed, or preferred, which is warranted by reaſon; not that which implies an abſurdity, or which bears no analogy to the known works of nature. When perſons in different boats, move in different directions along the ſea coaſt, they may at firſt ſight imagine that they are ſtanding ſtill, and the land is moving; but it is eaſy to conclude, that this is a fallacious appearance; for, on account of the boats moving in different directions, the land ought likewiſe to move in different directions at the ſame time, which is an evident abſurdity.

Thus alſo to a ſpectator on the plane, the clouds ſeem to be as high as the moon; but that they are vaſtly diſtant from it, is clearly proved by thoſe who aſcend to the tops of high mountains; for they ſee the clouds below their feet, at the ſame time that the moon ſeems to be as much above their heads as when they were upon the plane.

The ſun, the moon, and eſpecially the planets, appear to move with great irregularities round the earth; therefore it is moſt probable that they move round ſome other centre, agreeably to ſome general laws of nature; and analogous to the other, even what we call the meaneſt works of nature, which our utmoſt endeavours always find to be ſtrictly conformable to, or depending on, ſome ſimple and general law.

Various hypotheſes have been formed, or ideal ſyſtems of the world have been framed, for the purpoſe of accounting for the apparent irregularities; the principal of which ſyſtems we ſhall mention in this chapter; but in order to ſhow how far any one of them may anſwer the deſired object, it will be neceſſary previouſly to mention ſome of the moſt ſtriking appearances, or difficulties, which they are intended to explain, and to obviate.

The moon and the eight planets are evidently opaque bodies, and they only ſhine by reflecting the light which they receive from the ſun; which is deduced from this, viz. that their illuminated part is always that which is directly towards the ſun, the reſt being always dark. From the appearance alſo of the boundary of light and darkneſs upon their ſurfaces, we conclude that they are ſpherical or nearly ſpherical bodies; which is confirmed by moſt of them having been found to turn periodically round their axes.

The moon, we are led to ſuppoſe, keeps nearly within the ſame diſtance of the earth; for her apparent diameter does not vary much; and from often repeated meaſurements, it appears to be never leſs than 29′, 30″; nor ever greater than 33′.

The moon comes to the meridian later every day, cuts it at different heights, and remains a different length of time above the horizon. Its phaſes, or appearances of its ſhining part, have already been deſcribed.

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The planet *Venus*, the brighteſt of the planets, when viewed through a teleſcope, is found to undergo changes analogous to thoſe of the moon. Her apparent diameter varies conſiderably, ſometimes being five or ſix times greater than at other times. She is ſometimes found to come to the meridian with the ſun; it then precedes the ſun, ſo as to appear to move from eaſt to weſt, and this precedency increaſes until it becomes equal to 3 hours 10′, or to an arc of 47°, 30′. At this period Venus ſeems to be ſtationary for a ſhort time, after which the time of her coming to the meridian before the ſun decreaſes gradually, and at laſt they both come to the meridian at the ſame time. After this coincidence, ſhe culminates later than the ſun, and continues to move apparently from weſt to eaſt, until ſhe comes to the meridian about 3 hours 10′ later, which is her greateſt elongation from the ſun; for at this period ſhe again ſeems to remain ſtationary for a ſhort time, then ſhe appears again to move from eaſt to weſt, and ſo on. The declination of Venus varies conſiderably; ſometimes receding from the equator as much as 27° north or ſouth of it. When Venus appears eaſterly of the ſun, ſhe ſets after the ſun, of courſe is ſeen in the evening, and is then called the *evening ſtar*. When ſhe appears weſtward of the ſun, ſhe then riſes before the ſun, and being ſeen in the morning, is called the *morning ſtar*.

Mercury is ſeldom ſeen, on account of its ſhort diſtance from the ſun, which never exceeds 1 hour 50′ in time, or an arch of about 27° 30′. It performs its movements much quicker than Venus; but, as far as has been obſerved, it has been found to move like Venus, viz. to be ſometimes direct, at other times retrograde, and at its greateſt elongations from the ſun, ſtationary.

The planet *Mars* ſometimes appears to come to the meridian together with the ſun, at other times it precedes or follows the ſun. It is ſome time directly oppoſite to the ſun, ſo as to be ſeen on the meridian at midnight. When Mars is thus oppoſite to the ſun, its diameter is about five times greater than when it appears near to, and comes to the meridian at the ſame time with, the ſun. The apparent motion of Mars is alſo ſometimes direct, or from eaſt to weſt; ſometimes retrograde. Between thoſe changes it appears ſtationary for a ſhort time. Its phaſes may be clearly diſcerned through a teleſcope; for its ſhining part is ſometimes full and round, and at other times gibbous, but never horned like the new moon.

The like remarks are true with reſpect to the other planets. They being alſo direct, retrograde, or ſtationary at different times, and, as far as can be obſerved, ſhewing different phaſes, like Mars.

The principal hypotheſes or ſyſtems of the world, which have been formed in order to account for thoſe phenomena, may be reduced to three, which are

are known by the names of the *Ptolemaic*, the *Tychonic*, and the *Copernican*, or *Newtonian*, *ſyſtems*.

Ptolemy, an Egyptian philoſopher, who wrote about the year 140, endeavoured to eſtabliſh the vulgar idea, which is derived from firſt appearances, uncontrolled by reaſon. He ſuppoſed that the earth was fixed and immoveable in the centre of the univerſe, and that all the celeſtial bodies performed their revolutions about it in the following order, viz. the Moon was next to it, then came Mercury, Venus, the Sun, Mars, Jupiter, and Saturn; the other three planets not being known at that time. Beyond Saturn, he ſuppoſed the exiſtence of various immenſe orbs, which he called the ſtarry firmament, and the cryſtalline orbs under the names of *primum mobile*, and *cœlum empyreum*; all which were ſuppoſed to turn round the earth once in 24 hours, beſides their having proper and peculiar movements.

If this ſyſtem had been true, the planets Mercury and Venus ought ſometimes to have been ſeen in oppoſition to the ſun, which phenomenon was never obſerved. I need not adduce more objections; as they will naturally be manifeſted in ſpeaking of the true ſyſtem, which was revived by the genius of Nicholaus Copernicus, who was born at Thorn in Pruſſia, A. D. 1473, and which was afterwards eſtabliſhed upon a ſafe foundation, by the incomparable Sir Iſaac Newton.

I ſaid the ſyſtem *revived* by Copernicus; for the ſame had long before been introduced into Greece by the great Pythagoras, and his diſciples, who had probably learned it from the wiſe men of the Eaſt.

According to this ſyſtem, which we ſhall preſently deſcribe in a more particular manner, the ſun remains immoveable in the centre, and all the planets, reckoning the earth one of them, move round it at different diſtances, and in different times, Mercury being neareſt to the ſun; then the others come in the following order with reſpect to their diſtances; viz. Venus, the Earth, Mars, Jupiter, and, laſtly, Saturn.

This ſyſtem was adopted and retained, until Ariſtotle, and the philoſophers that came after him, embraced the vulgar, or Ptolemaic, ſyſtem; and their authority impoſed it upon mankind, till Copernicus revived the Pythagorean idea; and the induſtry, the diſcoveries, and the reaſoning of almoſt all the ſucceeding philoſophers, eſtabliſhed it upon the ſtrongeſt foundation of rational evidence.

I have ſaid almoſt all the philoſophers, &c.; becauſe another ſyſtem, which partakes of both the above-mentioned ſyſtems, was offered to the public by Tycho Brahe, a very diſtinguiſhed Daniſh aſtronomer, who has otherwiſe rendered eſſential ſervices to aſtronomy, and who wrote about the middle of the 16th century. This diſtinguiſhed character ſeems to have admired the ſimplicity and the beauty of of the Copernican ſyſtem; but a ſtrict interpretation of, and his reſpect for, certain paſſages of the Bible, prevented his aſſent to the idea of the earth's motion, in conſequence of which he formed the following ſyſtem. He ſuppoſed the earth to ſtand immoveable in the centre of the univerſe, and the ſun to revolve about it every 24 hours: the planets he thought went round the ſun in their periodical times, Mercury being neareſt to the ſun, then Venus, Mars, Jupiter, and Saturn, and of courſe to revolve alſo round the earth. But ſome of Tycho's diſciples ſuppoſed the earth to have a diurnal motion round its axis, and the ſun, with all the planets, to move round the earth in one year.

The embarraſſment and perplexity, under which this ſyſtem laboured, were too evident. The moſt inconſiſtent ſuppoſition was, that the planets performed their revolutions round two centres, viz. the diurnal round the earth, and the periodical round the ſun. But its inconſiſtencies will be naturally manifeſted by the following deſcription of the true or Copernican ſyſtem, which ſoon after Tycho's time was confirmed and explained in almoſt all its parts, by the unanſwerable arguments and wonderful diſcoveries of Repler, Galileo, Newton, and others.

According to this ſyſtem, the ſun, an immenſe globe, conſtantly emitting abundance of heat and light, is ſituated in a part of the univerſe, where it revolves about a centre, which centre is within its ſurface, and which has not been found to alter its diſtance from the fixed ſtars.

The planets (of which our earth is one) do all revolve about the ſun at different diſtances, therefore in different *orbits* (viz. paths), and in different times. The comets, when they do appear, are alſo found to go round the ſun. The order, in which the planets are ſituated with reſpect to their diſtances from the ſun, is as follows: Mercury is neareſt to the ſun, Venus is the next, then comes the Earth, Mars, Ceres, Pallas, Jupiter, Saturn, and, laſtly, the Georgian planet.

The Moon goes round the earth, and of courſe with it, round the ſun. Jupiter, when viewed through a pretty good teleſcope, is ſeen to have four moons, which revolve in different paths about it, and go with it round the ſun. Saturn alſo, when viewed through a powerful teleſcope, is found to be attended by ſeven moons, which revolve in different orbits round it, and go with it round the ſun. Beſides the ſeven moons, Saturn is alſo found to have a remarkable ring, which will be deſcribed hereafter. The Georgian planet, when viewed through the moſt powerful teleſcopes, appears to have ſix moons, which move in different orbits about that planet, and go with it round the ſun. The other five planets have not been found to have any moons.

The above-mentioned moons are otherwiſe called *ſatellites*, or *ſecondary planets*; their reſpective *primary planets* being thoſe about which they revolve. All the planets move from the eaſt towards the weſt, and in the ſame direction do the moons revolve round their primaries; excepting thoſe of the Georgian planet, which ſeem to move in a contrary direction.

Beſides the above-mentioned movements round the ſun, the earth and moſt of the planets have a rotatory motion round their own axes, which motion is in the direction from eaſt to weſt; and, reaſoning from analogy, it ſeems probable that all the planets, as well as the ſatellites, move round their reſpective axes in the ſame direction, viz. from eaſt to weſt.

Before we proceed any farther, it will be neceſſary to aſſiſt the learner in the comprehenſion of this ſyſtem by a diagram. See fig. 8, Plate XXVI. which exhibits a view of this ſyſtem, as it would appear to a ſpectator ſituated at a conſiderable diſtance above the ſun, in a line perpendicular to the earth's orbit. But it muſt be obſerved, that in this figure the diſtances of the planets from the ſun, and of the ſatellites from their primaries, are not repreſented in their due proportions, which the ſize of the plate cannot admit of; nor are their orbits repreſented in their true ſhapes, which are *elliptical*, but ſo little different from circles, that, in a diagram of this ſort, they could hardly be diſtinguiſhed from circular paths.

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With reſpect to this figure, we need only obſerve that the motion of all the planets round the ſun, which ſtands in the centre, is in the direction of the letters A B C D E, and the motion of the ſatellites round their primaries, is in the direction of the letters *a b c d e*. The marks or characters of ſuch planets, as have any character given them by the aſtronomers, are marked upon their reſpective orbits in a line from the centre of the figure upwards. The aſtronomers denote the ſun by the character ☉.

Thus (we have ſaid above) would the planets appear to move, if the ſpectator were ſituated above the ſun in a line perpendicular to the orbit of the earth. But ſuppoſe that the ſpectator ſhould be ſituated ſideway, viz. in the ſame plane with the orbit of the earth, but farther from the ſun than any of the planets; then, it is evident, that if the orbits of the planets were all in the ſame plane, the ſpectator would ſee the planets move all in the ſame ſtraight line. This, however, is not the caſe; for the orbits of the planets are a little inclined to each other; in conſequence of which the ſpectator would ſee them move backwards and forwards, in lines inclined to each other, ſomewhat like thoſe of fig. 9, Plate XXVI.

Of the real diſtances of the fixed ſtars from the ſun, as alſo from each other, we are utterly ignorant. Certain it ſeems, that the diſtance of the neareſt fixed ſtar from us exceeds by a great many millions

millions of times the diameter of the largeſt planetory orbit, as that of the Georgian planet. It is not in our power to ſay whether the ſtars are of equal bulks, and appear of different ſizes, only on account of their different diſtances; or they differ both in ſize and diſtance. Every circumſtance we are acquainted with ſeems to ſhew that they ſhine by the emiſſion of their own light, and that therefore they are of the nature of our ſun. Probably each ſtar is the centre of a particular ſyſtem, and has a number of planets revolving about itſelf, and deriving both light and heat from it; but thoſe planets, if exiſting, are quite inviſible to us.

If it be ſuppoſed that each ſtar is equal to our ſun, the extremely ſmall diameters under which they appear, and which cannot be meaſured with certainty by means of any micrometer, is ſufficient to indicate the aſtoniſhing diſtances to which even the neareſt ſtars are removed from us.

After having indulged our fancy in a ſhort contemplation of ſo many ſuns, and ſo many ſyſtems, let us return to our ſolar ſyſtem, and enquire what retains the planets in their orbits round the ſun.

This queſtion, which had long perplexed the moſt learned and inquiſitive philoſophers, was at length ſatisfactorily anſwered by Sir Iſaac Newton's theory. A ſimple but general theory, which he deduced from the known laws of nature, which he demonſtrated ſtrictly to account for all the phenomena, and which has been wonderfully confirmed by all the ſubſequent

ſubſequent aſtronomical diſcoveries and calculations *.

I ſhall endeavour briefly to explain the principles of this theory; but, for the comprehenſion of what follows, the attentive reader ſhould recollect what has been explained in the firſt volume of theſe Elements, reſpecting the doctrine of motion, eſpecially concerning the curvilinear motion of a body, which is acted upon by two powers at the ſame time, one of which powers is uniform, and the other variable.

Newton obſerving, according to the known theory, that the attractive force of the earth acts at all thoſe heights which are acceſſible to us, and that it decreaſes in proportion as the ſquares of the diſtances increaſe, naturally conjectured that it might act at all other diſtances under the ſame law of decrement; therefore the force of that attraction at any given diſtance being known, one may eaſily calculate the quantity of that force at any other given diſtance.

Newton likewiſe, obſerving that the attraction is mutual amongſt the terreſtrial bodies, juſtly ſuppoſed that all the bodies of the ſyſtem might mutually attract each other, their attractive forces being as the quantities of matter directly, and the ſquares of the diſtances inverſely.

Now if this attractive property alone had exiſted

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* Newton's Principia Math. Phil. Nat.

in the world at its creation, it is evident that, ſooner or later, according to their diſtances, the planets, both primary and ſecondary, would have all been drawn with an accelerated motion directly towards the ſun, which is by far the largeſt body of the ſyſtem; and the whole would have coaleſced in one body. Therefore Newton ſuppoſed that at the creation each planet was impelled by a ſingle ſtroke, ſuch as would by itſelf compel it to move at ſome uniform rate in a ſtraight line for ever, in a direction perpendicular to that of the ſun's attraction; provided it moved in an unreſiſting medium, or with a proportionate retardation in a reſiſting medium *.

Now thoſe premiſes being admitted, it neceſſarily follows, that the action of both powers, (viz. of the attractive force which acts unremittedly, and of the above-mentioned impulſe) would compel each planet to move in a curve line concave towards the common centre of attraction, which centre muſt be within the ſun, in conſequence of the great ſize of that luminary †.

With thoſe principles Newton began to calculate and ſtrictly to demonſtrate, the conſequences which muſt neceſſarily ariſe therefrom, and proved that the periods, the diſtances, the velocities, and the very ſhapes of the planets, ſuch as had been obſerved by aſtronomers, were conformable to thoſe principles.

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* The medium through which the planets move, if not quite unreſiſting, muſt very nearly approach that ſtate.

† See the 9th chapter of the firſt part of theſe Elements.

principles. The apparent inequalities of the motions of the primary planets, of the ſatellites, and eſpecially of our moon, are all depending on the ſame; and it is wonderful to remark, that every aſtronomical diſcovery or terreſtrial meaſurement, made ſince Newton's time, has been found conformable to his theory.

Thus we have drawn a conciſe, comprehenſive, but ſuperficial ſketch of the ſolar ſyſtem. It is now neceſſary to enter into a more particular examination of its parts.—The ſizes, ſhapes, and movements of each primary as well as ſecondary planet; their diſtances from the ſun and from each other; their phaſes, their mutual dependence; and the beſt practical methods of aſcertaining thoſe particulars, will be deſcribed in the following chapters.

CHAP. IV.

DEFINITIONS, AND GENERAL LAWS, RELATIVE TO THE PLANETS.

VENUS and Mercury certainly ſurround the ſun, and their orbits are included within the earth's orbit; whence they are called the *inferior planets*.

That they really ſurround the ſun is evident from their having been ſeen ſometimes before, then on one ſide, then beyond, the ſun, (which is proved by the diminution of their apparent ſize, and by their diſappearing behind the ſun) after which they are ſeen on the other ſide, &c. When they are before the ſun, they generally are above or below its diſc; but ſometimes they appear like dark ſpots over the diſc itſelf of the ſun.

That their orbits are within the orbit of the earth is alſo evident; for otherwiſe they would ſometimes be ſeen in *oppoſition* to the ſun; viz. would appear to riſe from the horizon when the ſun appears to ſet, which is never the caſe.

On the contrary, the orbits of all the other planets include that of the earth; whence they are called

called the *ſuperior planets*; and, in fact, at proper periods, they are ſeen in *oppoſition* to the ſun, viz. they are ſeen to riſe when the ſun appears to ſet; or they are ſeen upon the meridian at midnight.

That the orbits of the planets are ſo ſituated is alſo proved from the appearance of their luminous faces; for of that half of each planet, which is illuminated by the ſun, we can only ſee ſuch a portion as the above-mentioned ſituations of their orbits can poſſibly admit of. Thus, when Venus V, fig. 10, Plate XXVI. is nearly in *conjunction* with the ſun S, viz. is ſeen from the earth T, in the ſame part of the heavens, her bright face appears full and round; becauſe all her illuminated face is turned towards us. On the contrary, when Venus is nearly between the earth and the ſun, as at *v*, then its bright face is turned entirely from us, in conſequence of which ſhe diſappears, or is ſeen like a dark ſpot upon the diſc of the ſun. When Venus is not quite between us and the ſun, then ſhe appears horned like the new moon, or more or leſs illuminated, according to its ſituation.

The ſuperior planets are never ſeen horned, becauſe they can never get between the earth and the ſun, nor nearly ſo. Thus Mars M, whoſe orbit includes that of the earth T, and includes likewiſe the ſun, always preſerves a full and ſhining face, as at M or *m*; but when it ſtands at O or P, it appears a little gibbous, or ſomewhat deficient from full.—

The ſame thing may be ſaid of the other ſuperior planets.

All the planets, the earth included, move in elliptical orbits, though not much different from circles; and the ſun is ſituated at, or near to, one of the foci of each of them. That focus is called the *lower focus.* If we ſuppoſe the plane of the earth's orbit, which cuts the ſun through the centre, to be extended as far as the fixed ſtars, it will mark among them a great circle, which is the *ecliptic*, and with which the ſituations of the orbits of all the other planets are compared. A *trajectory* is the curve path in general of any celeſtial body.

The planes of the orbits of all the other planets do alſo paſs through the centre of the ſun; but if extended as far as the fixed ſtars, they form circles different from one another, as alſo from the ecliptic; one part of each orbit being on the north, and the other on the ſouth, ſide of the ecliptic. Therefore the orbit of each planet cuts the ecliptic in two oppoſite points, which are called the *nodes* of that particular planet; and the nodes of one planet cut the ecliptic in places different from the nodes of another planet. A line which paſſes from one of the two nodes of a planet to the other, or the line in which the plane of the orbit of that planet cuts the plane of the ecliptic, is called the *line of nodes*. That node, where the planet paſſes from the ſouth to the north ſide of the ecliptic is called the *aſcending node*, and the aſtronomers denote it by the character ☊. The other node is called the *deſcending node*, as is denoted by the character ☋.

The angle, which the plane of a planet's orbit makes with the plane of the ecliptic, is called the *inclination* of that planet's orbit.

A perpendicular being let fall from a planet to the ecliptic, the angle, which is formed at the ſun, by two lines, one drawn from the point where the perpendicular falls, and the other from the earth to the ſun, is denominated the *angle of commutation.* The line between the above-mentioned point where the perpendicular falls, and the ſun or the earth, is called the *curtate diſtance* from the ſun or from the earth.

A line drawn from the lower focus of a planet's orbit, (viz. where the ſun is) to either end of the conjugate axis of its orbits (which line is equal to half the tranſverſe axis) is called the *mean diſtance* of that planet. But according to ſome authors, the *mean diſtance* is a mean proportional between the two axes of that planet's orbit.

The diſtance of either focus from the centre of the elliptical orbit, is called its *excentricity.*

The *apſes*, or *apſides*, are two points in a planet's orbit, which are fartheſt and neareſt to the ſun; the former of which is called the *higher apſis*, or *aphelion*; the latter is called the *lower apſis*, or the *perihelion.* The diameter, which joins thoſe two points, is called the *line of the apſides*, and is ſuppoſed to paſs through the centre of the ſun. They are not, however, always in the ſame ſtraight line which paſſes through

through the ſun; for they are ſometimes out of a right line, making an angle greater or leſs than 180°; and the difference from 180° is called the *motion of the line of the apſides.* When the angle is leſs than 180°, the motion is ſaid to be in *antecedentia*; viz. contrary to the order of the ſigns of the ecliptic. When the angle is greater than 180°, the motion is ſaid to be in *conſequentia*, or in the order of the ſigns.

When the ſun and the moon are neareſt to the earth, they are ſaid to be in *perigee.*—When at their greateſt diſtance from the earth, they are ſaid to be in *apogee.*

The *argument of latitude* is the angle formed in the planet's orbit, at the ſun, by two lines, one of which comes from that planet, and the other from its aſcending node.

The *true anomaly*, or, as is ſometimes called, the *equated anomaly*, is the angle at the ſun, which is formed by the *radius vector*, or line drawn from the ſun to the planet, and the line drawn from the ſun to the aphelion of the planet. The *mean anomaly* is the angular diſtance of a planet from its aphelion (taken at the ſame time with the true anomaly), ſuppoſing it to move uniformly with its mean angular velocity. The difference between the true and mean anomaly, is called the *equation of the centre*, or the *proſthaphereſis.*

"If a circle be ſuppoſed drawn on the line of the apſides as a diameter, and through the place of the planet

planet a perpendicular to the line of the apſides, be drawn till it meet the circumference of the circle; then the angle formed by two lines, one drawn from the centre of the planet's orbit to the aphelion, and the other to the point where the perpendicular through the planet's place, interſects the circumference of the circle, is called the *excentric anomaly*, or the *anomaly of the centre*."

The *direct motion* of a planet, as ſeen from the earth, is when it appears to move from weſt to eaſt, viz. according to the order of the ſigns, or in *conſequentia*. Its *retrograde motion*, or motion in *antecedentia*, is when it appears to move from eaſt to weſt, viz. contrary to the order of the ſigns. But when the planet ſeems to remain a certain time in the ſame place, it is then ſaid to be *ſtationary*.

When ſeen from the earth, it is evident that the inferior planets muſt have two conjunctions with the ſun, and that they muſt be direct in their ſuperior conjunctions, retrograde in their inferior conjunctions, and ſtationary ſome time before and after. But the ſuperior planets are direct at the time of their conjunction with the ſun, retrograde at the time of their oppoſition, and ſtationary ſome time before and after their oppoſition.

" The apparent velocities of the planets, whether direct or retrograde, are accelerated from one of the ſtationary points, to the midway between that and the following ſtationary point; from thence they are retarded until the next ſtation. Their greateſt direct

direct velocity is in their conjunctions, and their greateſt retrograde velocity is in the oppoſition of the ſuperior planets, and in the lower conjunction of the inferior planets."

The inferior planets appear ſmalleſt in their direct motion, and largeſt in their retrograde motion. The ſuperior planets appear largeſt in their oppoſition to the ſun, and ſmalleſt in their conjunction. The inferior cannot appear to go farther from the ſun than the angle which the radius of their orbit ſubtends at the earth.

Even when ſeen from the ſun, the planets do not appear to move equably in their orbits. In other words the real movements of the planets, (the earth being one of them) are not equable in their orbits; for in ſome parts of their orbits they move faſter, or percur a greater ſpace, than in others, though they always move the ſame way. But thoſe which at firſt ſight may appear to be irregularities, will, upon ſtrict examination, be found regulated by certain general, conſtant, and admirable laws; the principal of which are as follows:

I. If a ſtraight light be drawn from a planet to the ſun, and this line be ſuppoſed to be carried along by the periodical motion of the planet, then the areas, which are deſcribed by this right line and the path of the planet, are proportional to the times of the planet's motion; for inſtance, the area thus deſcribed in two hours is the double of that which is deſcribed in one hour, and a third part of that which is deſcribed in ſix hours; though the arc which is deſcribed by the planet itſelf in two hours, is not the double of the arc which is deſcribed by the ſame in one hour; nor the third part of that which is deſcribed by the ſame in ſix hours.

II. The planets are at different diſtances from the ſun, and perform their periodical revolutions in different times; but it has been found that the cubes of their diſtances, or of the principal axes of their elliptical orbits, are conſtantly as the ſquares of their periodical times; viz. of the times of performing their periodical revolutions.

Thoſe two remarkable propoſitions are called Kepler's laws; becauſe Kepler was the firſt, who, by a careful examination of the diſtances and periodical times of the planets, found them out; but it was Sir I. Newton, who demonſtrated them on the principles of attraction, &c. according to his theory *.

This wonderful harmony, which has been found to regulate the motions of the planets round the ſun, as alſo to regulate the motions of the ſatellites round their reſpective primaries; and the want of

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* The above-mentioned propoſitions, together with whatever relates to the velocities, &c. of bodies revolving in curves, round a centre of attraction, as the planets do round the ſun, are demonſtrated in the theory of curvilinear motion, which the reader will find in the firſt volume of theſe Elements, p. 138, and following.

all ſorts of regularity, when the ſun and planets are ſuppoſed to turn round the earth as a centre, are quite ſufficient to confirm the Copernican ſyſtem, were we even in want of any other proofs.

I ſhall endeavour to render the principle of this grand theory; namely, the *univerſal attraction*, more intelligible to beginners, by means of the following familiar explanations and examples.

The centre of attraction of the ſolar ſyſtem, which has been ſaid to be within the body of the ſun, muſt not be conſidered as a point endued with the attractive power; but it muſt be conſidered as the point of equilibrium between all the bodies of the ſolar ſyſtem. The point of equilibrium between the ſun and any one planet, is nearer to the centre of the ſun than to the centre of the planet, by as much as the bulk or attractive power of the planet is leſs than the bulk or the attractive power of the ſun. Now, call this the firſt centre of equilibrium, then, if we conſider a ſecond planet, the centre of equilibrium between the firſt centre and this planet, will be nearer to the firſt centre than to the planet, by as much as the attractive force of the ſecond planet is leſs than the combined attractive force of the ſun and firſt planet. Thus we may take into the account a third planet, then a fourth, &c. Laſtly, the common centre of attraction of them all will be found to be within the body of the ſun, becauſe the bulk of the ſun is vaſtly bigger than that of all the planets put together.

The attractive forces are not only to be obſerved between the planets and the ſun, but they are mutual and proportional between them all; ſo that the planets attract each other; and, in fact, when they come near, they ſenſibly diſturb each other's motion. The primary planets attract their ſatellites, and the latter attract the former. The moon raiſes tides in the ocean, in conſequence of its attraction, &c.

The mutual attraction of bodies is familiarly illuſtrated by the example of a boat and ſhip upon water, and tied by a rope, whence a ſtrong evidence of the true ſyſtem is derived. "Let a man "either in a ſhip or boat pull the rope (it is the "ſame in effect at which end he pulls, for the rope "will be equally ſtretched throughout) the ſhip "and boat will be drawn towards one another; but "with this difference, that the boat will move as "much faſter than the ſhip, as the ſhip is heavier "than the boat. If the ſhip is 1000 or 10000 "times heavier than the boat, the boat will be "drawn 1000 or 10000 times faſter than the ſhip; "and meet proportionably nearer the place from "which the ſhip ſet out. Now, whilſt one man "pulls the rope, endeavouring to bring the ſhip "and boat together, let another man in the boat "endeavour to row it off ſideways, or at right-"angles, to the rope; and the former, inſtead of "being able to draw the boat to the ſhip, will "find

" find it enough for him to keep the boat from " going farther off; whilſt the latter, endeavouring " to row off the boat in a ſtraight line, will, by " means of the others pulling it towards the ſhip, " row the boat round the ſhip at the rope's length " from her. Here the power employed to draw " the ſhip and boat to one another, repreſents the " mutual attraction of the ſun and planets, by which " the planets would fall freely towards the ſun with " a quick motion, and would alſo in falling attract " the ſun towards them. And the power em-" ployed to row off the boat, repreſents the pro-" jectile force impreſſed on the planets at right-" angles, or nearly ſo, to the ſun's attraction; by " which means the planets move round the ſun, " and are kept from falling to it. On the other " hand, if it be attempted to make a heavy ſhip go " round a light boat, they will meet ſooner than the " ſhip can get round, or the ſhip will drag the boat " after it.

" Let the above principles be applied to the ſun " and earth, and they will evince, beyond a poſſi-" bility of doubt, that the ſun, not the earth, is the " centre of the ſyſtem; and that the earth moves " round the ſun as the other planets do.

" For, if the ſun moves about the earth, the " earth's attractive power muſt draw the ſun to-" wards it from the line of projection, ſo as to " bend its motion into a curve. But the ſun being " at leaſt 227000 times as heavy as the earth, by

" being

" being ſo much weightier as its quantity of matter " is greater, it muſt move 227000 times as ſlowly " toward the earth, as the earth does toward the " ſun; and conſequently the earth would fall to the " ſun in a ſhort time, if it had not a very ſtrong " projectile motion to carry it off. The earth " therefore, as well as every other planet in the " ſyſtem, muſt have a rectilineal impulſe to prevent " its falling into the ſun.

" There is no ſuch thing in nature as a heavy " body moving round a light one as its centre of " motion. A pebble faſtened to a mill-ſtone by a " ſtring, may by an eaſy impulſe be made to circulate round the mill-ſtone; but no impulſe can " make a mill-ſtone circulate round a looſe pebble, " for the mill-ſtone would go off, and carry the " pebble along with it.

" The ſun is ſo immenſely bigger and heavier " than the earth, that if he was moved out of his " place, not only the earth, but all the other planets, " if they were united into one maſs, would be carried along with the ſun, as the pebble would be " with the mill-ſtone."*

I ſhall conclude this chapter with a very plain and familiar illuſtration of the planet's elliptical orbits, taken from the ſame laſt quoted author, for the ſake of thoſe readers who are not qualified to read the demonſtrations

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* Ferguſon's Aſtronomy, Chap. III.

monſtrations of the theory of curvilinear motion, as given in the firſt volume of theſe Elements.

" If a planet at B, fig. 1. Plate XXVII. gravi-" tates, or is attracted toward the ſun S, ſo as to " fall from B to *y* in the time that the projectile " force would have carried it from B to X, it will " deſcribe the curve B Y, by the combined action " of theſe two forces, in the ſame time that the " projectile force ſingly would have carried it from " B to X, or the gravitating power ſingly have " cauſed it to deſcend from B to *y*; and theſe two " forces being duly proportioned, and perpendicular " to each other, the planet, obeying them both, " will move in the circle B Y T U *.

" But if, whilſt the projectile force would carry " the planet from B to *b*, the ſun's attraction (which " conſtitutes the planet's gravitation) ſhould bring " it down from B to 1, the gravitating power would " then be too ſtrong for the projectile force; and " would cauſe the planet to deſcribe the curve " B C. When the planet comes to C, the gravi-" tating power (which always increaſes as the " ſquare of the diſtance from the ſun S diminiſhes) " will be yet ſtronger for the projectile force; and

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* To make the projectile force balance the gravitating power ſo exactly, as that the body may move in a circle, the projectile velocity of the body muſt be ſuch as it would have acquired by gravity alone in falling half the radius of the circle.

" by

" by conſpiring in ſome degree therewith, will ac-
" celerate the planet's motion all the way from C
" to K, cauſing it to deſcribe the arcs B C, C D,
" D E, E F, &c. all in equal times.

" Having its motion thus accelerated, it thereby
" gains ſo much centrifugal force, or tendency to
" fly off at K in the line K *k*, as overcomes the
" ſun's attraction; and the centrifugal force being
" too great to allow the planet to be brought nearer
" the ſun, or even to move round him in the circle
" K *l m n*, &c. it goes off, and aſcends in the curve
" K L M N, &c. its motion decreaſing as gradually
" from K to B, as it increaſed from B to K, be-
" cauſe the ſun's attraction now acts againſt the
" planet's projectile motion, juſt as much as it
" acted with it before. When the planet has got
" round to B, its projectile force is as much dimi-
" niſhed from its mean ſtate about G or N, as it
" was augmented at K; and ſo the ſun's attraction
" being more than ſufficient to keep the planet
" from going off at B, it deſcribes the ſame orbit
" over again, by virtue of the ſame forces or
" powers.

" A double projectile force will always balance
" a quadruple power of gravity. Let the planet
" at B have twice as great an impulſe from thence
" towards X, as it had before; that is, in the ſame
" length of time that it was projected from B to *b*,
" as in the laſt example, let it now be projected
" from B to *c*; and it will require four times as
" much

" much gravity to retain it in its orbit; that is, it
" muſt fall as far as from B to 4, in the time that
" the projectile ſorce would carry it from B to *c*;
" otherwiſe it would not deſcribe the curve BD, as
" is evident by the figure. But, in as much time
" as the planet moves from B to C in the higher
" part of its orbit, it moves from I to K, or from
" K to L, in the lower part thereof; becauſe, from
" the joint action of theſe two forces, it muſt al-
" ways deſcribe equal areas in equal times through-
" out its annual courſe. Theſe areas are repre-
" ſented by the triangles BSC, CSD, DSE, ESF,
" &c. whoſe contents are equal to one another,
" quite round the figure.

" Should it appear ſtrange, that when one of the
" two forces has got the better of the other, it ſhould
" not continue to carry the planet on in its direc-
" tion; the difficulty will be removed by conſider-
" ing the effects of thoſe powers as deſcribed in the
" preceding paragraphs. Suppoſe a planet at B to
" be carried by the projectile force as far as from
" B to *b*, in the time that gravity would have
" brought it down from B to 1; by theſe two
" forces it will deſcribe the curve BC. When the
" planet comes down to K, it will be but half as
" far from the ſun S, as it was at B; and therefore,
" by gravitating four times as ſtrongly towards him,
" it would fall from K to V in the ſame length of
" time that it would have fallen from B to 1, in the
" higher part of its orbit, that is, through four times

" as much ſpace; but its projectile force is then ſo " much increaſed at K, as would carry it from K " to *k* in the ſame time; being double of what it " was at B, and is therefore too ſtrong for the gravitating power, either to draw the planet to the " ſun, or cauſe it to go round him in the circle " K*lmn*, &c. which would require its falling from " K to *w*, through a greater ſpace than gravity can " draw it, whilſt the projectile force is ſuch as would " carry it from K to *k*; and therefore the planet " aſcends in its orbit KLMN, decreaſing in its velocity for the cauſes already aſſigned."

CHAP. V.

OF THE MOTION OF THE EARTH ROUND THE SUN, AS ALSO OF THE MOTION ROUND HER OWN AXIS.

IT has been ſhewn in the preceding pages, that, on various accounts, the earth, analogous to the reſt of the planets, moves round the ſun, and not the ſun round the earth. It is now neceſſary to examine the various particulars which belong to that motion, and to ſhew that the phenomena are the ſame as if the ſun moved round the earth after the apparent manner which has been deſcribed in the ſecond chapter of this part.

The real motion of the earth is in an ellipſis, near one focus of which the ſun is ſituated*.

If

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* According to De la Lande's determination, if we reckon the tranſverſe axis of this elliptical orbit equal to 200000, then the mean diſtance of the earth from the ſun, viz. from the focus, in which the ſun is ſituated, is 100000; and the excentricity of its orbit is 1681,395.

According to the beſt eſtimates in round numbers, the mean diſtance of the earth from the ſun is 95 millions of miles;

If we ſuppoſe that the plane of the earth's orbit be extended as far as the fixed ſtars, it will there mark a circle, which is the ecliptic, and ſo immenſely great is the diſtance of the fixed ſtars from the ſolar ſyſtem, that whether the earth be in one part or another of its orbit, the ſtars will conſtantly appear to have the ſame order, relative ſituation, and magnitude.

Since the plane of the earth's orbit paſſes through

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miles; the tranſverſe axis of its elliptical orbit is twice that diſtance, viz. is equal to 190 millions of miles, and the excentricity is 1597325 miles.

Dr. Keill, calculating the true anomaly, on the ſuppoſition that the tranſverſe axis of the earth's orbit is to the excentricity as 100000 to 1691, found it equal to 29° 2′ 54″.

The greateſt equation of the centre (viz. the difference between the true and mean anomaly) according to Dr. Maſkelyne's determination for the year 1780, is 1° 55′ 30″,9. It is generally allowed that this equation and the excentricity are ſubject to a regular diminution.

The earth's aphelion at preſent is when the ſun is in 8° 40′ 12″ of ♋; and the increaſing annual motion of this aphelion according to the beſt obſervations, is about 1′ 2″. And the preceſſion of the equinoxes being about 50″,25 annually, we ſhall have 11″,75 for the actual motion of the aphelion. The time required by the ſun to paſs over 11″,75 of longitude, being added to the *ſidereal year*, will give 365^d, 6^h, 14′, 2″, for the *anomoliſtic year*, or the time occupied by the earth in revolving from aphelion to aphelion. Mr. O'Gregory's Aſtronomy, §. 316.

the

the ſun, it follows that, whilſt we inhabitants of the earth, ſee the ſun in the direction of a certain point of the ecliptic, an obſerver in the ſun would ſee the earth in the direction of the oppoſite part of the ecliptic; thus, in fig. 11. Plate XXVI. S repreſents the ſun, A B C D is the orbit in which the earth moves from the weſt to the eaſt, ſo as to perform the entire revolution in the compaſs of one year. The external circle is the ecliptic, with the 12 ſigns marked upon it. Now a ſpectator at S will perceive the earth at A, as if it coincided with the ſign ♈. When the earth is at B, the ſame ſpectator will perceive it to coincide with ♋; and ſo on. But an inhabitant of the earth, when the earth is at A, will ſee the ſun as if it were at ♎, and when the earth is at B, he will perceive the ſun as coinciding with ♑, &c. It is evident from the figure, that whether the ſun be ſuppoſed to move round the earth, or the latter round the former, the apparent annual motion of the ſun along the ecliptic muſt be exactly the ſame.

Beſides the above-mentioned annual motion, the earth has a motion round its own axis, which produces the viciſſitudes of day and night, whence it is called the *diurnal rotation*; and which is analogous to the movements of the other planets; for, of the other planets, thoſe which, from their having ſpots upon their ſurfaces, may be ſeen to move, have been found to have a ſimilar motion round their own axes,

axes, as will be more particularly ſpecified hereafter.

This diurnal motion of the earth round its own axis, (viz. round an imaginary line) is performed from the weſt towards the eaſt in 24 hours; and every point of its ſurface muſt deſcribe a whole circle in the ſame time, excepting the two points which are at the extremities of the axis, viz. the *poles*. The different parts of the earth's ſurface muſt likewiſe deſcribe larger or ſmaller circles, according as they are nearer to, or farther from, the poles; thoſe parts, which are equidiſtant from the poles, deſcribing the largeſt circle, which circle is the *equator*.

Now, as a ſpectator on the ſurface of the earth muſt turn with it in the direction from the weſt towards the eaſt, it is evident that all the bodies of the univerſe which do not adhere to the earth, muſt appear to turn in a contrary direction, viz. from the eaſt towards the weſt; and thoſe celeſtial bodies, which are directly over the equator of the earth, muſt appear to deſcribe the largeſt circles, whilſt thoſe which are directly over the poles of the earth, muſt appear to remain immoveable; hence we attribute to the ſtars, or to the heavenly ſphere, the ſame axis, poles, equator, &c. as if that ſphere turned, and the earth ſtood ſtill.

In conſequence of this rotatory motions of the earth, and becauſe the parts of it, which, being nearer to the equator, deſcribe larger circles, and of courſe have a greater centrifugal force; the equatorial parts of the earth are more removed from its centre, ſo as to give the earth the figure of an oblate ſpheroid [*]. And ſuch is the caſe with the other planets; viz. their equatorial diameter is larger than their polar diameter, whence they are alſo found to have an oblate ſpheroidical figure, which affords a moſt ſtriking corroboration of the earth's diurnal rotation [†].

I need hardly add that any given part of the earth's ſurface has day light, or night, according as it is turned towards the ſun, or from it; for that half of the earth, which is towards the ſun, is illuminated, and a line drawn from the centre of the ſun to the centre of the earth, is perpendicular to the circle of the interſection of light and ſhadow; hence, when a ſpectator on any particular part of the ſurface of the earth, arrives at that circle in its way towards the ſun, and begins to diſcover the ſun, he imagines that the ſun is riſing above his horizon, &c.

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[*] See the firſt volume of theſe Elements, p. 315.

[†] If it be aſked, whence does the earth derive its diurnal rotatory motion? The anſwer is, that probably the earth derived it from its having received that original impulſe which counteracts the ſun's attraction, not in the direction of its centre, but on one ſide of it. See the firſt volume of theſe Elements, chap. VIII.

If the axis of the earth had been ſituated in a poſition perpendicular to the plane of the earth's orbit, which is the ſame as the plane of the ecliptic, the circle of the interſection of light and darkneſs would have evidently paſſed through the poles of the earth, and of courſe the days would have been conſtantly equal to the nights. But the caſe is, that the axis of the earth is inclined to the plane of the ecliptic, and makes an angle with it of about 66° 32′. Therefore the plane of the ecliptic does not coincide with that of the equator, but muſt make an angle with it of 23°, 28′ (viz. an angle equal to the complement, or to what 66° 32′ wants, of 90°.)

This inclination of the axis, or of the ecliptic, varies a little as it ought to do, agreeably to the Newtonian theory *. In the year 1736, Dr. Maſkelyne determined the *obliquity of the ecliptic*, as it is called, to be 23°, 28′, 10″; and it appears that it diminiſhes at the rate of 50″ in a century, or half a ſecond in a year. But to prevent obſcurity,

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* About 2100 years ago, Pytheas found the obliquity of the ecliptic to be 23°, 49′, 30″. about A. D. 880. Albategnius found it equal to 23°, 35′, 40″. A. D. 1140. Almacon found it equal to 23°, 33′, 30″. A. D. 158. Tycho Brahe found it equal to 23°, 29′, 30″. A. D. 1689, Flamſteed found it equal to 23°, 28′, 56″. and A.D. 1736. Condamine found it equal to 23°; 28′, 24″.

let us neglect this trifling variation, and in the following illuſtration, let us conſider this inclination of the axis, as if it were conſtantly the ſame.

Then the axis of the earth, beſides its retaining the ſame inclination towards the plane of the ecliptic, does alſo remain always directed to the ſame ſtar; or in other words, if a line be drawn parallel to that axis whilſt the earth is in any part of its orbit, then, when the earth is in any other part of its orbit, the axis will always be parallel to that line; excepting a regular and ſmall variation.

Now the various ſeaſons of the year and various lengths of days and nights, are owing to the above-mentioned inclination of the axis to the orbit, and to that axis moving round the ecliptic in a direction parallel to a line nearly immutable. The preceſſion of the equinoxes is owing to the laſt-mentioned ſmall variation. The effects, in ſhort, are the ſame as have been explained in the chapter, where the phenomena were deſcribed on the ſuppoſition that the earth ſtood immoveable, and the celeſtial objects moved round it; yet it will be neceſſary to illuſtrate thoſe effects on the true theory, by means of a diagram or two.

Fig. 2. Plate XXVII. repreſents the earth in different parts of its elliptical orbit; the ſun S being in one of its foci. The ſpectator is ſuppoſed to be without the orbit of the earth at a conſiderable diſtance, and to look upon it obliquely.

In the firſt place it is obſervable, that whether at A, or at C, or B, or D, the axis of the earth is always directed the ſame way, viz. the directions of the axis in all thoſe ſituations of the earth, are all parallel to each other. The ſmall deviation which produces the preceſſion of the equinoxes, will be taken notice of in the ſequel.

In the ſecond place it ſhould ſeem, that, on account of the above-mentioned conſtant direction of the axis, if, when the earth is at B, its axis is directed towards a certain ſtar E; then, when the earth is at A, it ought to point towards ſome other ſtar F, the diſtance of which from E muſt be equal to the tranſverſe axis AB of the earth's orbit. The apparent diſtance of thoſe ſtars is meaſured by the angle EAF, which, on account of the paralleliſm of the lines EB, AF, is equal to the angle BEA, which is the angle under which the orbit of the earth would be ſeen from E; hence the angle AEB, or EAF, is called the *parallax of the great orbit*.

It is eaſy to conceive that the farther the points E and F are from the earth's orbit, the ſmaller muſt the angle EAF, or BEA, be. Now from the moſt accurate obſervations, it appears that this angle is leſs than one minute; and it is not known how much ſmaller it really is; hence we may perceive that the diſtance of the ſtars is aſtoniſhingly great*. The

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* If the angle AEB, or its equal the angle EAF, could be known with certainty, the diſtance of the ſtars would be

The cauſe of the inequalities of the days and nights at different times of the year, as alſo the different ſeaſons, will be eaſily conceived by inſpecting the figure; for they both ariſe from the inclination of the axis of the earth to the orbit.

Firſt, In the ſpring, when the earth is in that part of its orbit, in which a ſpectator in the ſun would ſee the earth coincide with the ſign ♎, Libra, of the ecliptic, the inhabitants of the earth ſee the ſun in the direction of ♈, Aries. At that time the circle *terminator* of light and darkneſs, paſſes through the poles *n*, *s*; therefore the earth in its diurnal rotation about its axis *n*, *s*, has every part of its ſurface as long in the light as in the ſhade; viz. the days are equal to the nights; the ſun at that time being ſucceſſively vertical to the equatorial parts of the earth.

Secondly, As the earth proceeds in its orbit from the weſt towards the eaſt, along the ſigns ♏, ♐, and ♑, the ſun is ſeen to advance along the ſigns ♉, ♊, and ♋; and gradually becomes vertical to thoſe parts of the earth which are on the north of the equator. So that when the earth is in ♑, the ſun

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be found by an eaſy trigonometrical calculation; for in the triangle AEB, one ſide AB is known, being the tranſverſe axis of the earth's orbit, the angle EBA is equal to the inclination of the axis of the earth to the orbit; therefore, knowing likewiſe the angle AEB, the other parts would be eaſily calculated.

is in ♋, and is perpendicular to thoſe parts of the earth, which are under the tropic; viz. about 23°, 28′, from the equator; therefore the inhabitants of the northern hemiſphere will enjoy ſummer, on account of the ſolar rays falling more perpendicularly, &c.; and they will have their days longer than the nights in proportion as they are more diſtant from the equator; but thoſe whoſe latitude exceeds 66°, 32° north, will have conſtant day light; for, by inſpecting the figure, it will be perceived that the earth, at that time, in its daily revolution, has all the part *y n x*, within the polar circle, in that half of its ſurface which is illuminated by the ſun.

At the ſame time the inhabitants of the ſouthern hemiſphere have winter; their days being ſhorter than their nights, in proportion as they are farther from the equator; and thoſe, whoſe latitude exceeds 66°, 32′, ſouth, have conſtant night.

The earth then continues its courſe along the ſigns ♒, ♓, and ♈, at the ſame time that the ſun is ſeen to move along the ſigns ♌, ♍, and ♎; at which time the circle terminator of light and darkneſs paſſes again along the poles *n*, *s*, of the earth; therefore the days are equal to the nights all over the earth.

After this the earth advances along the ſigns ♉, ♊, and ♋, at which time the inhabitants of the northern hemiſphere have winter, their days being ſhorter than their nights, &c.

The

The four points of the ecliptic, in which the earth is repreſented in the figure, are called its *cardinal points*; ♑ and ♋ being the ſolſtitial points, whilſt ♎ and ♈ are the equinoctial points; but it muſt be obſerved, that thoſe four ſituations of the earth, at the two equinoxes and two ſolſtices, are not equidiſtant; becauſe the ſun is not in the centre, but in one focus of the earth's elliptic orbit. This will be made more evident by means of fig. 3. Plate XXVII. where the earth's orbit is delineated, as it would appear to a ſpectator ſituated above the plane of it. S is the ſun in one of the foci of the ellipſis A C B D. A, B, C, D, are the ſituations of the earth at the two ſolſtices, and at the two equinoxes, (as in fig. 2.) P is the centre of the ellipſis; therefore the diſtance B P is equal to A P, E P is equal to P F, and the elliptical arcs AE, EB, BF, FA, are all equal to one another. But the ſun is in the focus S, which is on one ſide of the centre P; therefore in ſummer, when the earth is at B, the ſun is farther from it than in the winter when the earth is at A; B S being evidently longer than A S; and, in fact, the diameter of the ſun appears larger in winter than in ſummer; its greateſt apparent diameter, in winter, ſubtending an angle of 32′ 38″,6, and its leaſt diameter, in ſummer, ſubtending an angle of 31′ 33″,8.

Farther, the ſun becomes perpendicular to the equatorial parts of the earth; (that is, the equator interſects the ecliptic) when the earth is at C, and likewiſe

likewiſe when it comes to D (for they muſt evidently be in the ſame line with the ſun); but B E being equal to E A, and B C being longer than B E; B C muſt be much longer than C A; and for the ſame reaſon, B D is alſo longer than D A; conſequently the earth has a longer arc, C E B F D, to percur from the vernal equinox to the autumnal equinox along the ſigns ♎, ♏, ♐, ♑, ♒, and ♓, than the arc D A C along the ſigns ♈, ♉, ♊, ♋, ♌, and ♍; the ſun, during the ſame periods, appearing to move along the oppoſite ſigns. Hence the earth employs about eight days longer in going from the firſt point of Libra to the firſt of Aries, than in going from the latter to the former. Or, which amounts to the ſame thing, the ſun appears to be in the northern hemiſphere about eight days longer than in the ſouthern.

Thoſe eight days longer, which the earth employs in going from ♎ to ♈, are not entirely owing to the greater length of the arc C B D; but is partly owing to the earth's moving along that arc at a ſlower rate than along the arc D A C; the reaſon of which is, that the centre of attraction S is farther from the former arc than from the latter, alſo that the *areas* S y B, A S x, and not the *arcs* B y, A x, are proportionate to the *times* of the earth's moving along thoſe arcs B y, A x, (ſee page 85, of this volume).

Thus let the earth be at B, from which place, in a certain time, it goes to y; and the line which joins the earth and the ſun, deſcribes the area S B *y*. When the earth is at A, let it move along an arc A *x*, until the area S A *x*, which is deſcribed by the above-mentioned line, may be equal to the area B S *y*; then the earth will be found to have moved along the arc A *x* in the ſame compaſs of time that it moved along the arc B *y*. But thoſe arcs A *x*, B *y*, are unequal, A *x* being longer than B *y*; for they are nearly in the inverſe proportion of their diſtances from the ſun S. Hence the apparent motion of the ſun along the ecliptic, or the real motion of the earth in her orbit, as ſeen from the ſun, is not equable, it being ſlower in the ſummer than in the winter *.

The preceſſion of the equinoxes, which has been deſcribed above, as an irregularity, according to the apparent motion of the celeſtial bodies, is eaſily explained on the true theory of the ſolar ſyſtem.

The earth has been already deſcribed to be an oblate ſpheroid, viz. to have a greater quantity of matter accumulated about its equatorial parts, in conſequence of which thoſe equatorial parts, being attracted with greater force both by the ſun and the moon, are drawn ſooner under them than if they were not ſo prominent, by about 20′, 18″, of

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* The difference of thoſe motions is ſuch, as that the ſun ſometimes appears to be even 2° ſhorter, or more advanced, than it ought to be if it moved equably.

time, or 50″,25 of a degree in a twelvemonth*. The effect of this is, that the axis of the earth does not remain exactly parallel to itſelf, though it retains the ſame inclination to the plane of the ecliptic; ſo that if at preſent it points towards a certain ſtar, in about 72 years time it will be found directed to another point of the heavens, which is to the weſt of that ſtar, and at that rate it will proceed to move conſtantly weſtward, and of courſe it will deſcribe a circle round the pole of the ecliptic, the radius of which is equal to the inclination of the axis of the earth to the axis of the ecliptic, viz. to about 23°, 28′. That circle will be accompliſhed in about 26 thouſand years, at the end of which time the axis of the earth will again be parallel to the ſituation, *n s*, of fig. 2. Plate XXVII. In the half of that time, viz. in about 13 thouſand years, the half only of that circle will be accompliſhed, ſo that at the end of 13 thouſand years, the axis of the earth will ſtand in the ſituation of the dotted line *o p*.

As the poles, or the axis of the earth, performs the above-mentioned movement, it is evident that the ſolſtitial and equinoctial points muſt likewiſe move at the ſame rate.

This motion is ſaid to be *weſtward*, or in *antecedentia*, viz. contrary to the order of the ſigns;

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* De la Londé's Aſtronomy, B. XXII.

whereas the other motion, whereby the earth and the planets are carried round the ſun, is *eaſtward*, or in *conſequentia*, meaning in the direction of the ſigns, viz. from Aries to Taurus, then to Gemini, Cancer, &c.

In conſequence of this motion of the axis of the earth, or of the preceſſion of the equinoxes, the conſtellations which formerly coincided with the cardinal points of the ecliptic, are now removed from them. Thus the conſtellation of Aries, which at the time of Hipparchus was near the vernal equinox, viz. near the interſection of the equator with the ecliptic, is now removed from it, or rather that interſection is removed from the conſtellation of Aries, by about 30°, or nearly a whole ſign, and in the ſame manner are all the other conſtellations removed about one ſign from their former ſituations; yet the twelve portions of the ecliptic, which are called *Dodecatimoria*, ſtill retain the ſame names and characters which they had at the time of Hipparchus. Thus the interſections of the equator and the ecliptic are called the beginning of ♈, and the beginning of ♎: but the conſtellations of Aries and Libra are now removed from thoſe interſections. For the ſake of diſtinction the twelve portions of the ecliptic are called *anaſtrous ſigns*, viz. ſigns without ſtars; and the conſtellations themſelves are called *ſtarry ſigns*.

What

What has been explained in this chapter reſpecting the motion of the earth in her orbit round the ſun, is applicable, with very little variation, to the motions of the other planets in their reſpective orbits, as will be ſhewn hereafter.

CHAP. VI.

OF THE PHASES AND MOTIONS OF THE MOON.

AFTER the ſun, the moon is by far the moſt ſplendid of the celeſtial objects; and as ſuch it has at all times been diſtinguiſhed, both by the rude and by the moſt civilized nations of the earth. It revolves round the earth, and of courſe it goes with it round the ſun. Its orbit is nearly an ellipſe, one of whoſe foci is within the body of the earth. But that orbit is ſubject to conſiderable variations; with reſpect to figure, excentricity, &c. which are incomparably greater than the variations of the orbits of the earth, or of the other primary planets. This ariſes from the action of the ſun upon the moon, which ſometimes conſpires with, and at other times is contrary to, the earth's action upon the ſame. Yet thoſe apparent irregularities are all conformable to, and depending upon, the grand law of univerſal attraction or gravitation. Previous to the enumeration and illuſtrations of the lunar movements which ariſe therefrom, it will be proper to deſcribe the body itſelf of the moon as far as it is known,

known, and its *phaſes*, or various appearances under which it is ſeen from the earth.

The moon is an opaque body, like any of the planets; therefore that half of it, which is turned towards the ſun, is illuminated by it, whilſt its other half receives no light from the ſun; and of its illuminated half, we ſee ſuch a portion as its ſituation in her orbit can admit of.

Were the ſurface of the moon ſmooth and poliſhed like the ſurface of a looking glaſs, the image of the ſun, which, in certain ſituations, would be reflected to us, would only appear like a very bright point. But the ſurface of the moon is far from being ſmooth, and its inequalities reflect the ſun's light in all directions; hence we ſee all thoſe parts of that ſurface which are illuminated by the ſun, and which are at the ſame time within the direction of our ſight.

Even to the naked eye ſome of thoſe irregularities of the moon's ſurface appear like leſs bright or darkiſh ſpots, which appearance has ſuggeſted the vulgar idea of the moon's having a face with eyes, &c. But when viewed through a teleſcope, the ſurface of the moon appears covered with vaſt irregularities, with ridges, mountains, and pits of infinite variety; but we can ſpeak only of the half of its ſurface, viz. of that which is turned towards the earth; for it is remarkable that the moon always turns nearly the ſame ſide towards the earth, and of courſe its other half is quite inviſible to us.

I ſaid it turns *nearly* the ſame ſide; for ſometimes ſhe turns a little more of one ſide, and at other times a little more of the other ſide, towards us. This is called the *moon's libration*, and is owing to her equable rotation about her own axis once in a month, in conjunction with her unequal motion in her orbit round the earth. "For if the moon "moved in a circle, whoſe centre coincided with "the centre of the earth, and turned round her axis "in the preciſe time of her period round the earth, "the plane of the ſame lunar meridian would al- "ways paſs through the earth, and the ſame face of "the moon would be conſtantly and exactly turned "towards us. But ſince the real motion of the "moon is in an orbit nearly elliptical, having the "earth in one of its foci, and the motion of the "moon about her axis is equable; that motion, "as ſeen from the earth, muſt be unequal; for "every meridian of the moon by its rotation, de- "ſcribing angles proportional to the times, the "plane of no one meridian will conſtantly paſs "through the earth. Dr. Gregory, in his Elements "of Aſtronomy, divides the libration of the moon "into the following three kinds*.

1ſt, "*Her libration in longitude*, or a ſeeming motion to and fro, according to the order of the ſigns of the zodiac. This libration is nothing, twice in every periodical month; viz. when the

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* Mr. O. Gregory's Aſtronomy, §. 463, &c.

moon is in her apogee, and when in her perigee; for in both theſe caſes, the plane of her meridian, which is turned towards us, is directed alike towards the earth."

2dly, "*Her libration in latitude*, which ariſes from hence, that her axis not being perpendicular to the plane of her orbit, but inclined to it, ſometimes one of her poles, and ſometimes the other will nod, as it were, or dip a little towards the earth; and conſequently ſhe will ſometimes ſhew more of her ſpots, and ſometimes leſs of them, towards each pole. This libration, depending on the poſition of the moon, in reſpect to the nodes of her orbit, and her axis being nearly perpendicular to the plane of the ecliptic, is properly ſaid to be in *latitude*. It is completed in the time in which the moon returns again to the ſame poſition in reſpect of her nodes."

3dly, "There is alſo a third kind of libration; by which it happens, that although another part of the moon be not really turned to the earth, as in the former libration, yet another is illuminated by the ſun. For, ſince the moon's axis is nearly perpendicular to the plane of the ecliptic, when ſhe is moſt ſoutherly, in reſpect to the north pole of the ecliptic, ſome parts near to it will be illuminated by the ſun, while, on the contrary, the ſouth pole will be in darkneſs. In this caſe, therefore, if the ſun be in the ſame line with the moon's ſouthern limit, then, as ſhe proceeds from conjunction with the ſun towards

wards her aſcending node, ſhe will appear to dip her northern polar parts a little into the dark hemiſphere, and to raiſe her ſouthern polar parts as much into the light one. And the contrary to this will happen two weeks after, while the moon is deſcending from her northern limit; for then her northern polar parts will appear to emerge out of darkneſs, and the ſouthern polar parts to dip into it. And this ſeeming libration, or rather theſe effects of the former libration in latitude, depending on the light of the ſun, will be completed in the moon's ſynodical revolution."

Since the moon moves round the earth in an orbit nearly elliptical, the earth being in one of the foci, therefore this opaque globular body muſt appear larger or ſmaller in proportion as it comes nearer to, or goes farther from, the earth; and, in fact, its apparent diameter has been found ſometimes to meaſure as much as 34′, and at other times not more than 29′, 30″. When the moon is at its mean diſtance from the earth, its apparent diameter is 31′, 8″, nearly. Its mean diſtance from the earth is 240000 miles, or probably ſomewhat ſhorter than 240000 miles; hence its diameter is reckoned equal to about 2180 miles; which is to that of the earth as 1 to 3,65. Therefore the ſurface of the moon is to that of the earth as 1 to 13,3225 (viz. as the ſquares of their diameters); and the bulk of the moon is to that of the earth as 1 to 48,627 (viz. as the cubes of their diameters). But on the ſuppoſition that the moon is more denſe than the earth in the proportion of 5 to 4, the quantity of matter in the moon muſt be to the quantity of matter in the earth, as 1 to 38,9.

The ſpots which are ſeen on the ſurface of the moon, are not mere variations of color, or of light and ſhade, but they ariſe from real inequalities of ſurface, ſuch as mountains, vales, pits, ridges, hollows, &c. which is evidently proved by their ſhadows, which they caſt in due direction, according to the ſituation of the ſun, and by the elevated parts becoming illuminated by the ſun before the lower parts.

In every ſituation of the moon the elevated parts of its ſurface caſt a ſhadow on the adjoining lower parts in the direction from the ſun. But the cavities are dark on the ſide of the ſun.

When the line, which ſeparates the light from the ſhade on the diſc of the moon, is turned towards us, we ſee it through a teleſcope, not as a regular line, but notched and full of irregularities, eſpecially ſome ſmall bright dots or ridges a little diſtant from the illuminated part of the diſc, which are the tops of mountains and other elevated parts, that are illuminated by the ſun, before their lower parts * can receive its rays.

That

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* By means of micrometrical meaſurements, and proper calculations, the heights of the lunar mountains have been meaſured

That edge of the moon's diſc, which, by its being turned towards the ſun, is on the illuminated ſide of it, appears always ſmooth and well defined, even through very good teleſcopes; whereas, conſidering the roughneſs of the moon's ſurface, we might perhaps expect to ſee it jagged or uneven. But it muſt be conſidered, that all the parts adjoining to that edge of the moon, are full of irregularities, and that the elevations of ſome parts may ſtand before the hollows of other parts, ſo as to form upon the whole the appearance of a ſmooth ſurface. It is probable, however, that the atmoſphere of the moon may contribute to the production of an apparent ſmooth edge.

Some of the ſpots, however, of the moon ſeem not to be merely the ſhadows of elevated places; for they have been found to vary a little in intenſity.

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meaſured and expreſſed in miles (the method will be deſcribed hereafter). But thoſe meaſurements by different aſtronomers, who have uſed different methods, and more or leſs accurate inſtruments, do not agree with each other. From the lateſt and moſt accurate obſervations, it appears that the moon has mountains of about 25000 Engliſh feet, and upwards, in height; viz. much higher than our mountains. See Herſchel's Paper on the Mountains of the Moon. Philoſophical Tranſactions, volume for 1780; and Schroeter's Work on the Heights of Lunar Mountains.

A bright ſpeck or two, or even three, have ſometimes been obſerved on the dark part of the moon's diſc, and ſo far from the illuminated part as not to depend upon the ſun's rays. Thoſe lucid ſpots have been conjectured to be the eruptions of volcanoes, which after a certain time become extinct and diſappear. Dr. Herſchel in 1787 ſaw three of thoſe volcanoes at once in the dark part of the moon; two of which were barely viſible or almoſt extinct; the third was more vivid and exhibited an elongation like an eruption or lava of luminous matter, reſembling a ſmall piece of burning charcoal, covered by a very thin coat of white aſhes *.

If there be fire or combuſtion in the moon, it ſeems neceſſary that the moon ſhould have an atmoſphere; yet, until very lately, it has been generally believed that the moon had no atmoſphere. However, the nicer obſervations of latter times made with the moſt improved inſtruments, ſeem to prove that the moon has really an atmoſphere, which is manifeſted by the following facts.

It has been remarked by certain aſtronomers, that the moon does not always appear equally bright, which may probably be owing to its atmoſphere being more or leſs loaded with vapours. It is perhaps for the ſame reaſon that, in total lunar eclipſes, the colour of the moon is not always the ſame, and that

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* See the Philoſophical Tranſactions for 1788.

in total ſolar eclipſes, a luminous circle round the moon has ſometimes been obſerved. Caſſini aſſerts to have obſerved, that Saturn, Jupiter, and the fixed ſtars, had their circular figures changed into elliptical, when they approached either the dark or the illuminated edge of the moon; which may naturally be attributed to the refraction of a lunar atmoſphere. Schroeter obſerves, that the two *cuſps* or apexes of the luminous horns, in a new moon, appear tapering in a very ſharp and faint prolongation, which is a ſtrong indication of a lunar atmoſphere. He alſo obſerved, that when once Jupiter came very near the moon, two of its ſatellites appeared indiſtinct for a ſhort time before they went quite behind the body of the moon*.

If we allow to the moon an atmoſphere which, with reſpect to denſity, &c. bears the ſame proportion to its ſize, as our atmoſphere does to the ſize of the earth, we muſt conclude that the obſcure parts of it, when viewed from the earth, cannot ſubtend an angle as great as one ſecond in addition to the apparent ſize of the moon; and ſuch an atmoſphere ſeems to be perfectly compatible with the above-mentioned facts.

Excepting the above-mentioned ſmall variation in the intenſity of ſome of the ſpots of the moon, and the volcanic appearances, the reſt of the moon's ſurface is not ſubject to any perceivable changes;

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* See his Paper in the Philoſophical Tranſ. for 1792.

hence aſtronomers have had ample opportunity of delineating and of deſcribing the irregularities of its ſurface. In fact, ſeveral aſtronomers have publiſhed the *ſelenographia*, or maps of the face of the moon; and ſome have given maps of its appearance in all the different ſtates of the moon, from the day that the new moon becomes viſible until it vaniſhes. In order to diſtinguiſh the mountains, or other remarkable ſpots of the moon from each other, ſome aſtronomers, as Hevelius, have given them the names of known places on the ſurface of the earth; whilſt others have given them the names of diſtinguiſhed perſons, ſuch as the names of Plato, Archimedes, &c. The beſt ſelenographers are Florentius, Langrenus, Hevelius, Grimaldus, Caſſini, Ricciolus, and De la Hire. A very good drawing of the moon's viſible ſurface was lately made with great care and attention by a diſtinguiſhed artiſt, John Ruſſell, Eſq. R. A. an engraving of which will probably be ſpeedily publiſhed.

That the phaſes of the moon depend on its ſituation relatively to the earth and the ſun, has been already briefly mentioned in the preceding pages; but it will be neceſſary in this place to explain and to illuſtrate them by means of a diagram.

In fig. 4, Plate XXVII. RZ repreſents part of the earth's orbit, T is the earth. The circle ABCDEFH repreſents the moon's orbit, with the moon in different parts of it. S is the ſun. Here in the firſt place it muſt be obſerved, that in every ſituation, that half of the moon, as well as of the earth which is facing the ſun, is illuminated by it, whilſt the other half is in darkneſs. MN repreſents the circle which ſeparates the illuminated from the dark part of the moon. PO (which, conſidering the ſize of the moon with reſpect to its orbit, may be taken for a right line) repreſents the circle which divides that half of the moon, which is viſible to us, from that which is not viſible to us; and which therefore may be called the *circle* of *viſion*.

Now it is evident, that when the moon is at A, viz. in oppoſition to the ſun, its illuminated half is turned entirely towards the earth, or the circle of viſion coincides with the terminator of light and darkneſs. In that ſituation we ſay the moon is *full*, and in that caſe it ſhines all night long; for the ſun and the moon being in oppoſition, the one muſt appear to riſe when the latter appears to ſet; hence the moon is on the meridian at midnight.

When the moon comes to B, then its illuminated half is not turned entirely towards the earth; therefore we ſee the moon as is repreſented at *b*[*]; viz. the illuminated part will not be quite circular, but will appear gibbous.

When

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[*] Should the novice aſk what produces the difference between the repreſentation of the moon at B, and at *b*, he is informed that at B the moon is repreſented as it would appear

When the moon is at C, ſo that the *elongation*, viz. the angle made at the earth by two lines CT and ST, drawn from the moon and from the ſun to the earth, may be a right angle, then the half of its illuminated part is viſible from the earth, viz. the moon appears as at *c* *. In this caſe the moon appears to be *biſected*, and is ſaid to be at its *laſt quarter*, or in her *quadrate aſpect*, or *quadrature*, becauſe it then appears to be a quarter of a circle removed from the ſun, STC being a right angle.

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pear to a ſpectator ſituated in the heavens above the plane of the moon's orbit, whereas *b* is as it appears to a ſpectator on the earth at T. The ſame thing muſt be underſtood of A and *a*, C and *c*, &c. and he may eaſily render this and other phaſes familiar to himſelf, by placing a candle at ſome diſtance from himſelf, and holding a ball of any kind in the fingers of one hand, which he may place round his head in various aſpects. In this caſe the candle repreſents the ſun, the ball repreſents the moon, and the experimenter repreſents the earth.

* The angle of elongation STL, in every ſituation of the moon, is always nearly equal to the angle MLO, the arc of which MO is that part of the moon's illuminated diſc, which is viſible to us. Thus, when the moon is at F, produce SL towards X; then the angles TLP and MLS are equal, being both right angles; the vertical angles OLS, and PLX are alſo equal; therefore MLO is equal to TLX. But TLX is the external angle of the triangle STL, therefore equal to the angles LST, LTS; and becauſe the ſun is at an immenſe diſtance, and the angle LST is exceedingly ſmall, therefore STL is nearly equal to TLX, or to MLO.

When the moon is at D, then, as a ſmall part of its illuminated part is turned towards the earth, we ſee it horned as at *d*. All this time the moon has been waning or decreaſing in the extent of its illuminated part, and it continues to do ſo until it reaches the point E, which is called its *conjunction* with the ſun, they both appearing to be in the ſame point of the ecliptic. In that ſituation the dark part of the moon is entirely turned towards the earth, of courſe the moon diſappears, and in that ſtate we call it the *new moon*, becauſe preſently after that it begins to make its appearance anew, and continues to increaſe until its *full*, viz. when it comes again at its oppoſition A. When the moon is at F, a ſmall part of its illuminated face is turned towards the earth, and we ſee it as at *f*, viz. as we ſaw it when it ſtood at D; with this difference, however, that when at D, the convex ſide of the luminous part was turned towards the eaſt, but when at F, that convex ſide is turned towards the weſt; for in both caſes it is turned towards the ſun, and in the firſt caſe the moon riſes not long before the ſun; whereas in the latter caſe it ſets not long after the ſun.

When the moon is at G, viz. again in a quadrate aſpect, GTS being a right angle, it looks as it did when it ſtood at C, excepting that now the convex part is turned towards the weſt, whereas before it was turned towards the eaſt; obſerve *g*. In this ſituation, viz. when the moon is at G, we commonly

monly ſay that it is at its *firſt* quarter. The moon then continues to increaſe, ſo that at H it looks gibbous, as repreſented at *h*; then full, &c.

It muſt be remarked, that when we firſt begin to ſee the new moon, beſides the bright part as at *f*, we ſee the reſt of the moon's diſc faintly illuminated; the reaſon of which is, that in that ſituation the greateſt portion of the earth's illuminated half is turned towards the moon; ſo that the earth performs the ſame office to the moon as the moon does to us; and much more ſo; for the earth appears about 15 times bigger to a ſpectator in the moon, than the moon appears to us; therefore the earth reflects a great deal more of the ſun's light upon the moon, than the moon reflects upon the earth. By inſpecting fig. 4, it will be clearly perceived, that the earth preſents the ſame phaſes to the moon, as the latter does to us; it being full to the moon when the moon is new to us; new to the moon when the moon is full to us, &c.

The poſition of the moon's cuſps, or a right line touching the points of her horns, is always perpendicular to the ecliptic, but is differently inclined to the horizon at different times of the ſame day. Sometimes that line is perpendicular to the horizon, and then the moon is ſaid to be in her *nonageſimal degree* *.

The

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* It is then in the higheſt point of the ecliptic above the horizon, which is 90° from both ſides of the horizon, where it

The moon, the earth, and the other planets, being opaque bodies, muſt neceſſarily caſt a ſhadow on the ſide oppoſite to the ſun; and as every one of the planets is ſmaller than the ſun, that ſhadow muſt evidently be conical. Now the earth's conical ſhadow is longer than the diſtance T A of the moon; and the ſhadow of the moon, though ſhorter than that of the earth, is likewiſe longer than the ſaid diſtance; therefore, when the moon is at E, viz. between the ſun and the earth, its ſhadow muſt fall upon part of the earth's ſurface (it cannot cover a whole hemiſphere, becauſe the moon is much ſmaller than the earth); during which time the inhabitants of that part of the earth loſe ſight of the ſun, and this is called an *eclipſe of the ſun.* A ſpectator in the moon would at the ſame time ſee a round ſpot paſs over the illuminated diſc of the earth.

When the moon is at A, then the earth is between it and the ſun, in conſequence of which the ſhadow of the earth covers the whole diſc of the moon, and this is called an *eclipſe of the moon.* At

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it is then cut by the ecliptic. This never happens when the moon is on the meridian, except when ſhe is at the very beginning of Cancer, or Capricorn. The meaning of this note will be illuſtrated by the deſcription of the movements of the moon, which will be found in the ſubſequent part of the preſent chapter.

the ſame time, a ſpectator in the moon would loſe ſight of the ſun*. By inſpecting fig. 4, it will be clearly perceived that an eclipſe of the ſun can only happen at the time of the new moon, and an eclipſe of the moon can only happen at the time of full moon. Here it may be naturally aſked why does not an eclipſe of the ſun take place at every new moon, viz. at every conjunction of the ſun and moon; as alſo why does not an eclipſe of the moon take place at every full moon, viz. at every oppoſition? The anſwer to this queſtion is, that the moon, either at the conjunction or oppoſition, ſeldom paſſes acroſs the line which joins the centres of the ſun and of the earth, but generally goes either below or above that line; often however the moon paſſes, not with its centre, but with ſome other part of its body, acroſs that line, and then the eclipſes are not *total* but *partial*, viz. a part only of the ſun's diſc, or of the moon's diſc, is eclipſed; but the particulars which relate to the time, duration, and quantity of eclipſes will be examined after the explanation of the moon's movements.

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* The ſhadow of the moon upon the earth, in a ſolar eclipſe, is always circular, and the edge of the ſhadow of the earth on the moon is always a circular arch, which is another ſtrong proof of both the moon's and the earth's being globular, or nearly ſo.

The moon moves along its whole orbit round the earth from the weſt towards the eaſt, at a mean, in 27 days, 7 hours, 43′, 5″, which compaſs of time is called a *periodical month*, or revolution; but the moon, in going from one conjunction to the next, employs a longer time, viz. 29 days, 12 hours, 44′ 3″, which time is called a *ſynodical month*, or a *lunation*. For whilſt the moon in its proper orbit finiſhes its courſe, the earth, together with the moon and its orbit, are going on their way round the ſun, and are advanced almoſt a whole ſign of the ecliptic towards the eaſt; ſo that the point of the moon's orbit, which in the former poſition was placed in a right line joining the centres of the earth and the ſun, is now more weſterly than the ſun; therefore, when the moon has again arrived to that point, it will not yet be ſeen in conjunction with the ſun.

Thus, let AB, fig. 5, Plate XXVII. repreſent part of the earth's orbit, with the earth at T, and the moon at L, viz. in conjunction with the ſun S. Then, as the moon performs her courſe about the earth in her orbit LACD, and by the time it has arrived to the ſame point of her orbit, the earth will have moved from T to *t*, and the above-mentioned ſame point of her orbit will be at *l*, (*t l* being parallel to TL), which is not in the line *t* S; ſo that the moon arrives at *l*, and deſcribes its whole orbit before its conjunction with the ſun; for the accompliſhment of which conjunction, the moon muſt go

over

over the arch *l* M, and ſomething more; for whilſt the moon is moving along that arc, the earth continues to move on in her orbit. Upon the whole the moon performs a ſynodical revolution, or whole lunation, (viz. from new moon to new moon) in 29 days, 12 hours, and 44′ 3″, being 2 days, 5 hours, and 58 ſeconds, longer than her mean periodical month *.

The arc T *t*, which the earth performs whilſt the moon goes from one conjunction with the ſun to the next conjunction, is ſimilar to the arc *l* M; for TS being parallel to *t l*, the angles *t* ST, and S *t l*, are equal; then ſince thoſe angles are at the centres of the arcs *t* T and *l* M, it follows that thoſe arcs muſt be ſimilar. Every day the moon appears to recede from the ſun by about 12 degrees and ſome minutes: this is called the *diurnal motion of the moon from the ſun.*

The orbit of the moon is not in the ſame plane with the orbit of the earth, viz. in the plane of the ecliptic, but is inclined to it at an angle of

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* The above-mentioned mean periodical month is the revolution from a fixed point, with reſpect to the equinoxes, and to the ſame point again; but on account of the preceſſion of the equinoxes, the mean periodical month with reſpect to the fixed ſtars, viz. the time employed by the moon in going from a given fixed ſtar, all round the earth, and again to the ſame ſtar, is a little longer; viz. it is 27 days, 7 hours, 43′, and 12″.

about

about 5°; and thoſe two planes cut each other in a right line, which paſſes through the centre of the earth; therefore the centre of the moon cannot be ſeen to coincide with the ecliptic, excepting in the two points at the extremities of the ſaid right line, where the two circles interſect each other. Thoſe two points of interſection are called the *nodes*, (as has been ſaid of the planets) one of which is called the *aſcending node*, or the *dragon's head*, and is marked ☊; beyond this node the moon moves along that half of its orbit which is on the north ſide of the ecliptic. The other point of interſection is called the *deſcending node*, or the *dragon's tail*, and is marked ☋. Beyond this node, and until it reaches the aſcending node, the moon moves along the ſouthern ſide of the ecliptic. The right line, which paſſes through the centre of the earth, and joins the two nodes, is called *the line of nodes*. Now it is to be remarked that thoſe nodes are not conſtantly in the ſame place; or, which is the ſame thing, the moon's orbit does not conſtantly interſect the ecliptic in the ſame points; ſo that the line of nodes continually moves from the eaſt towards the weſt, contrary to the direction of the ſigns of the ecliptic; therefore, if the moon be obſerved to croſs the ecliptic at any particular place, at the next lunation it will be found to croſs the ecliptic at another place, which is a little weſtward of the former. By this continual ſhifting from the eaſt towards the weſt, the line of nodes performs the whole revolution in the compaſs of about 18 years, 228^d. 5^h.; after which time the nodes return to the ſame points of the ecliptic.

It is evident that the centre of the moon is farther from the ecliptic, according as it is farther from the nodes. The points of her orbit, which are fartheſt from the ecliptic, and which are called the *limits*, muſt evidently be equidiſtant from the nodes. The above-mentioned diſtance of the moon from the ecliptic, when ſhe is in different parts of her orbit, and which does not exceed 5° 18′ 6″, is called the moon's latitude; for the latitude of a celeſtial object is its angular diſtance from the ecliptic, and is meaſured by an arc of a circle drawn through the moon, and perpendicular to the ecliptic.

This deſcription of the moon's motion in her orbit, the inclination of that orbit to the ecliptic, and the retrogradation of the nodes, naturally ſhew why are the eclipſes both of the ſun and of the moon, ſometimes partial, and at other times total, why they do not take place at every new and full moon; and laſtly, why the eclipſes return very nearly in the ſame order after about every 19 years.

Thus, for the ſake of perſpicuity, we have deſcribed what relates to the inclination of the moon's orbit to the ecliptic in a general manner; but there are ſeveral irregularities to be noticed with reſpect to the inclination and the ſhape of that orbit, as alſo to the motion of the moon in it.

Upon the whole, the ſhape of that orbit is elliptical, or nearly ſo, as in fig. 6, Plate XXVII. with the

the earth at T in one of its foci. AP is the greater axis, and is likewiſe the line of the *apſides*, or the line of the moon's neareſt and greateſt diſtance from the earth. A is the *higheſt apſis*, and is called the *apogeon*, or *apogee*, where the moon is fartheſt from the earth. P is the *loweſt apſis*, and is called the *perigeon*, or *perigee*, where the moon is neareſt to the earth. T C is the *excentricity*.

We ſhall expreſs the principal irregularities in the following ſeven paragraphs.

1ſt. The line of the apſides has been obſerved to have an angular motion round the earth from the weſt towards the eaſt, or in the direction of the ſigns of the ecliptic, but not always conſtantly ſo; viz. the apogee of the moon's orbit, when ſhe is in the ſyzygies, goes forward, with reſpect to the fixed ſtars, at the rate of 23′ each day, and backwards in the quadratures by 16′ 20″ per day; therefore the mean annual motion is 40°; hence it performs the whole circle, and returns to the ſame ſituation, in the ſpace of almoſt nine years*.

2dly. When the earth (and of courſe the moon alſo) is in the aphelion, the moon's motion is ſomewhat quicker than when the earth, &c. is in perihelion; hence the periodical months of the moon are ſomewhat ſhorter in the former caſe than in the latter.

3dly. When the moon is in the ſyzygies, then,

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* De la Lande ſtates the tropical revolution of the apogee at 8^{y}. 311^{d}. 8^{h}. 34′. 57″. the ſidereal revolution at 8^{y}. 312^{d}. 11^{h}. 11′. 39″. and the diurnal motion at 6′. 41″,0698.

cæteris paribus, ſhe moves round the earth quicker than when ſhe is in the quadratures. For its gravity towards the earth is, by the action of the ſun, increaſed in the latter caſe, and diminiſhed in the former; ſo that from the conjunction to her firſt quadrature, the gravity of the moon towards the earth is continually increaſed, and ſhe ſlackens a little its motion; from that quadrature to the oppoſition, her gravity towards the earth is gradually diminiſhed, and ſhe keeps increaſing her motion; from the oppoſition to the other quadrature, her gravity increaſes again, and her motion is again gradually diminiſhed; and laſtly, from that quadrature to the conjunction, that gravity is gradually diminiſhed, and that motion is again gradually increaſed*. The moon is more diſtant from the earth at the quadratures than at the oppoſition to, or at the conjunction with, the ſun.

4thly. Beſides the above-mentioned cauſe, the unequable motion of the moon in her orbit ariſes alſo from the elliptical figure of that orbit, which has the earth in one of its foci; for as the moon muſt deſcribe equal areas in equal times round the earth (in the ſame manner as the planets have been ſaid to deſcribe round the ſun), it evidently follows, that *cæteris paribus*, the moon muſt move quicker in her perigeon than in her apogeon.

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* The famous Tycho Brahe, who firſt diſcovered this inequality in the moon's motion, called it the *moon's variation*.

5thly. The orbit itſelf of the moon undergoes various changes during every revolution; ſo that its excentricity is continually increaſing and decreaſing. It is greateſt when the line of the apſides coincides with the ſyzygia, and leaſt when the line of the apſides coincides with the quadratures. The difference is ſo great as to exceed the half of the leaſt excentricity.

6thly. The nodes of the moon's orbit move very irregularly; ſo that the line of nodes ſucceſſively acquires all ſorts of ſituation with reſpect to the ſun; and in the courſe of every year it paſſes twice through the ſyzygies, and twice through the quadratures. During one whole revolution of the moon, the nodes go back from eaſt to weſt with conſiderable quickneſs when they are in the quadratures; but having paſſed thoſe points, they gradually ſlacken their motion, and are quite at reſt when they come to be in the ſame direction with the ſyzygies.

7thly. The inclination of the plane of the moon's orbit to the ecliptic (which has been ſaid to make in general an angle of 5°) varies by ſeveral minutes, and is greateſt when the moon is in the quadratures, and leaſt when ſhe is in her oppoſition or conjunction. The above-mentioned inclination alſo increaſes, and is at its maximum, when the nodes are in the ſyzygies; but the inclination diminiſhes as the line of nodes has paſſed the ſyzygies, and is at its minimum when that line coincides

cides with the quadratures. Upon the whole, it ſeems that the inclination of that orbit to the ecliptic is at the leaſt about 5°, and at the moſt about 5° 18′ 6″.

All the irregularities of the moon's motions are rather leſs in her oppoſition than in her conjunction.

Thoſe which we have called irregularities of the moon's motion, are ſo far from being real errors or defects, that they are the juſt and natural conſequence of that grand law of nature, the univerſal and mutual gravitation of matter; and the works of nature would be truly defective if the abovementioned apparent irregularities were not found to exiſt, as has been abundantly demonſtrated by the great Newton. What renders the calculation of the moon's influence, motions, and ſituations, at different times, extremely intricate and perplexing, is the difficulty of determining the quantities of thoſe forces which act upon the moon, and upon which the theoretical calculations are eſtabliſhed. The quantities of thoſe forces muſt be deduced from their effects, viz. from obſervations; and thoſe obſervations require exact inſtruments, and diligent obſervers. In fact, it is owing to the induſtry of late and preſent aſtronomers, as alſo to the mechanical and mathematical improvements of the ſhort period which has elapſed ſince Newton's time, that the tables of the lunar motions have been brought

to

to a wonderful degree of accuracy, and that they are daily receiving farther corrections.

The only equal motion of the moon, is its revolution round its axis, which, either in part or in all, is performed exactly in the ſame time, in which ſhe performs her revolution in her orbit round the earth; hence ſhe always preſents the ſame half of its ſurface to us, whilſt its other half is never ſeen by us; yet on account of the moon's orbit being elliptical and not circular, as alſo on account of the inclination of that orbit to the ecliptic, we can at times ſee part of that half of the moon, which, in general, is not viſible to us; and this is the *libration* of the moon, as has been mentioned in the preceding pages.

It follows from the above-mentioned rotation of the moon round her axis, that in the compaſs of one year we inhabitants of the earth have nearly 365 $\frac{1}{4}$ days, whereas the inhabitants of the moon, if there be any, have only about 12 $\frac{7}{18}$ days; every one of their days being equal to about 29 $\frac{1}{2}$ of our days.

From obſervations carefully made on the ſpots of the moon, and from proper calculation, it has been determined that the axis of the moon is inclined to the ecliptic at an angle of 88° 17′ very nearly [*].

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[*] Caſſini found that the nodes of the moon's equator agree with the mean place of the nodes of its orbit; therefore, they have the ſame mean motion.

The above-mentioned apparent irregularities of the moon's motion produce ſeveral remarkable phenomena, with reſpect to the moon's riſing to its ſetting, and to its continuance above the horizon of thoſe places which are not under the equator. Two of thoſe phenomena have obtained peculiar appellations, viz. the *harveſt moon*, and the *hunter's moon*.

It has been mentioned in the preceding pages, that the moon appears to recede from the ſun at the daily rate of about 12° and ſome minutes; but it does not follow that the moon muſt riſe every day later by a proportionate length of time, viz. by about 50 minutes of time; for, on account of the different angles made by the horizon and different parts of the moon's orbit, this retardation differs conſiderably in places of high latitude, and it is only equable or nearly ſo, with reſpect to places ſituated under the equator. The cauſe of thoſe phenomena is clearly and familiarly explained by Mr. Ferguſon, in the 16th chapter of his aſtronomy, from which I ſhall make the following abridgement.

The plane of the equinoctial is perpendicular to the earth's axis; and therefore, as the earth turns round its axis, all parts of the equinoctial make equal angles with the horizon, both at riſing and at ſetting; ſo that equal portions of it always riſe or ſet in equal times. Conſequently, if the moon's motion were equable and in the equinoctial, at the rate of 12° 11′ from the ſun every day, as it is in her orbit, ſhe would riſe and ſet 50 minutes later every day than on the preceding

preceding day; for 12° 11′ of the equinoctial riſe or ſet in 50′ of time in all latitudes.

But the moon's motion is ſo nearly in the ecliptic, that we may conſider her at preſent as moving in it. Now the different parts of the ecliptic, on account of its obliquity to the earth's axis, make very different angles with the horizon; and in equal times, whenever this angle is leaſt, a greater portion of the ecliptic riſes than when the angle is larger, as may be eaſily perceived by looking at a common celeſtial globe. Thus in fig. 7 and 8, Plate XXVII. L repreſents the latitude of London, AB is the horizon, FP the axis of the world, E *e* the equator, K *k* the ecliptic. Now, on account of the oblique poſition of the ſphere in the latitude of London, the ecliptic has a high elevation above the horizon, making the angle AUK of about 73° ½, as repreſented in fig. 7, when the ſign of Cancer is upon the meridian, at which time Libra riſes in the eaſt. But when the other part of the ecliptic is above the horizon, viz. when the ſign of Capricorn is upon the meridian, and Aries riſes in the eaſt, then the ecliptic will make with the horizon the much ſmaller angle *k* U A, as repreſented in fig. 8, which angle is only about 26° ½, that is 47 degrees ſmaller than the former angle. And by inſpecting thoſe figures, it may be eaſily conceived that, as the celeſtial ſphere appears to turn round the axis FP in a given portion of time, as for inſtance, three or four hours, a greater portion of the ecliptic will riſe during that time, when the ecliptic

ecliptic is in the ſituation of fig. 8, than when it is in the ſituation of fig. 7.

In northern latitudes, the ſmalleſt angle made by the ecliptic and horizon is when Aries riſes, at which time Libra ſets; the greateſt when Libra riſes, at which time Aries ſets. From the riſing of Aries to the riſing of Libra (which is 12 ſidereal hours) the angle increaſes; and from the riſing of Libra to the riſing of Aries , decreaſes in the ſame proportion; hence it appears that the ecliptic riſes faſteſt about Aries, and ſloweſt about Libra.

On the parallel of London, as much of the ecliptic riſes about Piſces and Aries in two hours, as the moon goes through in ſix days; therefore, whilſt the moon is in theſe ſigns, ſhe differs but two hours in riſing for ſix days together; that is about 20′ later every day or night than on the preceding, at a mean rate. But in 14 days afterwards, the moon comes to Virgo and Libra, which are the oppoſite ſigns to Piſces and Aries; and then ſhe differs almoſt four times as much in riſing; namely, one hour and about 15′ later every day or night than the preceding, whilſt ſhe is in theſe ſigns. As the ſigns, Taurus, Gemini, Cancer, Leo, Virgo, and Libra, riſe ſucceſſively, the angle of the ecliptic with the horizon increaſes gradually; and decreaſes in the ſame proportion as they ſet; and for that reaſon, the moon differs gradually more in the time of her riſing every day whilſt ſhe is in theſe ſigns, and leſs in her ſetting: after which, through the other ſix ſigns, viz. Scor-

pio,

pio, Sagittary, Capricorn, Aquarius, Piſces, and Aries, the riſing difference becomes leſs every day, until it be at the leaſt of all, namely, in Piſces and Aries.

The moon goes round the ecliptic in about 27 days and 8 hours; but not from change to change in leſs than about 29 days and 12 hours: ſo that ſhe is in Piſces and Aries at leaſt once in every lunation, and in ſome lunations twice.

If the earth had no annual motion, the ſun would never appear to ſhift his place in the ecliptic; and then every new moon would fall in the ſame ſign and degree of the ecliptic, and every full moon in the oppoſite; for the moon would go preciſely round the ecliptic from change to change. So that if the moon was once full in Piſces or Aries, ſhe would always be full when ſhe came round to the ſame ſign and degree again. And as the full moon riſes at ſun-ſet (becauſe when any point of the ecliptic ſets, the oppoſite point riſes) ſhe would conſtantly riſe within two hours of ſun-ſet, on the parallel of London, during the week in which ſhe were full. But in the time that the moon goes round the ecliptic from any conjunction or oppoſition, the earth goes almoſt a ſign forward; and therefore the ſun will ſeem to go as far forward in that time, namely, $27^\circ\frac{1}{2}$; ſo that the moon muſt go $27^\circ\frac{1}{2}$ more than round, and as much farther as the ſun advances in that interval, which is $2^\circ\frac{1}{15}$, before ſhe can be in conjunction with, or oppoſite

to,

to, the ſun again. Hence it is evident, that there can be but one conjunction or oppoſition of the ſun and moon in a year in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute hands of a watch, which are never in conjunction or oppoſition in that part of the dial-plate where they were ſo laſt before.

As the moon can never be full but when ſhe is oppoſite to the ſun, and the ſun is never in Virgo and Libra, but in our autumnal months, it is plain that the moon is never full in the oppoſite ſigns, Piſces and Aries, but in theſe two months. And therefore we can have only two full moons in the year, which riſe ſo near the time of ſun-ſet for a week together, as has been mentioned above. The former of theſe is called the *harveſt moon*, and the latter the *hunter's moon*.

When the moon is in Piſces and Aries, it muſt riſe with nearly the ſame difference of time in every revolution through her orbit, which is exactly the phenomenon of the harveſt moon; but it paſſes unobſerved, becauſe in winter thoſe ſigns riſe at noon, and, being then only a quarter of a circle diſtant from the ſun, the moon in them is in her firſt quarter, and riſes at about noon, at which time her riſing is not noticed. In ſpring thoſe ſigns riſe with the ſun, for the ſun is in them, conſequently the moon being in them too, is in conjunction with the ſun, and therefore its riſing is inviſible. In ſummer thoſe ſigns riſe at about midnight, and the ſun is three ſigns, or about 90° before them; therefore the moon in them muſt be in her third quarter, when it gives little light, and riſes late, on which accounts the phenomenon of her riſing for ſome nights with little difference of time, paſſes unnoticed. In autumn, however, the caſe is different; for the ſigns of Piſces and Aries then riſe at about ſun-ſet, and therefore the moon being in them, is in oppoſition to the ſun, conſequently full, and riſes in great ſplendour when the ſun ſets, and ſeems to prolong the day for the advantage of the huſbandman at about the harveſt time.

In northern latitudes, the autumnal full moons are in Piſces and Aries; and the vernal full moons in Virgo and Libra. In ſouthern latitudes, juſt the reverſe, becauſe the ſeaſons are contrary. But Virgo and Libra riſe at as ſmall angles with the horizon in ſouthern latitudes, as Piſces and Aries do in the northern; and therefore the harveſt moons are juſt as regular on one ſide of the equator as on the other.

As theſe ſigns, which riſe with the leaſt angle, ſet with the greateſt, the vernal full moons differ as much in their times of riſing every night, as the autumnal full moons differ in their times of ſetting; and ſet with as little difference as the autumnal full moons riſe; the one being in all caſes the reverſe of the other.

Hitherto, with reſpect to theſe phenomena, we have ſuppoſed that the moon's orbit coincided with the

the plane of the ecliptic; but ſince her orbit makes with it an angle varying from 5° to 5° 18′, and croſſes it only in the nodes, therefore her riſing when in Piſces and Aries, will ſometimes not differ above one hour and 40′ through the whole of the ſeven days; and at other times, when in the ſame two ſigns, the time of her riſing, in the courſe of a week will differ full 3 ½ hours, according to the different poſitions of the nodes with reſpect to thoſe ſigns; which poſitions are conſtantly changing, the nodes going backward through the whole ecliptic in about 18 years and 228 days. This revolution of the nodes will cauſe the harveſt moons to go through a whole courſe of the moſt and leaſt beneficial ſtates, with reſpect to the harveſt in about 19 years. The following Table ſhews in what years the harveſt moons are moſt or leaſt beneficial, from the year 1800 to 1861: the columns of years under the letter L, are thoſe in which the harveſt moons are leaſt beneficial; thoſe marked M, ſhew when they are the moſt beneficial; the former falling neareſt the deſcending node, the latter neareſt the aſcending node[*].

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[*] Mr. O'Gregory's Aſtronomy, chap. XVI.

Harveſt Moons						
M	L	M	L	M	L	M
1800	1807	1816	1826	1835	1844	1853
1801	1808	1817	1827	1836	1845	1854
1802	1809	1818	1828	1837	1846	1855
1803	1810	1819	1829	1838	1847	1856
1804	1811	1820	1830	1839	1848	1857
1805	1812	1821	1831	1840	1849	1858
1806	1813	1822	1832	1841	1850	1859
	1814	1823	1833	1842	1851	1860
	1815	1824	1834	1843	1852	1861
		1825				

" At the polar circles, when the ſun touches the ſummer tropic, he continues 24 hours above the horizon; and 24 hours below it, when he touches the winter tropic. For the ſame reaſon the full moon neither riſes in ſummer, nor ſets in winter, conſidering her as moving in the ecliptic. For the winter full moon being as high in the ecliptic as the ſummer ſun, muſt therefore continue as long above the horizon; and the ſummer full moon being as low in the ecliptic as the winter ſun, can no more riſe than he does. But theſe are only the two full moons which happen about the tropics; for all the others riſe and ſet. In ſummer the full moons are low, and their ſtay is ſhort above the horizon, when the nights are ſhort, and we have leaſt occaſion for moon-light: in winter they go high, and ſtay long above

above the horizon, when the nights are long, and we want the greateſt quantity of moon-light*."

I ſhall conclude this chapter with a ſhort account of the ſingular appearance of what is called the *horizontal moon, and horizontal ſun.*

In the firſt place it muſt be remarked, that both the ſun and the moon, when they are near the horizon, appear not quite round, but a little oval, the longeſt axis being parallel to the horizon. This ariſes from the different refractive power of the atmoſphere at different elevations, in conſequence of which the lowermoſt limb of the ſun, (and the ſame muſt be underſtood of the moon) appears more elevated than the upper limb; hence the vertical diameter is ſhortened a little, whilſt the horizontal diameter remains unaltered.

But the moſt ſingular phenomenon is, that both the ſun and the moon, when near the horizon, appear to the naked eye much larger than when they are higher up or upon the meridian, which enlarged appearance muſt undoubtedly be an optical deception; for if the diameter both of the ſun and the moon be meaſured by means of proper inſtruments, ſuch as a quadrant, a micrometer, &c. they will be found to be ſmaller in the former than in the latter ſituation, which is as it ought to be; becauſe when they are upon the horizon, thoſe celeſtial objects are evidently farther from us by the ſemi-diameter

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* Ferguſon's Aſtronomy, § 293.

of the earth, than when they are upon the meridian.

The explanation of this phenomenon has exerciſed the genius of diverſe able philoſophers, who have attempted it, and have offered their various hypotheſes to the public; yet the phenomenon is far from being thoroughly underſtood. One of the beſt of thoſe hypotheſes is, that as the moon appears leſs bright and leſs diſtinct near the horizon, than higher up, on account of its rays paſſing through a greater quantity of atmoſpherical air, vapours, &c. in the former caſe than in the latter; we imagine it to be at a much greater diſtance than when ſhe is higher up; for near objects appear, *cæteris paribus*, more bright and diſtinct than thoſe which are farther off. Then as the viſual angle of the moon is nearly the ſame at all elevations, and as our imagination makes us conceive it to be a great deal farther off when near the horizon; therefore, in that caſe we alſo conceive it to be a much larger object; for of two unequal objects that ſubtend the ſame angle at the eye, the largeſt muſt neceſſarily be the moſt diſtant. But upon this principle it ſhould ſeem that, whenever the moon, or the ſun, at a high elevation, happens to be rendered indiſtinct by the interpoſition of vapours, &c. it ought to appear as large as it does near the horizon, which does not ſeem to be the fact.

Another hypotheſis is, that the lower part of the apparent celeſtial hemiſphere ſeems to us larger than the higher part of it; for inſtance, if we gueſs at the altitude of a celeſtial object we always conceive it to make a greater angle with the horizon, or to be more elevated than it really is; therefore any portion of that lower part of the hemiſphere, or of any body in it, appears larger than when the ſame is higher up. But then one may naturally aſk, what makes us conceive the lower parts of the apparent celeſtial hemiſphere to be larger than thoſe which are higher up * ?

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* On this ſubject the reader may conſult Dr. Wallis's Works, Des Cartes's Works, Dr. Deſagulier's Philoſophy, Rowning's Philoſophy, Dr. Smith's Optics, Dr. Prieſtley's Hiſtory of Light, &c. Ferguſon's Aſtronomy, and almoſt all the modern Writers on Aſtronomy.

CHAP. VII.

OF THE TIDES, OR OF THE EBBING AND FLOWING OF THE SEA.

THE ſingular phenomena of the *ebbing* and *flowing* of the ſea, viz. of its alternately riſing and falling on the ſhores of moſt countries; and the connection which ſeemed to exiſt between thoſe phenomena and the movements of the moon, has been remarked and is mentioned by the writers of great antiquity *. But it was Kepler who firſt ſhewed that the *attraction* of the moon was the real cauſe of it. Newton, in a maſterly manner, enlarged and demonſtrated the various parts of the ſame theory, which has alſo received farther corrections and improvements from the obſervations and calculations of ſubſequent philoſophers.

Every day, a ſhort time after the moon's paſſage over the meridian, the waters of the ocean are ſeen to riſe on the ſhores of the adjacent lands; and this is called the *tide of flood*. From that time they

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* Such are Homer, Ariſtotle, Herodotus, Diodorus Siculus, Plutarch, &c.

gradually

gradually ſubſide, until about ſix hours after they are at the loweſt, which is called the *tide of ebb*. They then gradually riſe again, and make another tide of flood, or are at their higheſt a ſhort time after the moon has paſſed the inferior part of the meridian. After that, the waters ebb again, and ſo forth. The earth by its daily rotation round its axis goes from the moon to the moon again (or the moon appears to move round the earth from a given meridian to the ſame again) in about 24 hours and 50′; hence in that period there are two tides of flood and two of ebb.

The tides are more conſiderable about a day and a half after the new, or the full, moon. They are, *cæteris paribus*, alſo greater when the moon is in her perigee than in her apagee; and likewiſe higher about the equinoxes; ſo that the higheſt tides are obſerved when the above-mentioned three circumſtances take place at the ſame time, viz. when the moon is either new or full, at the ſame time that it is in her perigee, and about the time of the equinoxes.

Thoſe, and other leſs conſiderable, phenomena relative to the tides, are eaſily ſhown to depend on the attractions and poſitions both of the ſun and the moon, but principally of the moon; for though the ſun is immenſely larger than the moon, yet as he is vaſtly more diſtant, and the attraction decreaſes inverſely as the ſquares of the diſtances, it follows that the effect of the moon's attraction on the waters of the

the ſea, is much more conſiderable than that of the ſun's attraction. At a mean, that of the former is reckoned to be to that of the latter, as 5 to 2 *.

It is evident, that if three or more bodies, be at different diſtances from the moon, the neareſt of them will be attracted more forcibly than that which is a little farther off; this more forcibly than the next, and ſo on. After the ſame manner it muſt be conſidered that the attraction of the moon towards the different parts of the earth is not exactly the ſame; becauſe thoſe various parts are not equally diſtant from it. Thus, in fig. 9, Plate XXVII. where M is the moon, and A B C the earth, the parts of the earth at A are attracted with greater force than thoſe at B, and the latter more than thoſe which are at C. This difference of attraction is not greater than the force wherewith the ſolid parts of the earth adhere to each other, therefore it does not produce any derangement of figure among them; but it produces a very ſenſible effect upon the fluid parts of this globe; that is, upon the waters of the oceans. Thus the waters at A immediately under the moon, being attracted more than the centre B of the earth is, are cauſed to recede from

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* As by Mr. Daniel Bernoulli. See the paragraphs *ſur le flux & reflux de la Mer*, in De la Lande's Aſtronomy.

it more than the waters at D and E, which, as alſo the centre B, are equidiſtant from the moon; therefore the diſtance BA muſt become greater than the diſtance BD, or its equal BE. Alſo the parts at D, B, and E, being attracted with greater force than the more diſtant waters at C; it follows, that the diſtance BC muſt likewiſe become greater than BD or BE; hence it appears that the waters which ſurround the earth, muſt form, (as far as the ſituations of continents, iſlands, &c. will permit) an oblong, or oval, or ſpheroidical figure, whoſe greater axis is *ac* in the direction of the moon M, and whoſe ſhorter axis is *de*.

The orbit of the moon being elliptical, having the earth in one of its foci, it follows, that the moon's diſtance from the earth varies conſiderably, and of courſe its attraction muſt vary accordingly; hence the tides are more conſiderable when the moon is in her perigee, and leſs ſo in her apogee.

The attraction of the ſun produces a ſimilar elongation of the fluid which ſurrounds this globe; but, as has been mentioned above, not near ſo conſiderable as that which is produced by the moon. The effect is likewiſe greater when the ſun is nearer to the earth, as in the winter time, than when he is farther from it, as in the ſummer time.

It will be readily underſtood, that, according to the different ſituations of the ſun, and the moon, the tides which are raiſed by their reſpective attractions, will either conſpire with, or counteract, each other, in in a greater or leſſer degree. Thus in fig. 1, Plate XXVIII. T is the earth, M the moon, and S the ſun. Then A C B D is the ſpheroidical figure of the fluid part of our globe, which is formed by the action of the moon, whereof A B is the greater axis, and C D the leſſer; viz. the waters at A and B, or under and oppoſite to the moon, are higher than their uſual level; but at C and D they are lower than their uſual level. E F H G repreſents the oblong figure, which is produced by the action of the ſun; viz. the waters are higher than their uſual level under the ſun at E, and oppoſite to it at F; but they are lower than their uſual level at H and G. Now by inſpecting the figure it will be eaſily comprehended, that if the longer axes of both thoſe ſpheroids coincide, as is the caſe at the time of a full and of a new moon; viz. when the moon is in conjunction with, or oppoſition to, the ſun; then the effect is greater than in any other ſituation of thoſe luminaries. The very high tides, which are raiſed in thoſe caſes, are called *ſpring tides*. On the other hand, when the leſſer axis of one of thoſe ſpheroids coincides with the greater axis of the other ſpheroid, as is the caſe at the quadratures, viz. when the moon is 90° diſtant from the ſun; then the two powers counteract each other more or leſs, according as either of them is more or leſs powerful. The tides in thoſe caſes, being not ſo high as in ordinary, are called *neap tides*. Thus, where the leſſer axis C D of the moon's ſpheroid A C B D coincides with the greater

greater axis E F of the ſun's ſpheroid E H F G, there the two oppoſite powers nearly balance each other, and of courſe the riſe or fall of the water is nearly inſenſible. But where the greater axis A B of the moon's ſpheroid A C B D coincides with the leſſer axis HG of the ſun's ſpheroid E H F G, there the elevation of the waters at A and B (viz. about the extremities of that greater axis) will be very little leſs than if it were not ſo counteracted.

The ſituations of the ſun and principally of the moon, with reſpect to their declination or diſtance from the equator, produces another remarkable phenomenon relative to the tides; which is, that the two ſucceſſive tides of the ſame day are more or leſs unequal, according as the moon declines more or leſs from the equator; ſo that they are equal only when the moon has no declination, viz. when it is in the equator. Thus in fig. 2, Plate XXVIII. where the moon M is over the equator Q R, any given part of the earth will have the two ſucceſſive tides equal; for when, by the diurnal rotation of the earth round its axis NS, the part R comes to Q, the elevation of the water will be as great as in its former ſituation at R; and the ſame is the caſe with any other given part at *r*, for either when this part ſtands at *r*, or when about 12 hours after it comes to *q*, the floods, or the elevations, *r d*, *q d*, of the waters are exactly equal. But when the moon is diſtant from the equator, as is repreſented in fig. 3, Plate XXVIII. then the ſame part of the earth will have the two ſucceſſive tides of the ſame day unequal; for when the given part *r* is at *r*, the elevation *d r* of the water is not equal to the elevation *q d*, which is the high water or tide of the ſame part, when, about 12 hours after, this part is, by the diurnal rotation of the earth, come to *q*.

" In ſhort, when the moon declines from the equator towards either pole, the tides are alternately higher and lower at places having north or ſouth latitude. For one of the higheſt elevations, which is that under the moon, follows her towards the pole to which ſhe is neareſt, and the other declines towards the oppoſite pole; each elevation deſcribing parallels as far diſtant from the equator, on oppoſite ſides, as the moon declines from it to either ſide; and, conſequently, the parallels deſcribed by theſe elevations of the water are twice as many degrees from one another, as the moon is from the equator; increaſing their diſtance as the moon increaſes her declination, till it be at the greateſt, when the ſaid parallels are, at a mean ſtate, 47° from one another; and on that day, the tides are moſt unequal in their heights. As ſhe returns towards the equator, the parallels deſcribed by the oppoſite elevations, approach towards each other, until the moon comes to the equator, and then they coincide. As the moon declines toward the oppoſite pole, at equal diſtances, each elevation deſcribes the ſame parallel in the other part of the lunar day, which its oppoſite elevation deſcribed before. Whilſt the moon

moon has north declination, the greateſt tides in the northern hemiſphere, are when ſhe is above the horizon; and the reverſe whilſt her declination is ſouth*."

The ſame thing muſt be underſtood with reſpect to the effect which is produced by the ſun's attraction; allowing for the difference of powers.

When both the ſun and the moon are in the equator, and the moon is in her perigee, that is, neareſt to the earth, eſpecially when new or full; then the tides are the higheſt; becauſe the attraction of the moon is greateſt, becauſe it coincides with that of the ſun, and becauſe they act upon the equatoreal parts of our globe, which have the greateſt centrifugal force. And the effect would be increaſed ſtill more, if at the ſame time the ſun could be neareſt to the earth. But, as the ſun is nearer to the earth in winter than in ſummer, therefore it is nearer to it in February and October, than about the time of the equinoxes in March and September; hence the greateſt tides take place ſometimes after the autumnal equinox, and return a little before the vernal equinox.

With reſpect to the time of the return of the tides it is neceſſary to obſerve, that the tides do not return always at equal intervals of time. In order to comprehend the reaſon of this inequality, we muſt conſider the changeable ſituation of the earth's

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* Ferguſon's Aſtronomy, §. 304.

axis with reſpect to the moon; for that axis, in every lunation, inclines once towards the moon, once from the moon, and twice ſidewiſe to her; moving gradually from one of thoſe ſituations to the other, exactly as it does with reſpect to the ſun in the courſe of one year; the moon going round the ecliptic in one lunar month, as the ſun goes round the ecliptic in one year.

Farther, as the greateſt axis of the fluid ſpheroid, formed by the attraction of the moon, is always directed towards the moon, if we imagine that a plane be drawn along that greater axis, and perpendicular to the moon's orbit, it is evident that this plane marks the two oppoſite or ſucceſſive tides of flood, ſo that when any given place on the ſurface of the earth croſſes this plane, which it does twice a day, it muſt then have high water. Now it is eaſy to conceive, that when the axis of the earth is inclined towards or from the moon, it muſt then lay in the above-mentioned plane, which plane in either of thoſe caſes muſt evidently cut each parallel of latitude into two equal parts; conſequently, ſince the earth turns equably round its axis, a given point on the ſurface of it muſt be as long in going from one interſection with that plane to the other interſection on one ſide of it, as from the latter to the former on the other ſide of it. Or, in other words, the tides return to the ſame place at equal intervals of time. But when the axis of the earth inclines ſidewiſe to the moon, then the parallels

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of latitude are cut unequally by the above-mentioned plane; conſequently, in that caſe, the tides return to the ſame place at unequal intervals of time; for that place, having a certain latitude, will be a longer time in going from one interſection with the plane to the other interſection, than from the latter to the former.

From the foregoing theory, it follows that "when the earth's axis inclines to the moon, the northern tides, if not retarded in their paſſage through ſhoals and channels, nor affected by the winds, ought to be greateſt when the moon is above the horizon, leaſt when ſhe is below it; and quite the reverſe when the earth's axis declines from her; but in thoſe caſes they return at equal intervals of time. When the earth's axis inclines ſidewiſe to the moon, both tides are equally high; but they happen at unequal intervals of time. In ſummer, the earth's axis inclines towards the moon when new; and therefore the day-tides in the north ought to be higheſt, and night-tides loweſt about the change: at the full, the reverſe. At the quarter, they ought to be equally high, but unequal in their returns; becauſe the earth's axis then inclines ſidewiſe to the moon. In winter the phenomena are the ſame at full moon, as in ſummer at new. In autumn the earth's axis inclines ſidewiſe to the moon, when new and full; therefore the tides ought to be equally high and unequal in their returns at theſe times. At the firſt quarter the tides of flood ſhould be leaſt when the moon is above the horizon, greateſt when ſhe is below it; and the reverſe at her third quarter. In ſpring the phenomena of the firſt quarter anſwer to thoſe of the third quarter in autumn; and *vice verſa*. The nearer any time is to either of thoſe ſeaſons, the more the tides partake of the phenomena of theſe ſeaſons; and in the middle between any two of them, the tides are at a mean ſtate between thoſe of both *."

Thoſe general rules are perfectly verified by experience as long as no extraneous diſturbing cauſes interfere.

It has been but ſlightly mentioned in the preceding pages of this chapter, that the greateſt elevation of the waters takes place ſometime after the moon's paſſage over the meridian; and the ſame thing is true with reſpect to the ſpring tides, viz. that they take place ſometime after the conjunction, or the oppoſition of the ſun and moon. This is the caſe even in open ſeas, where, at firſt ſight, it might be expected that the greateſt elevation of the water would be directly under the moon, where the attraction is ſtrongeſt. But an obſervation ſimilar to that which has been made (page 89, vol. III.) relative to the greateſt heat of the day, which takes place a conſiderable time after the ſun's paſſage over

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* Ferguſon's Aſtronomy, §. 307.

the meridian, will eaſily explain the above-mentioned phenomenon of the tides; namely, that when a certain power communicates an energy, and though the action of that power be actually decreaſing; yet the effect, or the accumulation of the energy, will ſtill continue to increaſe as long as the waſte of that energy in a given time is leſs than the addition which is made to it in the ſame time. Thus, ſuppoſe that a perſon's expenditure amounts to 10 pounds per day; then, if to-day he receives 20 pounds, to-morrow he will have left 10 pounds; for he muſt ſpend the other 10 to-day. Then if to-morrow, inſtead of receiving 20 pounds, he receives 15, and, as uſual, he ſpends 10 pounds out of it, he will have left, in all, 15 pounds; and if the day after to-morrow he receives only 12 pounds, and as uſual ſpends only 10, he will have left upon the whole 17 pounds; which evidently ſhews that though his daily receipt is conſtantly decreaſing, yet his ſtock is increaſing, and will continue to increaſe as long as the daily receipt exceeds the daily expenditure.

Now, with reſpect to the tides, it muſt be conſidered, that the waters of the oceans, once put in motion by the attraction of the ſun and moon, would of themſelves continue to move for a conſiderable time, though the action of the ſun and moon ſhould be ſuſpended. Like a baſon of water, or like a pendulum, which, if once put in motion, will, without the renovation of the impulſe, continue

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to vibrate for a conſiderable time after. In the like manner, if the moon's attraction ſhould ceaſe, the moment ſhe has paſſed the meridian, the waters of the oceans would ſtill continue to riſe for ſome time after, in conſequence of the impulſe received before the ceſſation of the moon's action; and therefore they muſt continue to riſe much more when that action, inſtead of being annihilated, is only diminiſhed.

The time which elapſes between the moon's paſſage over the meridian, and the high water or flood, even in open ſeas, is not always the ſame; but it is ſometimes longer and at other times ſhorter than ordinary, which ariſes from the concurring action of the ſun; for when the moon is in her firſt and third quarters, the tides raiſed by the moon are accelerated by the ſun, becauſe in thoſe caſes the tides raiſed by the ſun alone would come on earlier than thoſe of the moon. And when the moon is in her ſecond and fourth quarters, the tides raiſed by her are retarded by the ſun; becauſe, in thoſe caſes, the tides raiſed by the ſun alone would come on later. In general, the greateſt height of the water in open ſeas, takes place about an hour after the moon's meridional paſſage.

Beſides the acceleration or retardation which ariſe from the influence of the ſun, the tides are conſiderably affected, in point of height and of periodical return, by local circumſtances. In the open ſeas the riſe of the water is ſmall in compariſon to what it is in contracted channels, wide-mouthed rivers, &c. where the water is accumulated by the contraction and oppoſition of the banks.

"The tides are ſo retarded in their paſſage through different ſhoals and channels, and otherwiſe ſo variouſly affected by ſtriking againſt capes and headlands, that to different places they happen at all diſtances of the moon from the meridian; conſequently at all hours of the lunar day. The tide propagated by the moon in the German ocean, when ſhe is three hours paſt the meridian, takes 12 hours to come from thence to London bridge; where it arrives by the time that a new tide is raiſed in the ocean: and therefore, when the moon has north declination, and we ſhould expect the tide at London to be greateſt when the moon is above the horizon, we find it is leaſt; and the contrary when ſhe has ſouth declination. At ſeveral places it is high-water three hours before the moon comes to the meridian; but that tide which the moon puſhes as it were before her, is only the tide oppoſite to that which was raiſed by her when ſhe was nine hours paſt the oppoſite meridian.

"There are no tides in lakes, becauſe they are generally ſo ſmall, that when the moon is vertical ſhe attracts every part of them alike, and therefore, by rendering all the water equally light, no part of it can be raiſed higher than another. The Mediterranean and Baltic ſeas have very ſmall elevations, becauſe the inlets by which they communicate with the

the ocean are ſo narrow, that they cannot, in ſo ſhort a time, receive or diſcharge enough to raiſe or ſink their ſurfaces ſenſibly *."

The time of high water in different parts of the world, or rather the time which elapſes between the high water tide and the moon's arrival at the meridian, can only be learned from experience; and therefore the obſervations made in different places relative to this, are collected into tables, which are to be met with in ſeveral almanacks, and in treatiſes on navigation, ſuch as Robertſon's, Bouguer's, &c.

The action of the moon upon the atmoſphere has been noticed in the ſecond volume of theſe Elements, page 242, and following.

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* Ferguſon's Aſtronomy, § 309 and 310.

CHAP. VIII.

OF THE NATURE AND MOVEMENTS OF THE SUN AND PLANETS.

THE movements, the appearances, and the mutual influence, of the ſun, the earth, and the moon, are undoubtedly more ſtriking and more intereſting to us than thoſe of the other celeſtial objects: hence particular notice has been taken of the ſame in the preceding chapters of this volume. But in deſcribing the appearances and the movements of the other celeſtial objects we ſhall endeavour to be more conciſe, eſpecially becauſe the ſimilarity of their motions to thoſe of the earth, will, in a great meaſure, ſuperſede the neceſſity of giving very minute explanations of ſeveral particulars.

In order to facilitate the comprehenſion of what follows, the reader is requeſted to recollect what has been in a particular manner explained before, relatively to the planets; namely, that the planets, both primary and ſecondary, move in elliptical orbits; and that the primaries, together with the ſun, move round a common centre of gravity, which centre

centre of gravity is not coincident with the centre of, but is not out of the body of, the ſun. Alſo the ſecondaries, or moons, or ſatellites which belong to a planet, revolve round a centre of gravity common to them and to their primary; ſo that in truth the point, which deſcribes the planetary orbit round the ſun is not the centre of ſuch a planet as has ſatellites, but is the common centre of gravity of that planet and its ſatellites; thus it is not the centre of the earth, but the common centre of gravity of the earth and moon, that deſcribes the annual orbit round the ſun. This centre of gravity is as much nearer to the centre of the earth than to that of the moon, by as much as the quantity of matter in the moon is leſs than the quantity of matter in the earth, viz. as 1 to 38,9; therefore, ſince the diſtance of the moon from the earth is 240000 miles *, by dividing this diſtance in the above-mentioned proportion, we ſhall find that the common centre of gravity of the earth and moon is only 6015 miles diſtant from the centre of the earth, which diſtance being but trifling, we have, for the ſake of avoiding prolixity, not noticed it in the explanation of the annual movements of the earth.

The reader is likewiſe requeſted to recollect Kepler's general laws relative to the planets; namely, that the areas deſcribed by a right line

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* See page 115 and 116, of this volume.

connecting the centre of attraction and the revolving planet, are always proportional to the times in which they are deſcribed, and that the cubes of their diſtances from the ſun are as the ſquares of the times of their periodical revolutions.

For the ſake of brevity, as alſo for the conveniency of compariſon, the diameters, diſtances, revolutions, and other remarkable particulars relatively to the ſun and planets, have been diſpoſed in a table which ſtands at the end of this chapter, and concerning which we ſhall ſubjoin the following explanations; we ſhall then add ſuch other particulars as could not conveniently be ſtated in the form of a table.

The 1ſt column of the table, which immediately follows the names of the principal bodies of the ſolar ſyſtem, contains the apparent mean diameters of thoſe bodies; that is, when they are at their mean diſtances from the earth. Thoſe diameters have been aſcertained by means of micrometrical meaſurements; but ſome uncertainty exiſts with reſpect to the two new planets, Ceres and Pallas; for the meaſurements of their diameters, as given by different aſtronomers, do not agree with each other. The moſt accurate obſervations hitherto made upon Mars, Jupiter, Saturn, and the Georgium Sidus, prove that there is a ſenſible difference between their equatorial and polar diameters; the former being longer than the latter, which is undoubtedly owing to the greater centrifugal force of their equatorial parts; as is the caſe with the earth. Though it be not proved by actual obſervations, yet analogy induces us to believe, that a ſimilar difference exiſts between the equatoreal and polar diameters of all the other planets.

The 2nd column of the table contains the diameters which the planets would appear to have to a ſpectator in the ſun. Thoſe are obtained by computation.

The 3d column contains the real mean diameters in Engliſh miles. Thoſe diameters are obtained by computation from their reſpective apparent diameters and diſtances.

The mean diſtances of the planets from the ſun, in round numbers of Engliſh miles, are contained in the 4th column of the table. Should any perſon wiſh to have thoſe diſtances more accurately, he may eaſily deduce them from the proportional numbers of the 5th column, and by the common rule of proportion; ſuppoſing that the mean diſtance of the earth, viz. 95 millions, is ſufficiently accurate.

The mean denſity of all the parts which form each planet, compared to that of water, is contained in the 6th column; and the 7th column contains the proportion between the quantity of matter in the ſun, as alſo in each planet, and that of the earth, which is reckoned one, or unity; thus Jupiter is reckoned to contain ſomewhat more than 312 times as much matter as the earth, &c.

The

The inclinations, or the angles which the orbits of the planets form with the plane of the ecliptic, are contained in the 8th column.

The 9th column ſhews the inclinations of the axes of ſome celeſtial bodies to their reſpective orbits. This column is deficient on account of the very great difficulty of making the neceſſary obſervations; for this inclination of the axis of a planet is only to be deduced from the oblique or curvilinear motion of the ſpots of the planet.

The diurnal rotations of the 10th column are alſo derived from the motion of the ſpots.

The 11th column contains the tropical revolutions, viz. the time employed by each planet in paſſing over the 12 ſigns of the zodiac. And the time which each of them employs in going from any fixed ſtar to the ſame again, is contained in the 12th column. The particulars of this, as well as of the two preceding columns, are expreſſed in days, hours, minutes, and ſeconds.

The 13th column contains the aphelia of the different planets, viz. the higher apſis, or the place of the ecliptic, towards which the planet is directed when it ſtands at that point of its orbit, which is the moſt diſtant from the ſun. Thoſe parts of the ecliptic are expreſſed in ſigns, degrees, minutes, and ſeconds.

The 14th column contains the ſecular motions of the aphelia of the preceding column; viz. the motion of the aphelion of each planet in 100 years.

This

This is obtained by dividing the difference between the place of the aphelion, as determined many years ago, and as aſcertained lately, by the number of centuries, or fractional parts of a century, elapſed between the above-mentioned two determinations.

Column the 15th, contains the eccentricities of the orbits, each mean diſtance being reckoned 100000. From this and the 4th column, the eccentricity of each orbit may be had in miles. Thus the earth's mean diſtance from the ſun is 95000000 of miles, and the eccentricity of its orbit is 1681,395; therefore ſay, as 100000 : 1681,395 :: 95000000 to a fourth proportional, viz. to 1597325,25, which is the eccentricity of the earth's orbit in miles.

The 16th column contains the greateſt equations of the centres, viz. the difference between the true and the mean anomaly for each planetary orbit.

The 17th column ſhews the place of the aſcending node of each planetary orbit, which gives the ſituation of the line of nodes. This may be expreſſed either by the characters of the ſigns of the zodiac, or by the number of ſigns, always reckoning from the firſt point of Aries; together with the odd degrees, &c. Thus 1^s, 15°, $20'$, $43''$, is the ſame as ♉, 15°, $20'$, $43''$, and 3^s, 7°, $55'$, $32''$, is the ſame as ♋, 7°, $55'$, $32''$.—The ſame obſervations may be applied to the 13th column.

The

The ſecular motion of the nodes, or movement in 100 years for each planet, is contained in the 18th column. Thoſe are obtained in the ſame manner as has been ſaid of the 14th column.

It was impoſſible to avoid ſome inaccuracies among the particulars of the annexed table, principally becauſe the obſervations, hitherto made, do not always afford very accurate reſults; we ſhall, however, endeavour to point them out in the following paragraphs; wherein the reader will find ſeveral particulars relative to the ſun and planets, which could not be expreſſed in the form of a table.

The ſplendor of the ſun even long before the diſcovery of teleſcopes has been obſerved to vary at different and uncertain times; when viewed through a teleſcope, the ſurface of the ſun is almoſt always found to contain certain dark ſpots of various ſizes and duration. It is from the motion of thoſe ſpots that the ſun has been found to move round its own axis, and that its axis has been found to be inclined to the ecliptic.

The conſtant emanation of heat and light from that immenſe body, has long ſuggeſted the idea of the ſun's being a globe of fire, of the ſpots being the ſcoria of the burning matter, and of ſome acceſſion of matter being neceſſarily required to ſupply the conſtant waſte which aroſe from the emanation of heat and light. But the more or leſs powerful teleſcopes uſed by different obſervers, and the tendency of preconceived ſyſtems, have given birth to a variety of opinions relative to the nature of the ſun. Thus the ſpots have been ſuppoſed to be bodies of very irregular figures revolving about the ſun, and very near its ſurface. Thoſe ſpots have alſo been conſidered as the tops of rocks or mountains, on the ſuppoſition that the ſun is an opaque body covered with a liquid igneous matter. They have likewiſe been looked upon as excavations in the luminous matters of the ſun. In the year 1788, a very learned and worthy gentleman publiſhed a diſſertation concerning the light of the ſun, in which he advanced *that the real body of the ſun is leſs than its apparent diameter; and that we never diſcern the real body of the ſun itſelf, except when we behold its ſpots; and that the ſun is inhabited as well as our earth; and is not neceſſarily ſubject to burning heat; and that there is in reality no violent elementary heat exiſting in the rays of the ſun themſelves eſſentially* *.

Several years after the publication of the laſt mentioned opinion, Dr. Herſchel began to publiſh in the Philoſophical Tranſactions, his theory concerning the nature of the ſun, and to which he was led by his numerous obſervations made with his moſt improved inſtruments, and the moſt perſevering induſtry. This theory, in brief, is as follows:

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* Morſels of Criticiſm by Edward King, Eſquire, F.R.S. and A.S.

The ſun, he thinks, is a moſt magnificent habitable globe ſurrounded by a double ſet of clouds. Thoſe, which are nearer its opaque body, are leſs bright and more cloſely connected together than thoſe of the upper ſtratum, which form the luminous apparent globe we behold. That luminous external matter, as Dr. Herſchel obſerves, is neither a liquid nor an elaſtic fluid of an atmoſpheric nature; for in either of thoſe two caſes, it could not admit of any chaſms, or openings. Therefore, it muſt be concluded, that this ſhining matter exiſts in the manner of empyreal, luminous, or phoſphoric clouds, reſiding in the higher regions of the ſolar atmoſphere. The doctor then is of opinion that the ſpots, commonly ſo called, are only accidental openings between the luminous clouds, through which we behold the opaque body of the ſun, or the inferior, leſs luminous clouds; hence the ſpots appear of different ſhades. In conſequence of this theory, Dr. Herſchel rejects the old names of ſpots, nuclei, penumbæ, faculæ and luculi, which other aſtronomers had given to the various appearances on the viſible ſurface of the ſun; and adopts the following terms, which we ſhall expreſs in his own words; and from an explanation of which the reader may acquire a more competent idea of his hypotheſis *.

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* See Dr. Herſchel's Papers in the Phil. Tranſ. for the years 1795 and 1801.

"*Openings* are thoſe places where, by the accidental removal of the luminous clouds of the ſun, its own ſolid body may be ſeen; and this not being lucid, the openings through which we ſee it may, by a common teleſcope, be miſtaken for mere black ſpots, or their nuclei."

"*Shallows* are extenſive and level depreſſions of the luminous ſolar clouds, generally ſurrounding the openings to a conſiderable diſtance. As they are leſs luminous than the reſt of the ſun, they ſeem to have ſome diſtant, though very imperfect reſemblance to penumbræ; which might occaſion their having been called ſo formerly."

"*Ridges* are bright elevations of luminous matter, extended in rows of an irregular arrangement."

"*Nodules* are alſo bright elevations of luminous matter, but confined to a ſmall ſpace. Theſe nodules, and ridges, on account of their being brighter than the general ſurface of the ſun, and alſo differing a little from it in colour, have been called faculæ, and luculi."

"*Corrugations*, I call that very particular and remarkable unevenneſs, ruggedneſs, or aſperity, which is peculiar to the luminous ſolar clouds, and extends all over the ſurface of the globe of the ſun. As the depreſſed parts of the corrugations are leſs luminous than the elevated ones, the diſc of the ſun has an appearance which may be called mottled."

" *Indentations* are the depreſſed or low parts of the corrugations; they alſo extend over the whole ſurface of the luminous ſolar clouds."

" *Pores* are very ſmall holes or openings, about the middle of the indentations."

The planet next to the ſun is Mercury. The proximity of this planet to the ſun, renders it ſeldom viſible, conſequently the aſtronomers have not had many opportunities of making numerous and accurate obſervations upon it. No ſpots have as yet been diſcovered upon its diſc, conſequently neither its rotation about its axis, nor the poſition of that axis, can be determined; yet Mr. Schroeter is induced, by ſome of his obſervations, to believe that the period of Mercury's rotation about its axis is 24 hours and 5 minutes *. That, according to its ſituation with reſpect to the earth and the ſun, this planet muſt ſhew phaſes, in great meaſure ſimilar to thoſe of the moon, has already been mentioned, and I think it needs no farther illuſtration. The tranſit of Mercury over the diſc of the ſun does by no means take place at every revolution of the planet; for ſince its orbit is inclined to the ecliptic, making with it an angle of about ſeven degrees, and croſſing it at the two nodes, it is evident that the planet cannot be ſeen to paſs over the diſc of the

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* De La Londe's Hiſtory of Aſtronomy for 1800.

ſun, unleſs its nodes happens to be in, or ſufficiently near, the line which joins the ſun and the earth.

Venus, vulgarly called the morning or evening ſtar, according as it precedes or follows the apparent courſe of the ſun, is a very brilliant planet, ſituated between us and Mercury. It has long been doubted whether any ſpots were really viſible upon its diſc; and indeed even at preſent it is far from being ultimately determined. Some aſtronomers have perceived ſpots and even mountains upon its diſc. Dr. Herſchel, however, could never ſee any ſuch appearances; hence he is of opinion, that neither the rotation of this planet, nor the poſition of its axis, can as yet be determined, that it has a conſiderable atmoſphere, and that from its apparent diameter, Venus ſeems to be larger, and not as commonly believed ſmaller than the earth. The ſame obſervations, which have been made with reſpect to the phaſes of Mercury, and to its tranſit over the ſun, muſt be underſtood of Venus alſo. Thoſe tranſits are of great uſe to aſtronomy; but the tranſit of Venus being much more uſeful on account principally of its moving ſlower; no pains have been ſpared in calculating the times of its taking place, or in obſerving it at the actual time. "The chief uſe (*ſays Dr. Halley*) of theſe conjunctions, is accurately to determine the ſun's diſtance from the earth, or its parallax, which aſtronomers have in vain attempted

tempted to find by various other methods; for the minuteneſs of the angles required, eaſily eludes the niceſt inſtruments. But in obſerving the ingreſs of Venus into the ſun, and her egreſs from the ſame, the ſpace of time between the moments of the internal contacts, obſerved to a ſecond of time, viz. $\frac{1}{15}$ of a ſecond of an arch, may be obtained by the aſſiſtance of a moderate teleſcope, and a pendulum clock, that is conſiſtent with itſelf exactly, for the ſpace of 6 or 8 hours. Now, from two ſuch obſervations rightly made in proper places, the diſtance of the ſun within a 500th part may be certainly concluded."

Of the earth and moon, enough has already been ſaid in the preceding chapters.

Mars is the planet which comes next to the earth in order from the ſun. The appearance of this planet is by no means ſo bright as that of Venus, or even that of Jupiter which is much farther from the ſun. Its colour is ſomewhat inclining to red. The beſt or moſt recent obſervations on this planet, ſeem to be thoſe which have been made by Dr. Herſchel, who obſerved ſeveral remarkably bright ſpots near each pole of Mars, which ſpots ſeemed to have a ſmall motion *. The reſults of his obſervations are that the inclination of the axis of

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* Philoſophical Tranſactions for 1784.

Mars to the ecliptic is 59°, 22′; the node of its axis is in ♓ 17°, 47′; the obliquity of Mars's ecliptic is 28°, 42′; the point Aries on its ecliptic anſwers to our ♐ 19°, 28′. Its equatorial is to its polar diameter nearly as 16 to 15.

Next to Mars come the two new planets, viz. the Ceres Ferdinandea, and Pallas, which, on account of their remarkably ſmall ſize, Dr. Herſchel propoſes to diſcriminate by the appellation of *aſteroids*. Nothing particular has as yet been diſcovered with reſpect to the appearances of thoſe planets. They ſometimes appear round and well defined, at other times they appear to be ſurrounded by a coma or hazineſs, the denſity and extent of which ſeem to vary with the ſtate of the atmoſphere. It is ſaid that Mr. Schroeter ſuſpects that the Ceres has two ſatellites. This, however, is much in want of confirmation.

The beautiful planet Jupiter is the next in order. With reſpect to ſplendour, this planet yields, upon the whole, only to Venus. When viewed through a tolerably good teleſcope, ſome zones or belts are ſeen upon its diſc, which run parallel to its equator or nearly ſo. Thoſe belts are of a darker ſhade and variable in number, in breadth, and in intenſity; hence they have been generally ſuppoſed to be aſſemblages of clouds, probably driven by certain winds of Jupiter's atmoſphere, which may blow in particular directions in different parts of that atmoſphere,

moſphere, ſomewhat like our equinoctial winds, or the monſoons. Some large ſpots have often been ſeen in thoſe belts, which have vaniſhed with the contiguous belt. Sometimes the belts are not continuate, but interrupted or broken; in which caſe the broken end ſhews, that the belts as well as the above-mentioned ſpot revolve in the ſame time; but it is remarkable that thoſe which are nearer the poles of the planet revolve ſomewhat ſlower than thoſe which are near its equator; but this time of rotation varies a little, and the time of rotation of the ſame ſpot diminiſhes*.

According to Schroeter, Jupiter's rotation about its axis is performed in 9^h, 55^m, 37^s. This rotation is much quicker than that of the earth about its axis; hence the difference between the equatorial and the polar diameters of Jupiter, is much greater in proportion than that which has been found between the two diameters of the earth; the equatorial parts of Jupiter having a very great centrifugal force. By the beſt meaſurements, the polar diameter of Jupiter is to its equatorial diameter as 12 to

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* Dr. Herſchel, in the year 1788, obſerved that the time of revolution of a certain ſpot altered in the following manner. From February 25, to March 2, it revolved in 9^h, 55^m, 20^s. From the 2nd to the 14th of March, in 9^h, 54^m, 58^s; and from the 7th to the 12th of April in 9^h, 51^m, 35^s.

13. The axis of Jupiter is nearly perpendicular to its orbit; ſo that upon it the change of ſeaſons muſt be next to nothing.

Jupiter is ſurrounded by four moons, or ſatellites, of different ſizes, which move about it in different times and different limits of elongation. In conſequence of their different movements, thoſe ſatellites, which can never be ſeen without a teleſcope, are found always differently ſituated. Fig. 4. Plate XXVIII. exhibits the ſituation of Jupiter and its four ſatellites on a particular night; and fig. 5, exhibits the ſame as they would appear to a ſpectator ſituated in the heavens, perpendicularly over their orbits. The numbers 1, 2, 3, and 4, denote the ſatellites, and the circles which paſs through them in fig. 5, repreſent their orbits; that ſatellite which performs its revolution neareſt to the planet being called the *firſt*, the next being called the *ſecond*, and ſo on.

It is from a variety of appearances, ſomewhat like thoſe of fig. 4, that the knowledge of the real diſtances, periods, and other particulars relative to thoſe ſatellites, has been derived; and the principal obſervations which have furniſhed it are as follows:

1. Each ſatellite is ſometimes ſeen on the eaſtern, and at other times on the weſtern, ſide of the planet. The greateſt diſtance from the primary, at which each of them is ſeen, points out the extent of its orbit; for this greateſt elongation is as much on one ſide

ſide of the planet as on the other ſide. The time which elapſes between thoſe two elongations, is about half the ſatellite's periodical revolution, or half the time of its greateſt elongation on one ſide, and the next elongation on the ſame ſide.

2. Every one of the four ſatellites, in going from the weſtern to the eaſtern ſide of the planet, certainly goes beyond or behind the planet; for in that caſe they are ſometimes hid by the planet, and at other times are ſeen either above or below it, but never over its diſc; whereas in their courſe from the eaſtern to the weſtern ſide of the planet, thoſe ſatellites which paſſed behind, now paſs over the diſc of the planet, thoſe which paſſed above, now paſs below, and *vice verſa*; which evidently proves that they move round Jupiter in the direction from the weſt towards the eaſt, the ſame way that all the planets move round the ſun.

3. " The paths of the ſatellites being reduced to their reſpective planet's centre, ſometimes appear rectilinear, paſſing through that centre, and inclined in a certain direction to its orbit. Afterwards they change more and more into ellipſes, during one quarter of the planet's annual revolution; and all the ſuperior conjunctions are then made *above* the planet's centre, and the inferior conjunctions *below* it: during a ſecond quarter of the planet's revolution, theſe ellipſes become narrower, the ſatellites are nearer the centre in their conjunctions, and at the

the end of a ſecond quarter of the revolution, all the ellipſes are again become right lines with equal inclination, but in a contrary direction. In the third quarter of the revolution, they are formed a-new into ellipſes, the ſuperior conjunctions are made *below* the centre, and the inferior ones *above*. Laſtly, in the fourth quarter of the revolution, when the planet is returning to the ſame point of its orbit, theſe ellipſes again decreaſe in breadth, and all returns to its firſt ſtate."

4. "The times of the ſuperior and inferior conjunctions of the ſatellites, being compared, their intervals are nearly equal to their ſemi-revolution."

In ſhort, all thoſe obſervations prove that the ſatellites move all one way, and almoſt equably round their primary, in curves that return into themſelves; the planet being in one of the diameters of each curve; that the planes of the orbits of the ſatellites are inclined to the plane of the orbit of the primary, and each croſſes it at two points, called the *nodes*, of which one is the *aſcending*, and the other the *deſcending* node; that when the earth happens to be in the direction of that line of nodes, then the ſatellites appear to move in ſtraight lines; otherwiſe they appear to move in ellipſes, the planes of which are turned with one ſide or with the other towards the earth, according as the earth happens to be ſituated on on one ſide or the other of the above-mentioned line of nodes *.

Every one of the ſatellites of Jupiter, like our moon, are liable to be eclipſed by paſſing through the ſhadow of their primary. Knowing the ſituation of Jupiter with reſpect to the ſun, which gives the direction of its ſhadow, and the movements of the ſatellite, one may eaſily calculate the time of an eclipſe of that ſatellite. In fact, tables of all the eclipſes of thoſe ſatellites are annually publiſhed in the Nautical Almanac, and other annual publications of the like kind.

The calculations and obſervations of thoſe eclipſes are not merely matters of uſeleſs curioſity; but they anſwer a moſt uſeful purpoſe, which is that of finding the longitude of one place from another on the ſurface of the earth, as will be particularly explained hereafter. Another grand diſcovery was originally deduced by Mr. Roemer from thoſe eclipſes, and

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* It is evident that the motion of the ſatellites round Jupiter is produced by the ſame cauſes as that of the planets round the ſun; viz. they are attracted by the planet, at the ſame time that they are actuated by an impulſive force which prevents their falling upon the planet; hence they muſt follow Kepler's laws; viz. each of them muſt deſcribe round the planet areas proportionate to the times; and the cubes of their mean diſtances from the planet muſt be as the ſquares of their periodical times.

has afterwards been confirmed by means of other obſervations, eſpecially thoſe made by Dr. Bradley upon the fixed ſtars; namely, that light moves not inſtantaneouſly, but progreſſively, employing a certain time in going through a certain ſpace; viz. it moves at the rate of almoſt 200000 miles in one ſecond of time; which was firſt determined by obſerving, that when the earth is between the ſun and Jupiter, in which caſe the earth is neareſt to Jupiter, the eclipſes of the ſatellites appear to take place *ſooner* by about 8 ¼ minutes, than they ſhould appear according to the calculation as ſtated in the tables; whereas, when the earth is fartheſt from Jupiter, or when Jupiter is beyond the ſun, then the eclipſes of the ſatellites appear to take place about 8 ¼ *later* than they ought to appear according to calculation; therefore light takes up a longer time in percurring a greater diſtance; and, as the difference between the two diſtances of Jupiter from the earth in the above-mentioned two ſituations, is equal to the diameter of the earth's orbit, which is equal to about 190000000 miles, we naturally conclude that light employs twice 8 ¼, or about 16 ½ minutes in percurring 190000000 miles.

The elements, or the periods, diſtances, and other particulars, relative to Jupiter's four ſatellites, are ſtated in the following table; from which the configuration, and the eclipſes of thoſe ſatellites may be calculated. It muſt be obſerved, however, that ſuch

ſuch a table requires to be corrected from time to time, and according as more accurate obſervations are made; for the motions of thoſe ſatellites are ſubject to irregularities ſimilar to, and even greater than, thoſe of our moon; they being ſubject to the ſame diſturbing cauſes, and likewiſe to their mutual actions upon each other.

The Satellites of Jupiter.

	Iſt.	IId.	IIId.	IVth.
Revolutions { periodic	$1^{d}\ 18^{h}\ 27^{m}\ 33^{s}$	$3^{d}\ 13^{h}\ 13^{m}\ 42^{s}$	$7^{d}\ 3^{h}\ 42^{m}\ 33^{s}$	$16^{d}\ 16^{h}\ 32^{m}\ 8^{s}$
Revolutions { ſynodic	$1^{d}\ 18^{h}\ 28^{m}\ 36^{s}$	$3^{d}\ 13^{h}\ 17^{m}\ 54^{s}$	$7^{d}\ 3^{h}\ 59^{m}\ 36^{s}$	$16^{d}\ 18^{h}\ 5^{m}\ 7^{s}$
Diſtance in ſemi-diameters of Jupiter	5,67	9,00	14,38	25,30
Diſtance in miles	252797	401265	641132	1128000
Mean diſtance, when Jupiter is at its mean diſtance	1′ 51″	2′ 57″	4′ 42″	8′ 16″
Semi-diameter of the ſhadow, in time	$1^{h}\ 7^{m}\ 55^{s}$	$1^{h}\ 25^{m}\ 40^{s}$	$1^{h}\ 47^{m}\ 0^{s}$	$2^{h}\ 23^{m}\ 0^{s}$
Semi-diameter of ſhadow, that of Jupiter being = 1	0,9941	0,9967	0,9857	0,9913
Semi-duration of eclipſe 90° from the node, when the inclination is leaſt	$1^{h}\ 3^{m}\ 45^{s}$	$1^{h}\ 16^{m}\ 5^{s}$	$1^{h}\ 3^{m}\ 40^{s}$	0 0 0
For circular ſhadow { greateſt inclination	3° 18′ 38″	3° 46′ 0″	3° 25′ 57″	2° 36′ 0″
For circular ſhadow { mean	3° 18′ 38″	3° 16′ 0″	3° 13′ 58″	2° 36′ 0″
For circular ſhadow { leaſt	3° 18′ 38″	2° 46′ 0″	3° 2′ 0″	2° 36′ 0″
For elliptical ſhadow { greateſt	3° 4′ 27″	3° 29′ 42″	3° 11′ 14″	2° 24′ 51″
For elliptical ſhadow { leaſt	3° 4′ 27″	2° 34′ 0″	2° 49′ 0″	2° 24′ 51″
Epoch of conj. 1760 for the meridian of Greenwich	$0^{d}\ 10^{h}\ 35^{m}$	$1^{d}\ 14^{h}\ 49^{m}\ 36^{s}$	$2^{d}\ 5^{h}\ 32^{m}\ 29^{s}$	$1^{d}\ 7^{h}\ 20^{m}\ 50^{s}$
Mean place of node 1760	10^{s} 14° 30′	10^{s} 13° 45′	10^{s} 14° 24′	10^{s} 16° 39′
Annual motion of node	0′ 0″	2′ 3″	0′ 0″	4′ 19″
Diurnal motion of ſatellites	6 23 29 20	3 11 22 29	1 20 19 4	0 21 34 16
Secular motion	7 25 31 13	3 23 10 39	1 22 9 19	6 29 50 29

Saturn comes next to Jupiter in order from the ſun. This planet can hardly be diſtinguiſhed from a fixed ſtar by the naked eye; but when ſeen through a good teleſcope, Saturn exhibits a moſt ſingular appearance. In ſhort, it is ſurrounded by a thin, flat, broad, and luminous ring, as is repreſented in fig. 6, Plate XXVIII. which does not touch the body of the planet; leaving a conſiderable ſpace all round. Beſides the ring, this planet is ſurrounded by ſeven moons of different ſizes, which revolve about it in different periods; but thoſe ſatellites cannot be ſeen without a moſt powerful teleſcope.

Upon the body of Saturn, belts, ſimilar to thoſe of Jupiter, but much leſs diſtinct, are alſo viſible; and thoſe belts ſeem to be parallel to the plane of the ring, and to the planet's equator, which is in the direction of the ring; the diameter of the planet in that direction, being to the diameter perpendicular to it, or to its polar diameter, as 11 to 10 nearly. From the motion of ſome broken parts of the belts or ſpots, it has been lately determined that Saturn turns round its axis, like the other planets, in the direction of the ſigns, in 10^h, 16^m, 2^s, nearly.

Saturn's ring is divided into two parts by a ſtrong, permanent, and well defined dark line *a a a*; and its outer edge, though very thin, ſeems however, in the opinion of Dr. Herſchel, to be not flat, but convex.

The ring in general looks brighter than the body of of the planet itſelf; and from its caſting a ſtrong ſhadow upon the planet, it has been naturally conjectured to be of a ſolid nature. The following dimenſions of this double ring of Saturn were determined by Dr. Herſchel.

	MILES.
Inner diameter of the ſmaller ring	146345
Outſide diameter of ditto	184393
Inner diameter of the larger ring	190248
Outſide diameter of ditto	204883
Breadth of the inner ring	20000
Breadth of the outer ring	7200
Breadth of the vacant ſpace, or dark zone	2839

Both the planet and its ring turn round the ſame common axis; but the ring ſeems to turn a little ſlower; viz. the ring turns in its own plane, in 10^h, 32^m, 15^s,4. The ſhape of the ring is nearly circular; but, in conſequence of its oblique ſituation, which is always parallel to itſelf, it appears of an elliptical figure, and this ellipſe appears moſt open when Saturn is 90° from the nodes of the ring upon the orbit of the planet, or when the longitude of Saturn is about 2^s, 17°, and 8^s, 17°. " In ſuch a " ſituation the minor axis is very nearly equal to " half the major, when the obſervations are reduced " to the ſun; conſequently the plane of the ring " makes an angle of about 30°, with the orbit of " Saturn. Or, according to ſome obſervations, the " inclination of the ring to the ecliptic is about 31°, " 22′."

Since

Since the oblique poſition of Saturn's ring remains always parallel to itſelf; or, which is the ſame thing, ſince the axis of that ring, like the axis of the earth, is always directed towards the ſame point in the heavens; therefore twice in a ſaturnian year the ring muſt be turned with its edge towards the earth, in which caſe it diſappears for a ſhort time; unleſs it be viewed through a moſt powerful teleſcope (indeed I may ſay, unleſs it be viewed through Dr. Herſchel's 40-feet teleſcope); for through it the edge of the ring appears like a very ſlender ray of light paſſing acroſs the diſc of Saturn*. It is evident that as Saturn moves and recedes from one of thoſe limits in which the ring is turned edgewiſe towards the ſun, ſo one ſide or ſurface of the ring becomes illumined by the ſun at the ſame time that the other ſurface is in the dark; and when Saturn has paſſed the other limit, then the latter ſurface of the ring becomes illumined, and the former is deprived of light.

The ſatellites of Saturn have not as yet proved ſo uſeful to aſtronomy or geography as thoſe of Jupiter; principally becauſe they cannot be ſeen unleſs very powerful teleſcopes be uſed. Five of thoſe

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* "According to Dr. Maſkelyne, the plane of the ring "paſſed through the earth on January 29, 1790; the earth "paſſing from the northern, or dark, to the ſouthern or en- "lightened ſide of the ring; the ring, therefore, then be- "came viſible, and will continue ſo till 1803."

ſatellites were diſcovered in the year 1685, by Caſſini and Huygens, who uſed teleſcopes conſiſting of two ſimple lenſes, but upwards of 100 feet in length; and thoſe were called 1ſt, 2d, 3d, &c. reckoning from the planet. Two others were diſcovered by Dr. Herſchel in the years 1787 and 1788, and theſe are ſmaller and nearer to the planet, on which account they ought to have been called the firſt and ſecond, at the ſame time that the other five ought to have been called 3d, 4th, 5th, 6th, and 7th; but, imagining that this might create ſome confuſion in the reading of old aſtronomical books, the five old ſatellites have been ſuffered to retain their numerical names, and the two new ſatellites are now called the 6th and the 7th; ſo that the 7th is the neareſt to the planet, then comes the 6th, then the 1ſt; and this is followed by the 2d, 3d, 4th, and 5th.

The inclinations of the orbits of the 1ſt, 2d, 3d, and 4th ſatellites, to the ecliptic, are from 30° to 31°. That of the 5th is from 17° to 18°. Of all the ſatellites of the ſolar ſyſtem, none, except the 5th of Saturn, has been obſerved to have any ſpots, from the motion of which the rotation of the ſatellite round its own axis might be determined. Then the 5th ſatellite of Saturn, as Dr. Herſchel has diſcovered, turns round its own axis; and it is remarkable, that, like our moon, it revolves round its axis exactly in the ſame time that it revolves round its primary.

The

The following table ſtates the particulars which have been aſcertained with reſpect to the ſatellites of Saturn. Speaking of the ſatellites of Saturn, we might have added, that they are retained in their orbits by the attraction of their primary; that they act upon each other, that their periods and other particulars are found by the means of peculiar obſervations, &c. but having ſaid enough with reſpect to thoſe particulars in our account of Jupiter's ſatellites, it will be ſufficient in this place to ſay, that all the remarks which have been made with reſpect to the ſatellites of Jupiter, are alſo applicable, with few obvious alterations, to the ſatellites of Saturn.

The Satellites of Saturn.

	VII.	VI.	I.	II.	III.	IV.	V.
	d h m s	d h m s	d h m s	d h m s	d h m s	d h m s	d h m s
Periods - - - -	0 22 40 46	1 8 53 9	1 21 18 27	2 17 41 22	4 12 25 12	15 22 41 13	79 7 48 0
Diſtances in ſemi-diameters of Saturn	$2\frac{5}{6}$	$3\frac{5}{9}$	$4\frac{3}{8}$	$5\frac{1}{2}$	8	18	54
Ditto in miles - -	107000	135000	170000	217000	303000	704000	2050000
Apparent diameters of orbits - - - -	57″	1′ 14″	1′ 27″	1′ 52″	2′ 36″	6′ 18″	17′ 4″

The Georgium Sidus, with its ſix ſatellites, have been entirely diſcovered by Dr. Herſchel. The planet itſelf may be ſeen with almoſt any teleſcope, but its ſatellites cannot be perceived without the moſt powerful inſtruments, and the concurrence of all other favourable circumſtances. One of thoſe ſatellites Dr. Herſchel found to revolve round its primary in 8^d. 17^h. 1^m. 19^s; the period of another he found to be 13^d. 11^h. 5^m. 1^s,5. The apparent diſtance of the former from the planet is $33''$.; that of the ſecond $44''\frac{2}{9}$. Their orbits are nearly perpendicular to the plane of the ecliptic.

The other four ſatellites were diſcovered a conſiderable time after, and of courſe Dr. Herſchel has had leſs time to make obſervations upon them. They are altogether very minute objects; ſo that the following particulars muſt be conſidered as being not accurate but probable. "Admitting the diſtance of the interior ſatellite to be $25''$,5, its periodical revolution will be 5^d. 21^h. 25^m.

"If the intermediate ſatellite be placed at an equal diſtance between the two old ſatellites, or at $38''$,57, its period will be 10^d, 23^h. 4^m. The neareſt exterior ſatellite is about double the diſtance of the fartheſt old one; its periodical time will therefore be about 38^d. 1^h. 49^m. The moſt diſtant ſatellite is full four times as far from the planet as the old ſecond ſatellite; it will therefore take at leaſt 107^d. 16^h. 40^m. to complete one revolution. All theſe ſatellites perform their revolutions in their orbits contrary to the order of the ſigns; that is, their real motion is retrograde."

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
	Apparent mean diameters, as ſeen from the earth.	Mean diameters as ſeen from the ſun.	Mean diameters in Engliſh miles.	Mean diſtances from the ſun, in round numbers of miles.	More accurate proportional numbers of the preceding mean diſtances.	Denſities to that of water, which is 1.	Proportions of the quantities of matter.	Inclinations of orbits to the ecliptic in 1780.	Inclinations of axes to orbits.	Rotations diurnal, or round their own axes.
The Sun - - -	32′. 1″,5	- -	883246	- - -	- - -	$1\frac{2}{15}$	333928	- - -	82°. 44′. 0″.	$25^d. 14^h. 8^m.$
Mercury - - -	10″.	16″.	3224	37000000	38710	$9\frac{1}{6}$	0,1654	7°. 0′. 0″.		
Venus - - -	58″.	30″.	7687	68000000	72333	$5\frac{11}{15}$	0,8899	3°. 23′. 35″.		$0^d. 23^h. 21^m.$
The Earth - -		17″,2	7911,73	95000000	100000	$4\frac{1}{2}$	1	0°. 0′. 0″.	66°. 32′.	$1^d.$
The Moon - -	31′. 8″.	4″,6	2180	95000000	100000	$5\frac{1}{2}$	0,025	5°. 9′. 8″. at a mean.	88°. 17′.	$29^d. 17^h. 44^m. 3^s.$
Mars - - - -	27″.	10″.	4189	144000000	152369	$3\frac{2}{7}$	0,0875	1°. 51′. 0″.	59°. 22′.	$0^d. 24^h. 39^m. 22^s.$
Ceres Ferdinandea	1″.		160	260000000	273550			10°. 37′. 56″,6 in 1801.		
Pallas - - - -	0″,5		80	266000000	279100			34°. 50′. 40″. in 1801.		
Jupiter - - -	39″.	37″.	89170	490000000	520279	$1\frac{1}{24}$	312,1	1°. 18′. 56″. in 1780.	90°. nearly.	$0^d. 9^h. 55^m. 37^s.$
Saturn - - -	18″.	16″.	79042	900000000	954072	$0\frac{13}{32}$	97,76	2°. 29′. 50″. in 1780.	60°. probably	$0^d. 10^h. 16^m. 2^s.$
Georgium Sidus -	3″. 54″	4″.	35112	1800000000	1908352	$0\frac{99}{100}$	16,84	0°. 46′. 20″. in 1780.		

	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.
	Tropical revolutions. d. h. m. s.	Sidereal revolutions. d. h. m. s.	Places of Aphelia, January 1800.	Secular motions of the Aphelia.	Excentricities; the mean diſtances being 100000.	Greateſt equations of the centres.	Longitudes of ☊; or places of aſcending nodes in 1750.	Secular motions of nodes.
The Sun - - -								
Mercury - - -	87. 23. 14. 32,7	87. 23. 15. 43.6	8^s. 14°. 20′. 50″.	1°. 33′. 45″.	7955.4	23°. 40′. 0″.	1^s. 15°. 20′. 43″.	1°. 12′. 10″.
Venus - - -	224. 16. 41. 27,5	224. 16. 49. 10,6	10^s. 7°. 59′. 1″.	1. 21′. 0″.	498	0°. 47′. 20″.	2^s. 14°. 26′. 18″.	0°. 51′. 40″.
The Earth - -	365. 5. 48. 49	365. 6. 9. 12	9^s. 8°. 40′. 12″.	0°. 19′. 35″.	1681,395	1°. 55′. 30″,9		
The Moon - -								
Mars - - - -	686. 22. 18. 27,4	686. 23. 30. 35,6	5^s. 2°. 24′. 4″.	1°. 51′. 40″.	14183,7	10° 40′. 40″.	1^s. 17°. 38′. 38″.	0°. 46′. 40″.
Ceres Ferdinandea	1681. 12. 9. 0		10^s. 25°. 57′. 15″. in 1802.		8140,64	9°. 20′. 8″.	2^s. 20°. 58′. 40″. in 1802.	
Pallas - - - -		1703. 16. 48. 0			24630		5^s. 22°. 28′. 57″. in 1802.	
Jupiter - - -	4330. 14. 39. 2	4332. 14. 27. 10,8	6^s. 11°. 8′. 20″. in 1800.	1°. 34′. 33″.	25013,3	5°. 30′. 38″.	3^s. 7°. 55′. 32″. in 1750.	0°. 59′. 30″.
Saturn - - -	10746. 19. 16. 15,5	10759. 1. 51. 11,2	8^s. 29°. 4′. 11″. in 1800.	1°. 50′. 7″.	53640,42	6°. 26′. 42″.	3^s. 21°. 32′. 22″. in 1750.	0°. 55′. 30″.
Georgium Sidus -	30637. 4. 0. 0.	30737. 18. 0. 0	11^s. 16°. 30′. 31″. in 1800.	1°. 29′. 2″	90804	5°. 27′. 16″.	2^s. 12°. 47′. in 1788.	1°. 44′. 35″.

CHAP. IX.

OF COMETS.

SOME other celeſtial bodies ſeem likewiſe to revolve about the ſun; but they differ from the nine planets that have been already deſcribed, principally in the following particulars: 1. The curves which they deſcribe round the ſun as a focus, if they do return into themſelves, as is moſt probable, are ellipſes ſo very eccentric, that any of thoſe bodies is only viſible to us whilſt it percurs that part of its orbit which is in the vicinity of the ſun; but during the much greater part of its courſe, it is quite inviſible to us. 2. Their periodical times are ſo very long, and difficult to be aſcertained, that it hardly falls to the lot of one man to ſee the ſame body return twice to the neighbourhood of the ſun; and even then it would be difficult to identify it. 3. Their ſhapes are neither well defined nor conſtant; but moſt of thoſe bodies are ſurrounded by an indefinite faint light, a tail, a hairy irradiation, or *coma*; from which they have been denominated *comets*. They are likewiſe vulgarly called *blazing ſtars*.

We are utterly ignorant of the number and of the uſe of comets in the fabric of the world.

The number of comets that have been ſeen and are recorded, is very great[*]. But a vaſt number muſt have eſcaped notice; for there are ſeveral comets ſo very ſmall as to be viſible only through teleſcopes, and ſuch have frequently been ſeen of late years, when particular attention has been paid to the ſubject.

With reſpect to the nature and the uſe of comets, various opinions have been entertained by different great and learned philoſophers; but as nothing very probable has been advanced, I ſhall refer thoſe who wiſh to examine ſuch opinions to the works of other authors[†].

The apparent motion of comets, like that of all other celeſtial bodies, is from the eaſt, towards the weſt, which ariſes from the diurnal rotation of the earth in the contrary direction. But comets have a proper and peculiar motion, each different from the others, and this motion is determined by tracing the ſituation of a comet with reſpect to the fixed ſtars.

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[*] Riccioli reckons 154, until the year 1651. But Lubienietz reckons 415 until the year 1665.

[†] Pliny, lib. II. chap. 25. Ariſt. *Meteor.* lib. 6. Plutarc *de plac. Phil.* Aulus Gellius. Seneca, lib. VII. Riccioli, *Alm.* II. 35. De la Lande's Aſtronomy, book XIX. Newton's *Principia*, book III. Vince's Aſtronomy. Gregory's Aſtronomy, chap. XXI.

Some comets perform their proper movements from the weſt towards the eaſt, which is the direction followed by all the planets. But others move in the contrary direction, viz. from the eaſt towards the weſt. Some of them move in the plane of the ecliptic, or within the zodiac; whilſt others go in different directions, even perpendicular to the plane of the ecliptic.

Upon the whole, it appears that every comet moves in a particular curve which has the ſun in its focus; that it moves ſo as to deſcribe round the ſun areas proportionate to the times; and that the curve appears to be an exceedingly excentric ellipſis; which clearly indicates that the comets are retained within certain limits by the ſame general law of nature, the univerſal gravitation of matter; that they muſt be actuated by an impulſive force, which prevents their falling towards the common centre of attraction, and that therefore they move in orbits like the planetary orbits, only much more excentric. Yet it muſt be conſidered, that ſince we ſee a comet only during a very ſmall part of its periodical courſe, from which ſmall part we muſt calculate and determine the whole orbit and the periodical time, every ſmall error committed in the obſervations of that ſmall part, produces a conſiderable difference in the reſult of the whole; nor can the quantity of that error be eaſily verified and corrected by future obſervations; firſt, becauſe the period or the return of a comet is very long; and ſecondly, becauſe the comet

comet itſelf cannot be identified. Indeed, the only reaſon aſtronomers have for ſaying that a certain comet has returned two or three or more times, is, that when the period of a comet has been determined from the obſervation of that ſmall portion of its orbit, which comes within the reach of obſervation; if after the lapſe of that period a comet appears about the ſame part of the heavens, they conclude that it probably is the ſame comet. Not above ſix or ſeven comets, amongſt all thoſe which have been ſeen, have as yet been calculated with accuracy ſufficient to render their period tolerably well known, which ſhews that the ſubject is ſtill in its infancy, and a vaſt number of farther obſervations is ſtill wanted for the purpoſe of generalizing and correcting the theory. But the opportunities for making ſuch obſervations ſeldom occur; therefore the progreſs of knowledge, relative to comets has been but ſlow. The wiſeſt ancient philoſophers conſidered the comets as periodical celeſtial bodies. Sir Iſaac Newton concluded, that they might deſcribe very excentric ellipſes, and might re-appear at every revolution. Dr. Halley verified this grand idea, by actual calculations upon the obſervations of ſeveral comets. It is ſuppoſed that it was the ſame comet which appeared in the years 1456, 1531, 1607, 1682, and 1759; ſo that this comet's period is about 75 years. Another comet, which was ſeen in the year 1532, is ſuppoſed to be the ſame that was ſeen in the year 1661, and was expected about the year 1789 or 1790; but did not appear. According to Halley, the great comet of the year 1680 is to re-appear in the year 2254; and is ſuppoſed to be the ſame that appeared at the time of Cæſar, and that appeared alſo in 219 and 2349 before our Saviour's birth*.

Even ſuppoſing that the period of a comet could be calculated with ſufficient accuracy; yet, conſidering the various cauſes which muſt diſturb the regular motion of that comet, we may eaſily imagine that the return of that comet may thereby be ſhortened or lengthened, or diverted, to ſuch a degree as to give it the appearance of a different comet. In conſequence of the excentricity of their orbits, the comets muſt in their courſes croſs each other, and likewiſe croſs the planetary orbits; hence they may come ſo very near one another, or ſo very near any of the planets, as to diſturb their motion, and even ſo as to ſtrike againſt and deſtroy any of them. Indeed, from ſuch an action, it is not improbable that the path of a comet may be changed into a parabola,

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* Several of thoſe who wiſh to account for the deluge upon the agency of natural cauſes, attribute that great convulſion to the near approach of that comet to the earth; for if the attraction of the moon alone is capable to raiſe conſiderable tides, the near approach of a body ſo much larger than the moon, muſt act with vaſtly greater force. See Whiſton's New Theory of the Earth; and De la Lande's *Reflexions ſur le Cometé*, Paris 1773.

or ſome other curve, and thus the comet may never return again. As for the methods of computation of the orbits of comets, I muſt refer the ingenious reader to other works*; but I ſhall only mention in this place, that the paths of comets have often been ſaid to be parabolical, and have been calculated upon that principle, not becauſe they are really ſo; for if they were parabolical, they could not return into themſelves; hence the comets would continue for ever to recede from the ſun; but becauſe the properties of a parabolical curve are calculated with much greater eaſe and expedition than thoſe of an elliptical curve; and at the ſame time the nature of a parabola is ſo very near the nature of a vaſtly eccentric ellipſis, that the reſult of the calculation upon either of them is nearly the ſame.

The times during which comets remain in ſight are various, but they hardly ever exceed ſix months, and ſome comets have not been ſeen for more than a few nights. Of thoſe which have remained

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* See the Third Book of Newton's *Principia*. De la Lande's Aſtronomy, B. XIX. Vince's Aſtronomy. Clairaut's *Theor. du Movem. des Cometés*. D'Alembert's Opuſc. Mathem. tom. II. Gregory's Aſtron. chap. XXI. which is a conciſe and ſatisfactory Diſſertation on Comets: alſo Bode's Papers on the Orbits of Planets and Comets, in the Memoirs of the Berlin Academy, from 1786 to 1787; and Sir Henry Englefield's Work on the Orbits of Comets.

in ſight for ſix months together, one is ſaid to have appeared in the year 64, at the time of Nero; another appeared about the year 603, at the time of Mahomet; a third comet of that continuance was ſeen in 1240, at the time of the irruption of Tamerlane; a fourth appeared in 1729, which remained in ſight from July the 31ſt, 1729, to the 21ſt of January, 1730. Comets that have appeared for ſhorter periods are recorded by ſeveral writers and particularly by Riccioli.

The proper movements of comets are alſo different from each other, and very variable with reſpect to the ſame comet. From the nature of planetary orbits in general, it is eaſy to conceive that as the comets deſcend towards the ſun, ſo they muſt quicken their pace, until they reach the perihelion, after which limit, they ſlacken their pace, and continue to do ſo in proportion as they recede from the vicinity of the ſun. When they are going off, and nearly vaniſhing, they ſometimes move ſo very ſlowly as to be hardly diſcernable amongſt the ſtars. But ſome comets have been obſerved to move with incredible quickneſs. The comet which appeared in 1472, paſſed through 120° in one day. The comet of 1760, altered its longitude by $41\frac{1}{2}°$ in one day. The comet of 1664, moved 164° in 17 days, &c.

Were the comets near the earth, the abovementioned quick movements would not excite any wonder; but when we conſider their prodigious diſtances, which in general far exceed the diſtances of the moſt remote planets, we cannot but be aſtoniſhed at the wonderful velocity with which they muſt move. Another ſource of inequality in the apparent motion of comets, ariſes from the motion of the earth, the effect of which muſt vary according to the direction both of the earth and of the comet.

That the comets are at moſt aſtoniſhing diſtances from us, is derived from their having little or no *parallax*; viz. when they are viewed from different parts of the ſurface of the earth, and are referred to the fixed ſtars, they appear to ſtand at the very ſame point of the heavens, or nearly ſo; which would not be obſerved if they were even within double the diſtance of the Georgian planet. I ſhall render this more intelligible by means of a diagram or two.

Let ABG, fig. 7, Plate XXVIII. be the earth, and D a comet. Then, if the comet D be ſeen from the centre T of the earth, or in that direction, viz. from O; the place of that comet referred to the fixed ſtars, will appear at G; but when ſeen from the ſurface of the earth or place A, the ſame comet will appear at E. The former is called the *comet's true place*, and the latter its *apparent place*. Now the diſtance GE between the true and the apparent places, is called the *parallax* of that comet. By inſpecting the figure, it will be eaſily comprehended, that the farther the comet D is from the

the earth, the ſmaller will the diſtance GE be, and *vice verſa*; therefore, when that diſtance or parallax is little or nothing, the diſtance of the comet is prodigiouſly great; nor can we aſſign the quantity of it. The nature of parallaxes will be better explained hereafter.

The preciſe place of a comet at any particular time of its appearance, may be determined by meaſuring its diſtance from any two contiguous fixed ſtars; and that place may be marked upon a planiſphere or globe: thus its different ſituations in different times during its appearance, may be marked down, and a line drawn through thoſe points will repreſent the track of the comet. The above-mentioned diſtances muſt be taken by means of a quadrant, or a micrometer; but even without any ſuch inſtruments, and merely by the uſe of a thread, we may find out whether a comet have any parallax, as alſo aſcertain its place. A comet, when juſt going out of ſight, moves ſo ſlowly as not to change its place ſenſibly in a few hours time. In this caſe therefore let the ſituation of the comet be obſerved twice during the ſame night, viz. once when it ſtands very high above the horizon, and another time when it ſtands near the horizon, which amounts to the ſame thing as to obſerve it from two different places at the ſame time. Then if the comet on both obſervations appears to retain the ſame ſituation with reſpect to the ſtars, we may conclude that it has no ſenſible parallax. The ſimple way of finding

finding the ſituation of the comet for this purpoſe, is to hold a thread with your two hands, and extending it between you and the comet, to move it by trial until it covers two contiguous ſtars, at the ſame time that it paſſes through the comet; which ſhews that the comet is in the direction of the two ſtars, &c. If the place of the comet be required more accurately for the purpoſe of delineating its track, you muſt obſerve once every night, or oftener, by means of a thread, the ſituation of the comet, with reſpect to four ſtars, ſuch as are contiguous to it, and are marked upon a celeſtial globe or planiſphere; for by this means you may every time make a dot at the preciſe place upon the globe, and afterwards, by joining thoſe points with a line, you will have the track of the comet. Thus let the comet be at A, fig. 8, Plate XXVIII. between the four ſtars, B, C, D, E; ſo that the line joining the ſtars B, D, may paſs through the comet; and ſo may alſo be the caſe with the line which joins the ſtars C and E. Then if you extend a thread, or place the edge of a piece of paper through the ſtars C and E, upon a globe or planiſphere, where ſuch ſtars are marked, and extend another thread through the ſtars B and E; the interſection of the two threads will point out the place A of the comet upon the globe, or planiſphere, where a mark may be made, &c.

Nothing certain can be ſaid with reſpect to the diſtances

diſtances of comets. Moſt of them move entirely beyond the planetary orbits, but ſome comets have deſcended below Mars, and it is ſaid even below the orbits of the inferior planets.

The figures and ſizes of comets vary conſiderably, and even the ſame comet alters its figure in the courſe of a few days. Some comets ſeem to be nothing more than a congeries of vapours ill defined, tranſparent throughout, and reflecting very little light. Others are of a ſimilar nature, excepting that a denſer ſubſtance more opaque, commonly called a *nucleus*, is ſeen within the rare or vapour-like ſubſtance. Almoſt all comets are ſurrounded by denſe atmoſpheres, which partly reflect the ſun's light, and at the ſame time prevent that light's falling in a conſiderable quantity upon the nucleus, or what may be conſidered to be ſolid part of the comet; ſo that the ſolid part, or nucleus, though brighter than the ſurrounding part, is, however, not ſo bright as Jupiter, or as part of the moon. But the brightneſs of a comet changes according as it recedes from, or approaches, the ſun; and at the ſame time it puts forth certain elongations of luminous matter, which have been called *beards*, or *comas*, *hair*, or *tails*, according to their different poſitions and appearances; for thoſe elongations ſometimes are very ſhort and hardly viſible, whereas at other times they are extended to a prodigious degree; and it is remarkable that this luminous elonga-

elongation or tail, is always directed from the ſun, as is ſhewn in fig. 9, Plate XXVIII. where the comet A is repreſented as it appeared ſucceſſively in two different parts of its progreſs round the ſun S. When the comet is eaſtward of the ſun, and moves from the ſun, it is ſaid to be *bearded*, becauſe the luminous elongation goes before it. When the comet is weſtward of the ſun, and ſets after him, it is then ſaid to have a *tail*, becauſe the luminous elongation follows it; and when the earth happens to be directly between the ſun and the comet, then the train of light is hid behind the body of the comet, and a little of it only is ſeen on the ſides of the comet, which is thereby ſaid to have a *coma* or *hairy* appearance.

" The tail of a comet, at its firſt appearance, is very ſhort, and increaſes as the comet approaches towards the ſun; immediately after its perihelion the tail is longeſt, and moſt luminous, and is then generally obſerved to be ſomewhat bent, and to be convex towards thoſe parts to which the comet is moving; the convex ſide being rather brighter and better defined than the concave ſide. When the tail arrives at its greateſt length, it then quickly decreaſes, and ſoon vaniſhes entirely; and about the ſame time the comet itſelf ceaſes to be ſeen. The matter of which the tail is formed is exceedingly rare, and ſo very pellucid, that the light of the ſmalleſt ſtars ſuffers no diminution in paſſing through it, as is remarked by Newton in his *Principia*, lib. III. prop. 41."

The ſplendour of comets increaſes in proportion as they approach the ſun, though at the ſame time their diameters, in conſequence of their receding from the earth, may appear to diminiſh.

The ſizes of the bodies of comets, as well as of their tails, is ſo various, as that ſome of them cannot be ſeen without a teleſcope, whilſt others have even equalled the diſc of the ſun; and ſuch was that which Seneca relates to have appeared at the time of the emperor Nero. The comet which Hevelius obſerved in the year 1652, ſeemed to equal the apparent ſize of the moon, but it had a pale, dim, and diſmal aſpect. Several comets have been ſeen, whoſe apparent ſize exceeded more than four times the diſc of Jupiter or of Venus.

The tails of comets are, in general, more expanded and leſs denſe, in proportion as they recede from the bodies of the comets. The comet of the year 1744, had the luminous elongation, ſomewhat like a fan, divided into various branches. The extenſion of the tails of comets is ſometimes aſtoniſhingly great. They have often been obſerved to extend more than 90°, or even half a circle; whence it has been calculated that their real lengths muſt exceed 60 or 80 millions of miles.

miles. It is remarkable that the tail of the ſame comet, obſerved at the ſame time, appears of different lengths from different parts of the earth's ſurface, and it appears longeſt from thoſe places which have a lower latitude, which probably ariſes from the ſuperior clearneſs and ſerenity of the ſky in thoſe places.

Whether the tails of comets be a train of pure light or of vapours, or of ſomething electrical, ſimilar to the *aurora borealis*, is impoſſible to be decided; but it appears that both the increaſe of ſplendour of a comet, and the appearance of a tail, are derived from the ſun.

"The great comet which appeared in the "year 1680, after its departure from the *peri*-"*helion*, projected ſuch a tail as extended itſelf "more than 40° in the heavens; nor can this "be a wonder; for it was ſo near the ſun, that "its diſtance from his ſurface at the *perihelion* "was but a ſixth part of the diameter of the "ſun's body; and therefore the ſun ſeen from "the body of the comet, would appear to fill "the greateſt part of the heavens, and its appa-"rent diameter would not be leſs than 120°; "and therefore the heat it received from thence "muſt be prodigiouſly intenſe beyond imagina-"tion; for it exceeded above 3000 times the "heat of red-hot iron. And therefore we muſt "allow, that the bodies of comets, which can "bear

"bear ſo great a heat, muſt be very denſe, hard, "and durable bodies; for if they were nothing "but vapours and exhalations, raiſed from the "earth and planets, as ſome have dreamt, this "comet, at ſo near an approach to the ſun, muſt "have been quite deſtroyed and diſſipated."— Keill's Introduction to Aſtronomy, Lect. XVII.

CHAP. X.

OF THE FIXED STARS.

BESIDES the planets both primary and ſecondary, and the comets which are ſeen at uncertain times, all the other lucid and brilliant objects, which, during the abſence of the ſun, we perceive in the heavens, are the *fixed ſtars*, ſo called from their preſerving, as far as we know, their ſituations with reſpect to each other, without any deviation.

The fixed ſtars appear to our eyes of different ſizes; but it is not in our power to ſay, whether that difference ariſes from their real difference of ſize, or from their being at different diſtances, or from both thoſe cauſes conjointly. The gradation of apparent ſize from the largeſt to the ſmalleſt ſtars, is great and indefinite; yet for the uſe of deſcription and diſcrimination, aſtronomers diſtinguiſh them into ſix, or more, orders, which naturally are of a vague and indefinite nature; calling the largeſt of them *ſtars of the firſt magnitude*; the next, *ſtars of the ſecond magnitude*, and ſo forth. The ſtars of the ſixth magnitude are thoſe which can barely be diſtinguiſhed

tinguiſhed by the naked eye. Thoſe which can only be ſeen by the help of the teleſcope, are called *teleſcopic ſtars*.

Several of the brighteſt and moſt remarkable ſtars are diſtinguiſhed by peculiar names; but the difficulty of diſcriminating the particular ſituations of them all, even of thoſe that have peculiar names, ſuggeſted an expedient which has been adopted from the remoteſt antiquity, and has been followed and improved in ſubſequent periods. By this method the ſtars are ſuppoſed to be, as they appear, in the concave ſurface of a ſphere, upon which the figures of men, beaſts, and other objects, are ſuppoſed to be delineated; then the ſituation of each ſtar is deſcribed by ſaying, that it is near the tail of a certain fiſh, in the bull's eye, juſt over the ſhoulder of Hercules, &c.

The ideal delineations of thoſe figures of animals, and other objects, which are called *conſtellations*, or *aſteriſms*, are diſperſed all over the heavens, and a particular ſituation is aſſigned to each, as may be ſeen upon a common celeſtial globe, or upon a planiſphere; yet ſome ſpaces remained here and there, which were out of the bounds of the contiguous conſtellations. The ſtars which were contained in thoſe places, were called *unformed ſtars*; but moſt of them are now comprehended into conſtellations newly adopted.

It is impoſſible to ſay what ſuggeſted the idea of adopting each particular conſtellation; but as far as can

can be conjectured from the dark documents of hiſtory, of tradition, and of fable, they ſeem to have been derived from different cauſes, ſuch as from the rainy ſeaſon, which uſually came on when a certain aſſemblage of ſtars appeared above the horizon; from the reſemblance, however imperfect, of certain groups of ſtars to particular objects; from the deſire of recording ſome remarkable event, or of paying homage to ſome diſtinguiſhed perſon, &c.

Thus, by mentioning the particular conſtellation to which each belongs, the ſtars may be pretty nearly, though by no means accurately, deſcribed; and this probably was the only mode of deſcribing the ſituations of the ſtars during ſeveral centuries; but at the revival of learning and ſcience, when particular attention began to be paid to aſtronomy, the above-mentioned indeterminate mode was gradually improved by the particular deſcription of the ſtars' apparent magnitude, by annexing a Greek letter, or a Roman letter, or a number, to each ſtar, and by forming catalogues of their right aſcenſions and declinations; by which means each particular ſtar may be readily and accurately known *.

The

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* The moſt accurate method of deſcribing the brightneſs or magnitudes of the ſtars, is undoubtedly that which Dr. Herſchel has adopted in his excellent catalogues of the comparative brightneſs of the fixed ſtars, the firſt of which catalogues

The following liſt contains the names of the conſtellations, the number of ſtars, as far as thoſe of the ſixth magnitude, that are contained in each conſtellation, as alſo the names and magnitudes of thoſe more remarkable ſtars of the annexed conſtellations, to which particular names have been given.

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catalogues is publiſhed in the Philoſophical Tranſactions for 1796. The others in the following volumes.

This method is to refer a given ſtar to two other ſtars, one of which is ſomewhat brighter, and the other ſomewhat leſs bright than the given one. "I place, *(he ſays)* each "ſtar, inſtead of giving its magnitude, into a ſhort ſeries, "conſtructed upon the order of brightneſs of the neareſt "proper ſtars. For inſtance, to expreſs the luſtre of "D, I ſay CDE. By this ſhort notation, inſtead of re"ferring the ſtar D to an imaginary uncertain ſtandard, I "refer it to a preciſe and determinate exiſting one. C is "a ſtar that has a greater luſtre than D; and E is another "of leſs brightneſs than D. Both C and E are neighbour"ing ſtars, choſen in ſuch a manner that I may ſee them at "the ſame time with D, and therefore may be able to "compare them properly. The luſtre of C is in the ſame "manner aſcertained by BCD; that of B by ABC; and "alſo the brightneſs of E by DEF; and that of F by "EFG."

CONSTELLATIONS OF THE ZODIAC.		
Names of Conſtellations.	Number of Stars.	Names of principal Stars, and their Magnitudes.
Aries - - -	66	
Taurus - -	140	Aldebaran - - - - 1
Gemini - -	85	Caſtor and Pollux - 1.2
Cancer - -	83	
Leo - - -	95	Regulus - - 1
Virgo - -	110	Spica Virginis - 1
Libra - - -	51	Zubeniſch Mali - 2
Scorpio - -	44	Antares - - 1
Sagittarius -	69	
Capricornus -	51	
Aquarius, and	108	Scheat - - 3
Piſces - - -	112	

Conſtellations on the North Side of the Zodiac.		
Names of Conſtellations.	Number of Stars.	Names of principal Stars, and their Magnitudes.
Urſa minor -	24	Stella poloris - - 2
Urſa major -	87	Dubhe - - - 1
Caſſiopeia -	55	
Perſeus - -	59	Algenib - - 2
Auriga - -	56	Capella - - 1
Bootes - -	54	Arcturus - - 1
Draco - -	60	Raſtaber - - 3
Cepheus - -	35	Alderamin - - 3
Canes Venatici, viz. Aſterian and Chara - -	25	
Cor Caroli -	3	
Triangulum -	10	

Conſtellations

Conſtellations on the North Side of the Zodiac.

Names of Conſtellations.	Number of Stars.	Names of principal Stars, and their Magnitudes.	
Triangulum minus	5		
Muſca	6		
Lynx	44		
Leo minor	24		
Coma Berenicis	40		
Camelopardalus	58		
Mons Menelaus	11		
Corona Borealis	21		
Serpens	50		
Scutum Sobieſki	8		
Herculus, cum Ramo et Cerbero	113	Ras Algiatha	3
Serpentarius ſive Ophiuchus	67	Ras Alhagus	3
Taurus Poniatowſki	7		
Lyra	22	Vega	1
Vulpecula et Anſer	37		
Sagitta	18		
Aquila	40	Altair	1
Delphinus	18		
Cygnus	73	Deneb Adige	1
Equuleus	10		
Lacerta	16		
Pegaſus	85	Markab	2
Andromeda	66	Almaac	2

Conſtellations on the South Side of the Zodiac.			
Names of Conſtellations.	Number of Stars.	Names of principal Stars, and their Magnitudes.	
Phœnix	13		
Officina ſculptoria	12		
Eridanus	76	Achernar	1
Hydrus	10		
Cetus	80	Menekar	2
Fornax Chemica	14		
Horologium	12		
Reticulus Rhomboidalis	10		
Xiphias	7		
Celapraxitellis	16		
Lepus	19		
Columba Noachi	10		
Orion	78	Betelgueſe	1
Argo Navis	50	Canopus	1
Canis major	30	Sirius	1
Equuleus Pictorius	8		
Monoceros	31		
Canis minor	14	Procyon	1
Chameleon	10		
Pixis Nautica	4		
Piſcis Volans	8		
Hydra	60	Cor Hydræ	1
Sextans	4		
Robur Carolinum	12		
Machina Pneumatica	3		
Crater	11	Alkes	3
Corvus	9	Algorab	3
Croſiers	6		

Conſtellations on the South Side of the Zodiac.		
Names of Conſtellations.	Number of Stars.	Names of principal Stars, and their Magnitudes.
Muſca - - - -	4	
Apis Indica - -	11	
Circinus - - -	4	
Centaurus - - -	36	
Lupus - - - -	24	
Quadra Euclidis -	12	
Triangulum Auſtrale - - -	5	
Ara - - - - -	9	
Teleſcopium - -	9	
Corona Auſtralis -	12	
Pavo - - - -	14	
Indus - - - -	12	
Microſcopium -	10	
Octans Hadleianus - - - -	43	
Grus - - - -	14	
Toucan - - -	9	
Piſcis Auſtralis -	20	Fomalhaut - - 1

The whole number of ſtars, as reckoned in the preceding liſts, amounts to 3186. But the naked eye can ſeldom diſtinguiſh a third part of that number; in more favourable climates ſome perſons eyes can diſtinguiſh more ſtars, in certain conſtellations, than thoſe which have been ſtated in the liſts. I do not attempt to add how many ſtars of one magnitude or of another are to be found in each conſtellation, as this cannot be determined with preciſion.

Beſides the ſeparate ſtars, a ſharp eye in a clear night may obſerve a few whitiſh ſpots called *nebulæ*; but a moſt remarkable broad and much extended whitiſh track may be obſerved at all times in the heavens. This is called, from its whiteneſs, the *galaxy*, *via lactea*, or *milky way*. This remarkable zone is irregularly extended, and varies in breadth from 4° to 20°. It paſſes through Caſſiopeia, Perſeus, Auriga, the foot of Gemini, Orion's Club, part of Monoceros, the tail of Canis major, through Argo Navis, Robur Carolinum, Crux, and the feet of the Centaur: beyond which it divides into two parts; its eaſtern branch paſſes through Ara, the tail of Scorpio, the eaſtern foot of Serpentarius, the bow of Sagittarius, Scutum Sobieſcianum, the feet of Antinous and Cygnus. Its weſtern branch paſſes through the upper part of the tail of Scorpio, the right of Serpentarius and Cygnus, and ends in Caſſiopeia.

Such are the objects which may be diſcerned by the naked eye in the region of the fixed ſtars; but, by the aſſiſtance of the teleſcope, the number, the beauty, and the variety of wonderful objects is increaſed to an aſtoniſhing degree; and much more ſo in proportion to the power of the teleſcope. An immenſe quantity of new ſtars is diſcovered. Several ſtars, which appear as ſingle ſtars to the naked eye, and even through ordinary teleſcopes, when viewed with higher powers, appear to be double, or treble, or quadruple, &c. viz. are found to be two or three, or more ſtars, ſo near to one another as to appear, through ordinary teleſcopes, as a ſingle ſtar[*]. They are alſo moſtly found to have peculiar colours, or tints, ſo that one ſtar will be of a greeniſh tint, another of a reddiſh, or bluiſh, &c.[†]. The numbers of nebulæ that can be diſcovered by the aſſiſtance of a powerful teleſcope, amounts to ſome thouſands[†]. The via lactea, and ſeveral of the nebulæ, are found to conſiſt of an aſtoniſhing number of apparently ſmall ſtars, ſituated very cloſe to each other; ſo much ſo, that in a ſmall part (as of about one degree in diameter) of ſome of thoſe nebulæ, or of the via lactea, there appears to be a greater number of ſtars than can be ſeen by the naked eye in the whole celeſtial ſphere.

It is remarkable that though the ſtars appear vaſtly to differ from one another in apparent grandeur, as they certainly do in point of brilliancy; yet their apparent diameter cannot be meaſured; for they always look like incommenſurable points; and if when viewed through certain teleſcopes, they ſeem to have a ſenſible diameter; that effect ariſes from ſome imperfection of the teleſcope, ſince it increaſes

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[*] α Herculis; δ Lyræ; α Geminorum; γ Andromedæ; μ Cygni; and a great many more, are double ſtars; ν Tyræ, is treble; λ Orionis, is quadruple, &c. &c.

[†] See Herſchel's catalogues of double ſtars and nebulæ in the Philoſophical Tranſactions.

and decreaſes in proportion as the teleſcope is more or leſs perfect, and according to its adjuſtment.

This obſervation, together with their total deficiency of parallax, ſhews the moſt incomprehenſible diſtance at which even the neareſt of the fixed ſtars muſt be ſituated.

That the ſtars ſhine not by reflected or borrowed light, like the planets; but by being ſelf luminous, like the ſun, may be eaſily and ſatisfactorily concluded from the following conſideration. The apparent ſize of the ſtars is certainly ſmaller than that of the ſatellites of Jupiter or of Saturn; their diſtances from us are likewiſe incomparably greater than thoſe of the ſatellites; but thoſe ſatellites cannot be ſeen by the naked eye, and ſome of them even require moſt powerful teleſcopes; therefore, if the ſtars ſhone by reflecting the light of the ſun, as the ſatellites do, they ought to be much leſs viſible than the ſatellites; which is not the caſe. We may therefore ſafely conclude, that the fixed ſtars are ſelf luminous like the ſun. They probably are of the ſame nature, and equally large, if not larger. And ſince ſuch immenſe bodies, ſo far removed from us as to be moſtly out of our ſight, could not be intended for our uſe, nor to interfere with the ſolar ſyſtem; it is moſt likely that they are the ſuns, or the centres, of as many ſyſtems, and that a number of planets and comets is revolving round each ſtar, from which they derive the vivifying influence of heat and light.

We may advance our conjecture a ſtep farther, and ſuppoſe that poſſibly ſome of the comets of each ſyſtem, which move in very excentric orbits, may, in their aphelia, come within the attractive power of ſome other ſtar or ſun, ſo as to paſs from one ſyſtem to another; and thus form a ſort of communication between the different ſyſtems; but as there is no end to conjecture, let us return to matter of fact.

Though the ſtars are called fixed, as they are in compariſon to other celeſtial bodies; yet they muſt not be conſidered as perfectly immoveable and unchangeable. Indeed the little movements, to which they have been obſerved to be ſubject, muſt not be conſidered as their proper movements; for they are to be accounted for upon the motion of the earth, the motion of light, &c. as will be ſhewn in the ſequel; but independent of motion from their reſpective ſituations, ſeveral changes have unqueſtionably been obſerved amongſt the ſtars, and probably a great many more will hereafter be obſerved; for the accurate catalogues of the ſizes, appearances, and ſituations of the ſtars which have been lately made, and the powerful inſtruments that are now in uſe, will enable the aſtronomers to diſcover the moſt minute variations of ſize, of brilliancy, and of ſituation.

Two ſtars of the ſecond magnitude, which were formerly viſible in the ſtern of the conſtellation *Argo Navis*, are now no longer to be ſeen. At the time of of the emperor Otho, a new ſtar appeared in Caſſiopeia, which diſappeared ſome time after. In the year 1600, Kepler obſerved a new ſtar in the ſwan's breaſt, which remained viſible during ſeveral years; but it became inviſible from the year 1660 till the year 1666, when it was again obſerved in the very ſame place by Hevelius, as a ſtar of the ſixth magnitude. A ſtar in the neck of the whale has the remarkable property of appearing and diſappearing alternately. Other ſtars appear to have their ſize or brilliancy increaſe and decreaſe periodically. A ſtar of this ſort is in *Hydra*, another in *Cygnus*, and a moſt remarkable one, called *Algol*, is in *Meduſa's head*. This *Algol* ſeems to have a period of 2 days and 21 hours, during which it varies from the ſize of the ſecond magnitude to that of the fourth in about 3½ hours, then returns to the former ſize in the ſame time, and retains that ſize for the reſt of the above-mentioned period. Such periodical changes in the brightneſs of ſtars, may probably be owing to their performing periodical rotations round their axes, and to their having ſpots on ſome part of their ſurfaces; ſo that when that part happens to be turned towards us, the ſtar muſt appear leſs bright than at other times. After the ſame manner the entire diſappearance and reappearance of certain ſtars may perhaps be accounted for.

If the reader wiſh to learn the ſituation of the conſtellations, and the names of the moſt remarkable

able ſtars, or to find the particular ſituations of certain ſtars, we muſt refer him to the catalogues, and to the celeſtial atlaſſes of Flamſteed, Bode, and others. A competent knowledge of the ſame may, however, be obtained by means of a common celeſtial globe, which being duly ſituated and rectified for the particular time of making the obſervation, will indicate the ſituation of the ſtars with ſufficient accuracy; ſo that the learner, having ſituated the globe (according to the precepts which will be given hereafter) in an open place and a ſerene night, when the moon does not ſhine, by looking at any particular conſtellation or ſtar on the upper part of the globe, and imagining that a ſtraight line, drawn from the centre of the globe, and through the given ſtar or conſtellation on the ſurface of the globe, be extended as far as the heavens, he will readily find the real ſtar or aſſemblage of ſtars in that identical ſpot, which is pointed out by the imaginary line*.

In this part of the world the moſt conſpicuous conſtellations, and therefore the beſt for a learner to begin with, are the *Great Bear* and *Orion*; and from the direction of the principal ſtars of thoſe conſtellations,

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* The beſt globes, both celeſtial and terreſtrial, with the lateſt engraved and moſt correct plates, as far as I know, are at preſent made by J. Cary, philoſophical inſtrument maker, in the Strand, London.

lations, he may, by referring to the globe, learn the contiguous ſtars, then thoſe which are farther off, and ſo forth. The Great Bear is undoubtedly the moſt uſeful, becauſe for this part of the earth it never ſets. Orion is viſible in the winter time towards the ſouth, and the arrangement of its ſtars is ſo remarkable, that once known, it is not afterwards eaſily forgotten.

CHAP. XI.

OF PARALLAX, REFRACTION, THE ABERRATION OF LIGHT, AND NUTATION.

WHEN a body, ſituated between us and the region of the fixed ſtars, is obſerved, and its place is referred to the ſtars, it is evident that it muſt appear to be nearer to one ſtar or to another, at the ſame time, according as it is viewed from one part of the earth's ſurface or from another. Thus an obſerver on the ſurface of the earth at A, fig. 10, Plate XXVIII. will imagine that the celeſtial body H, coincides with the ſtar O; at the ſame time that an obſerver on the ſurface of the earth at B, will obſerve the ſame body H, to coincide with the ſtar N. Here it muſt be obſerved, that the ſpectator B is in the right line which joins the centre of the earth, and the celeſtial body H; therefore he ſees that body perpendicularly over his head, and in the ſame manner (viz. againſt the ſame ſtar), as if he ſaw it from the centre of the earth; whereas this is not the caſe with the ſpectator at A, or with a ſpectator ſituated any where elſe upon the ſurface of the earth. Now the difference between the true place of of a celeſtial body (meaning the place which it ſeems to have when viewed in the direction of the centre of the earth*), and the place which it ſeems to have in the celeſtial ſphere, when viewed from any other part of the ſurface of the earth, is called by the aſtronomers the *parallax* of that body. Otherwiſe, in general terms, the parallax of an object is the difference between the places, that object is referred to in the celeſtial ſphere, when ſeen at the ſame time from two different places within that ſphere; or it is the angle under which any two places in the inferior orbits are ſeen from a ſuperior planet, or even from the fixed ſtars.

In the abovementioned figure, N is the true place of the body H; O is its apparent place; and the arc ON is its parallax. It is evident that the nearer the body H comes to the vertical line CZ, the ſmaller its parallax becomes; for when the body is in that vertical line as at *h*, the two lines, viz. that which paſſes through A, and the body *h*, as alſo that which paſſes through C, and the ſame body *h*, coincide; and of courſe, when the body is in the vertical

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* The ſituations of celeſtial objects are calculated always with reſpect to the centre of the earth, and in all the precepts that are given for the ſolution of aſtronomical problems, the diſtances and ſituations of celeſtial objects are always reckoned from their centres; hence the place which a celeſtial object ſeems to have when viewed from the centre of the earth is called its true place.

line, or in the zenith; it cannot have any parallax. On the contrary, when the body is at I, viz. in the horizon of the ſpectator A, then it has the greateſt parallax *o n*; becauſe the place of obſervation A, on the ſurface of the earth, is then the fartheſt poſſible from the other place of obſervation *b*, which is in the direction of the centre C.

It is alſo evident that, *cæteris paribus*, the farther a celeſtial body is from the earth, the ſmaller its parallax muſt be; thus the body P, which is farther from the earth AB*b*, than the body H, has its parallax N *p*, evidently ſmaller than the parallax ON, of the body H.

With reſpect to the meaſure of the above-mentioned parallax, it muſt be obſerved that the parallax NO of the body H, is the difference of the angles ZCH and ZAH; that is, of the angles ZCN and ZAO; which difference is equal to the angle AHC, or NHO; for the external angle ZAH, of the triangle AHC (Euclid's Elements, B. I. prop. 32.) is equal to the two internal and oppoſite angles AHC and ACH; therefore AHC is the difference between the two angles ZAH and ACH, or ZCH; hence this angle AHC (which is equal to NHO) meaſures, or is itſelf called, the *parallax* of the body H in that ſituation. AHC then is the angle under which the ſemidiameter AC of the earth appears to an eye ſituated at the celeſtial body H. The angle, which the diameter of the earth's orbit would ſubtend

to

to an eye ſituated in a celeſtial object, is called the *parallax of the great orbit.*

From what has been ſaid above, the following uſeful theorem is eaſily derived; viz. *the ſine of the parallax is to the ſine of a celeſtial body's angular diſtance from the vertex as the ſemi-diameter of the earth is to the diſtance of that body from the centre of the earth.* Thus the ſine of the angle AHC is to the ſine of the angle ZAH, as AC is to CH. For the ſides of plane triangles are as the ſines of the oppoſite angles; hence in the triangle AHC, the ſine of the angle AHC is to the ſine of the angle CAH (or ZAH), as AC, the ſemidiameter of the earth, is to CH, the diſtance of the body H from C. Therefore, if the parallax of a celeſtial body, when that body is at any given diſtance from the vertex, be known, we can eaſily find by the theorem, its parallax at any other diſtance from the vertex.

It alſo follows from the preceding explanation, 1ſt, that when bodies are at unequal diſtances from the centre of the earth, the ſines of their parallaxes are reciprocally as thoſe diſtances; 2dly, that when the bodies are at equal diſtances from the centre of the earth, the ſines of their parallaxes are as the ſines of their apparent diſtances from the zenith; and 3dly, that when the bodies are at unequal diſtances both from the centre of the earth and from the zenith, then the ſine of the parallax of one body is to that of another body, in a ratio compounded of the

the inverſe ratio of the diſtances from the centre of the earth, and the direct ratio of the ſines of the apparent diſtances from the zenith.

The general effect of the parallax of a celeſtial body is to let that body appear nearer to the horizon than it really is; therefore, in order to deduce the proper places of celeſtial objects from the obſervations, it is neceſſary to deduct the effects of the parallax; for the relative ſituations of celeſtial objects are always reckoned with reſpect to their centres and to the centre of the earth; whereas the obſervations cannot always be made in the direction of the centre of the earth.

The effect of the parallax being greater in proportion as the object is nearer to the earth, it follows that the moon which is the neareſt to us, is ſubject to a greater parallax than any other celeſtial body, and that parallax varies according to the different altitudes and different diſtances of the moon; then ſince the ſituation of the moon muſt be aſcertained for various uſeful aſtronomical purpoſes, thoſe various parallaxes of the moon are calculated, and are ſet in tables, which are to be met with in nautical almanacs, ephemerides, &c. The horizontal parallax of the moon varies from about 61′ 32″, to 53′ 52″. The mean horizontal parallax of the ſun is about 8″,75. The parallaxes of the other celeſtial objects are ſo very minute as ſeldom to require our attention.

Beſides the neceſſity of allowing for the effects of parallax in eſtimating the exact altitudes of celeſtial objects, the aſcertaining of parallaxes anſwers another very eſſential purpoſe in aſtronomy, viz. they are uſeful for finding the dimenſions and principally the diſtances of the celeſtial bodies from the earth; as alſo the dimenſions of their orbits.

When the diſtance of a celeſtial body from the earth is known, its horizontal parallax, and hence its parallax at any altitude, may be eaſily found; for in the right-angled triangle ACI, fig. 10, Pl. XXVIII. three parts being known (viz. the ſemi-diameter of the earth AC, the diſtance of the body CI, and the angle A, which is a right angle), the angle AIC, which is the horizontal parallax of the body I, is eaſily found, by trigonometry; alſo, if we have the parallax, we may eaſily determine the diſtance of the celeſtial body from the centre of the earth; for in that caſe the three angles and the ſide AC of the ſame triangle being known, the ſide or diſtance CI is eaſily determined*. When the diſtance of the celeſtial body is greater than 15000 ſemi-diameters of the earth, then that ſemi-diameter ſeen from that cœleſtial body, ſubtends an angle ſo ſmall

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* When the diſtance and apparent diameter of a celeſtial body are known, the real diameter of that body is thereby eaſily determined.

as not to exceed 14″, and of courſe very difficult to be obſerved with certainty.

Hitherto we have mentioned the effect of the parallax with reſpect to the altitude only of a celeſtial body, and have ſhewn that in conſequence of that parallax, the body always appears to be ſomewhat lower than it really is, except when it ſtands in the vertical line, or in the zenith. But it muſt be obſerved, that if the apparent place of a celeſtial object, relatively to the zenith, is different from its real place, the apparent relative ſituation of the ſame body, with reſpect to other circles, muſt alſo be different from its real ſituation; viz its apparent longitude, latitude, right aſcenſion and declination, muſt be different from its real longitude, latitude, &c. or from the longitude, latitude, &c. it would have, if it were viewed from the centre of the earth. Now the difference of longitude obſerved from the centre (or in the direction of the centre) of the earth, which is called the *true longitude*, and that ſeen from ſome other point of the ſurface of the earth, is called the *parallax of longitude*; the difference between the latitude, as obſerved from the centre, and that obſerved from the ſurface of the earth, is called the *parallax of latitude*; the difference of right aſcenſion, as obſerved from the centre, and that obſerved from the ſurface of the earth, is called the *parallax of right aſcenſion*; and laſtly, the difference between the declination, as obſerved from the centre, and that

that obſerved from the ſurface of the earth, is called the *parallax of declination.*

Refraction, as has been explained in the third volume of theſe Elements, is the bending of the rays of light, which is occaſioned by their paſſing obliquely from one medium into another medium of a different refractive power.

The atmoſphere, which ſurrounds the earth, is a refractive medium, and of courſe the rays of light which fall obliquely upon it, are bent by it; therefore the celeſtial objects which are neceſſarily ſeen through part of the atmoſphere, muſt appear to be in ſituations different from their real places, unleſs they be in the zenith; for in that caſe the rays of light which come from the celeſtial bodies to our eyes, fall not obliquely, but perpendicularly, upon the atmoſphere; in which caſe they ſuffer no bending or refraction. It naturally follows that the lower the ſituation of the body is, the greater, *cæteris paribus*, muſt its refraction be; for the rays of light fall more obliquely upon the atmoſphere.

Were the atmoſphere of an uniform denſity, the ray, which fell obliquely upon it, would be bent only at its entrance into the atmoſphere, and would afterwards proceed ſtraight through it; but as the atmoſphere is increaſing in denſity in proportion as it approaches the ſurface of the earth, therefore the ray of light is continually bent more and more as it approaches the earth, ſo as to become a curve line like AB, fig. 11, Pl. XXVIII.; and ſince to a ſpectator at B, upon the ſurface of the earth, the object C muſt appear in the direction which the ray of light CAB has, when it enters the eye at B; therefore the object, which really ſtands at C, muſt appear, in conſequence of the refraction, to ſtand at D.

The refractive power of the atmoſphere varies according to its gravity, to its temperature, and to its humidity; therefore the real quantity of refraction muſt be deduced from the compound effects of all thoſe cauſes.

Various experiments have been inſtituted with great care and attention for the purpoſe of determining the quantity of refraction which accompanies each particular degree of the air's gravity, temperature, and moiſture; but as it is impoſſible to aſcertain the actual ſtate of the upper regions of the atmoſphere with reſpect to thoſe particulars, it follows that the actual refraction for any given time cannot be known with certainty; yet from the indications of the barometer, thermometer, and hygrometer, the refractive power of the atmoſphere for any particular altitude, ſuch as is given in the tables of refraction, may in great meaſure be corrected*; but for ordinary purpoſes the mean refractions of the table are quite ſufficient.

It appears therefore that the celeſtial bodies are ſeen out of their real places, not only in conſequence

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* See Dr. Bradley's Rules in his Works.

of the parallax, but likewiſe in conſequence of the refraction of the atmoſphere; and that the parallax cauſes them to appear lower than they really are, whilſt the refraction makes them appear higher than their real places; therefore, in order to determine their real from their apparent places, a correction for the effect of refraction is alſo to be applied; and for this purpoſe the refractions for different altitudes, at a mean ſtate of the atmoſphere, are calculated and ſtated in a table, called the *table of refractions in altitude.*

Beſides the refraction in altitude, there are four other ſorts of refraction, the nature of which will be eaſily underſtood from what has been ſaid with reſpect to the different ſorts of parallax. In ſhort, if the effect of the refraction cauſes a body to appear in a place different from its real place, it follows that the apparent ſituation of that body with reſpect to other circles, muſt be different from its real ſituation; viz. in conſequence of the refraction, the *real* longitude, latitude, right aſcenſion, and declination of that body, muſt differ from its *apparent* longitude, latitude, &c. and thoſe differences conſtitute, or are called, *the refraction of longitude, the refraction of latitude, the refraction of right aſcenſion, and the refraction of declination.*

The quantity of refraction for every degree of altitude in a mean ſtate of the atmoſphere, is ſhewn by the following table, which conſiſts of two columns repeated. The firſt column contains the apparent

apparent altitudes, and the ſecond ſhews the correſpondent refraction, or the quantity which muſt be ſubtracted from the apparent altitude of the celeſtial object. Thus when a celeſtial body appears to be 36 degrees above the horizon, you will find againſt 36 degrees of apparent altitude in the table. 1′ 18″; which means that the refraction makes the object appear 1′ 18″ higher than it really is; hence that quantity muſt be ſubtracted from 36°, and the remainder 35° 58′ 42″, is the altitude of the object corrected of the effect of refraction.

Mean Aſtronomical Refraction in Altitude.

Apparent Altitude.		Refraction.		Apparent Altitude.		Refraction.		Apparent Altitude.	Refraction.		Apparent Altitude.	Refraction.
0°	0′	33′	0″	5°	0′	9′	54″	23°	2′	14″	44°	59″
0	5	32	10	5	30	9	8	24	2	7	45	57
0	10	31	22	6	0	8	28	25	2	2	46	55
0	15	30	35	6	30	7	51	26	1	56	47	53
0	20	29	50	7	0	7	20	27	1	51	48	51
0	30	28	22	8	0	6	29	28	1	47	49	49
0	40	27	0	9	0	5	48	29	1	42	50	48
0	50	25	42	10	0	5	15	30	1	38	52	44
1	00	24	29	11	0	4	47	31	1	35	54	41
1	20	22	15	12	0	4	23	32	1	31	56	38
1	40	20	18	13	0	4	3	33	1	28	58	35
2	0	18	35	14	0	3	45	34	1	24	60	33
2	20	17	4	15	0	3	30	35	1	21	65	26
2	40	15	45	16	0	3	17	36	1	18	70	21
3	0	14	36	17	0	3	4	37	1	16	75	15
3	20	13	34	18	0	2	54	38	1	13	80	10
3	40	12	40	19	0	2	45	39	1	10	85	5
4	0	11	51	20	0	2	35	40	1	8	90	0
4	30	10	48	21	0	2	27	41	1	5		
				22	0	2	20	42	1	3		
								43	1	1		

The horizontal refraction varies from 31′ to 36″, The refractions for other altitudes are alſo variable, but leſs and leſs in proportion as they recede from the horizon. In conſequence of the cauſes which have been mentioned above, namely, the temperature, gravity, &c. the refraction is greater in cold weather and cold climates than in warmer; it is generally greater in the morning than in the evening, &c. In conſequence of the refraction, the ſun, planets, ſtars, &c. begin to appear when they are actually below the horizon.

A very remarkable effect of the refraction of the atmoſphere is known under the name of *twilight* (*crepuſculum*), and it is the light which we perceive when the ſun is actually ſeveral degrees below the horizon; in which caſe it is evident that if the rays of light, which proceed from the ſun, were not bent by the atmoſphere, they could not poſſibly reach us; that light, therefore, which we receive from the ſun, either before its riſing or after its ſetting, and in conſequence of the refractive power, as alſo the reflection, of the atmoſphere, is the *twilight*. At a mean the twilight begins to appear in the morning, or ceaſes to appear in the evening, when the ſun is about 18° below the horizon. Whatever increaſes or decreaſes the refractive power of the atmoſphere, will, of courſe, increaſe or decreaſe the duration of the twilight, viz. will cauſe the twilight to begin when the ſun is more or leſs than 18° below the horizon. Thus, *cæteris paribus*, the twilight in cold climates laſts longer than in warmer climates. When the ſun, during the night, does not deſcend below the horizon more than 18°, as is the caſe with this iſland in the ſummer time, then the twilight laſts all night, or it is ſaid that there is no night. Within the polar circle, the ſun in conſequence of the refraction of the atmoſphere, eſpecially in that cold climate, begins to make its appearance ſome days before it ought to appear according to its real ſituation. According as the ſun either in its riſing or in its ſetting is a longer or a ſhorter time in percurring the 18° below the horizon, which ariſes from the different obliquity of its courſe, ſo the twilight begins ſooner or later before ſun riſe, and continues longer or ſhorter after ſun ſet. Hence, in this country, the twilight is longer in the ſummer time than in the winter; hence alſo, *cæteris paribus*, the twilight laſts longer in higher latitudes than near to the equator.

THE ABERRATION is an apparent movement of the ſtars, which was diſcovered towards the beginning of the laſt century, by Dr. Bradley, then aſtronomer royal. This apparent movement is the compound effect of the progreſſive motion of light, and of the motion of the earth in its orbit; in conſequence of which each fixed ſtar appears in the courſe of one year, to deſcribe a ſmall ellipſe, whoſe greater axis is about 40″.

In order to comprehend the cauſe of this apparent movement, let E, fig. 13, Plate XXVIII. be a ſtar, from

from which a ray of light proceeds towards us, and conſider this ray as a ſmall body moving from E to B. Let A B be a portion of the earth's orbit; for inſtance of 20″, and let CB repreſent the ſpace percurred by the light whilſt the earth has moved from A to B; ſo that the ſmall body or particle of light is at C, when the earth is at A; and both at the ſame time arrive at B. Thus CB and AB repreſent the reſpective velocities of the light and of the earth in 20″ of time. Draw CD equal and parallel to AB, and complete the parallelogram DCAB. Then, agreeably to the principles of the compoſition and reſolution of forces (ſee the firſt volume of this work), the velocity of light CB may be conſidered as the reſult of two velocities in the directions CD and CA; of which the velocity CD, being in the ſame direction, and equal in quantity to the velocity of A B of the earth, cannot be perceived; for the eye of an obſerver on the earth cannot be ſtruck by a body which moves with the ſame velocity and in the ſame direction as the eye itſelf; therefore that part of the velocity of light which is in the direction CA, is what affects the eye of the obſerver; and hence we perceive the ſtar in the direction AC or BD, which is parallel to AC. Then the angle CBD is called the *aberration*. In ſhort, CBD is the angle by which a ſtar ſeems to be removed from its true place, in conſequence both of the progreſſive motion of light, and of the motion of the earth in its orbit.

This

This compound effect being rather difficultly comprehended by beginners, I ſhall ſubjoin Dr. Bradley's own explanation, which places the phænomenon in a different light *. The doctor imagined CA, fig. 12, Plate XXVIII. to be a ray of light falling perpendicularly upon the line BD; that, if the eye be at reſt at A, the object muſt appear in the direction AC, whether light be propagated in time, or inſtantaneouſly. But if the eye be moving from B towards A, and light is propagated in time, with a velocity that is to the velocity of the eye as CA to BA, then light, moving from C to A, whilſt the eye moves from B to A, that particle of it, by which the object will be diſcerned, when the eye comes to A, is at C when the eye is at B. Joining the points B, C, he ſuppoſed the line CB to be a tube, inclined to the line BD in the angle DBC, of ſuch a diameter as to admit but one particle of light. Then it was eaſy to conceive, that the particle of light at C, by which the object muſt be ſeen, when the eye as it moves along, arrives at A, would paſs through the tube BC, if it be inclined to BD in the angle DBC, and accompanies the eye in its motion from B to A; and that it could not come to the eye placed behind ſuch a tube, if it had any other inclination to the line BD. If, inſtead of ſuppoſing CB ſo ſmall a tube, we imagine it to be the axis of a larger tube; then, for the ſame reaſon, the particle of light at C would

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* Philoſophical Tranſactions, N° 406.

not paſs through that axis, unleſs it is inclined to BD in the angle CBD. In like manner, if the eye moved the contrary way, from D towards A, with the ſame velocity, then the tube muſt be inclined in the angle BDC. Although, therefore, the true, or *real* place of an object is perpendicular to the line in which the eye is moving, yet the *viſible* place will not be ſo, ſince that, no doubt, muſt be in the direction of the tube; but the difference between the true and apparent place, will be, *cæteris paribus*, greater or leſs, according to the different proportion between the velocity of light and that of the eye. So that if we could ſuppoſe that light was propagated in an inſtant, then there would be no difference between the real and viſible place of an object, although the eye were in motion; for in that caſe, AC being infinite with reſpect to AB, the angle ACB, viz. the difference between the true and viſible place, vaniſhes. But if light be propagated in time, it is evident, from the foregoing conſiderations, that there will be always a difference between the real and viſible place of an object, unleſs the eye is moving either directly towards or from the object: and, in all caſes, the ſine of the difference between the real and viſible place of the object will be to the ſine of the viſible inclination of the object to the line in which the eye is moving, as the velocity of the eye is to the velocity of light.

The doctor then ſhews, that if the earth revolve round

round the ſun annually, and the velocity of light be to the velocity of the earth's motion in its orbit, as 1000 to 1, that a ſtar really placed in the very pole of the ecliptic, would, to an eye carried along with the earth, ſeem to change its place continually; and neglecting the ſmall difference on account of the earth's diurnal revolution on its axis, would ſeem to deſcribe a circle round that pole, every way diſtant from it 3½′; ſo that its longitude would be varied through all the points of the ecliptic every year, but its latitude would always remain the ſame. Its right aſcenſion would alſo change, and its declination, according to the different ſituations of the ſun, with reſpect to the equinoctial points, and its apparent diſtance from the north pole of the equator, would be 7′ leſs at the autumnal than at the vernal equinox.

The greateſt alteration of the place of a ſtar in the pole of the ecliptic, or which, in effect, amounts to the ſame thing, the proportion between the velocity of light and the earth's motion in its orbit being known, it will not be difficult, he obſerves, to find what would be the difference, upon this account, between the true and apparent place of any other ſtar at any time; and, on the contrary, the difference between the true and apparent place being given, the proportion between the velocity of light and the earth's motion in its orbit may be found.

Now, ſince the apparent declination of the ſtar, called ♈ Draconis, on account of the ſucceſſive propagation

propagation of light, would be to the diameter of the little circle which a ſtar would ſeem to deſcribe about the pole of the ecliptic, as 39″ to 40″,4; the half of this is the angle A C B. This, therefore, being 20″,2, AC will be to A B, that is, the velocity of light will be to the velocity of the eye (which in this caſe may be ſuppoſed the ſame as the velocity of the earth's annual motion in its orbit) as 10210 to 1; from whence it will follow, that light moves as far as from the ſun to the earth in 8′, 12″. This, Dr. Bradley obſerves, is very probably the truth, becauſe it is a medium between 7 and 11, which were the times which it had before been ſuppoſed to take up, according to different obſervations of the eclipſes of Jupiter's ſatellites. Comparing his obſervations on other ſtars, he afterwards concluded that light is propagated from the ſun to the earth in 8′, 13″; and the near agreement of his obſervations induced him to think that this ſuppoſition could not differ ſo much as a ſecond of a degree from the truth; ſo that the time which light ſpends in paſſing from the ſun to us may be determined by theſe obſervations within 5″, or 10″, which is ſuch a degree of exactneſs as we can never hope to attain from the eclipſes of Jupiter's ſatellites.

The near agreement of the reſult of Dr. Bradley's obſervations on the light of the ſtars, which we have all the reaſon to ſuppoſe that they ſhine by their own luſtre, with the reſult of Mr. Roemer's obſervations

obſervations on the light of the ſatellites of Jupiter, which ſhine by reflecting the light of the ſun, not only confirms the progreſſive motion of light, but likewiſe ſhews that the velocity of light is the ſame before as after reflection.

The aberration ariſing from the compound motion of light and of the earth, does alſo affect the planets, and the ſun; and though it be very little; yet in nice computations of occultations and other problems, this aberration muſt be calculated from the known velocities of light, the velocity and direction of the earth, and the diſtance of the planet in queſtion. The ſun's aberration in longitude is conſtantly 20″; for the earth moves through that ſpace in $8^m\ 7^s$, which is the time employed by light in paſſing from the ſun to us.

" Dr. Bradley, by his continued obſervations on the ſtars, perceived each year the period of the aberrations confirmed, according to the rules he had lately diſcovered; but beſides this, he found from year to year other differences, the conſideration of which led him to another brilliant diſcovery, that of the *nutation of the earth's axis.* This is a kind of libratory motion of the earth's axis, by which its inclination to the plane of the ecliptic is continually varying backwards and forwards, by a ſmall number of ſeconds. The whole extent of this change in the inclination of the axis, or, which is a conſequence of it, in the apparent

apparent declination of the ſtars, is about $19''$, and the period of the change is little more than nine years; or, the ſpace of time from its ſetting out from any point and returning to the ſame again, about 18 years and 7 months, being the ſame as the period of the moon's motions, on which indeed it chiefly depends, being the effect of the inequalities of the joint action of the ſun and moon upon the ſpheroidical figure of the earth, by which its axis is made to revolve with a conical motion, ſo that the extremity of it deſcribes a ſmall ellipſis, having its diameters $19'',1$, and $14'',2$, each revolution being performed in the time above-mentioned. This is a natural conſequence of the Newtonian ſyſtem of univerſal attraction, and had been hinted at by ſome, ever ſince the publication of the *Principia*." *

Thus we have pointed out the different apparent movements of the ſtars, and have ſhewn that they ariſe from the parallax, from the refraction of the atmoſphere, from the progreſſive motion of light, and from the movements of the earth. Yet it muſt be acknowledged, that independent

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* Mr. Gregory's Aſtronomy, Chap. XXII. For farther information on the ſubject of the nutation, ſee the Philoſophical Tranſactions for 1784. Dr. Maſkelyne's Aſtronomical Obſervations, 1776; and De la Lande's Aſtronomy, Vol. III.

pendent of thoſe apparent movements, ſome of the fixed ſtars have been found to have a proper though exceedingly ſmall motion. The preſent ſtate of aſtronomical knowledge cannot well account for this movement; perhaps the ſtars or whole ſyſtems, though immenſely diſtant from each other, may alſo have a mutual tendency or attraction; perhaps a congeries of ſyſtems, or the whole aſſemblage of them all, may turn round a common centre of attraction; but we muſt leave thoſe ſpeculations to poſterity.

CHAP. XII.

OF THE DIVISION OF TIME, AND OF THE EQUATION OF TIME.

ACCORDING to the common or vulgar ſignification, the *day* and the *night*, mean reſpectively the time of the ſun's remaining above the horizon, and the time of its remaining below it. For the ſake of diſtinction, this day is called the *artificial day*. The *natural day* is the time employed by the ſun in its apparent motion all round the earth, from one meridian and to the ſame again. This time is divided into 24 hours; each hour is divided into 60 minutes; each minute into 60 ſeconds; each ſecond into 60 thirds, &c. When the intervals of time are longer than one day, they may be reckoned by the number of days, and parts of a day, or by certain aſſemblages of days together, with odd days and parts of a day. Thoſe aſſemblages of days are called *weeks*, *months*, *years*, *cycles*, *periods*, *&c.*

The 24 hours, or 24 parts, of a natural day, are not always equal to the 24 parts of another natural day; or, in other words, the ſun does not always

always employ the ſame time in its apparent motion round the earth, from a given meridian to the ſame again. This, as has been explained in the preceding chapters of this volume, ariſes from the earth's orbit being elliptical, from the earth's axis being inclined to the plane of the ecliptic, and from the preceſſion of the equinoxes. But independent of the theory, the inequality of natural days is clearly manifeſted by means of the well known machines, called *clocks*, *regulators*, *time-keepers*, *chronometers*, or *longitude watches*; for by obſerving the ſun's tranſit over the meridian each day, it will be found that the ſun's centre comes to the meridian ſometimes before and ſometimes after the lapſe of ſuch 24 hours, as are ſhewn by the going of the clock, or chronometer; but the mean natural days, viz. thoſe that are between the longeſt and the ſhorteſt, are preciſely equal to the 24 hours of the clock; hence theſe are called *hours of true or mean time*, viz. the 24 equal parts of *mean days*.

That upon the whole, well regulated chronometers, are equable meaſures of time, is proved by their agreeing among themſelves, which they do within a trifling difference of a ſecond or two, and which difference may be aſcertained by the motion of the ſun itſelf, or by the time of its arrival to the meridian; for as that time, whether longer or ſhorter than the period of 24 hours of mean time, has been calculated from theory, and being meaſured by the clock at the time of the ſun's tranſit, the obſerver will eaſily perceive whether the clock indicates the ſame exceſs or defect from the 24 hours of mean time, as has been obtained by calculation, and is regiſtered in moſt almanacks. This exceſs or defect, which muſt be added to or ſubtracted from the 24 hours of mean time, or ſuch as are ſhewn by a well regulated chronometer, in order to obtain the real length of a natural day, is called the *equation of time*; and it ſometimes amounts to ſeveral minutes.

The natural day is either *civil* or *aſtronomical.* A different commencement of the civil day has been adopted by different nations. The Britiſh, French, Dutch, Spaniards, and others, begin the civil day at midnight; the ancient Greeks, Jews, Bohemians, Sileſians, with the modern Italians and Chineſe, begin it at ſun-ſetting; the ancient Babylonians, Perſians, Syrians, and modern Greeks, begin it at ſun-riſing.

The *aſtronomical day* at any place commences when the ſun's centre is on the meridian of that place, and its 24 hours are reckoned from 1 to 12; and again from 1 to a ſecond 12; diſtinguiſhing the firſt 12 by the initial letters P. M. which mean *poſt meridiem* or *in the afternoon*; and the ſecond 12 hours by the initials A. M. which mean *ante meridiem*, or *in the forenoon*. Aſtronomers, however, generally reckon through the 24 hours from noon to noon; ſo that what is commonly called the hour of 10 in the morning of April the 6th, is called by the aſtronomers the 22d hour of April the 5th;

and 3 o'clock in the morning of October the 20th, is expreſſed by the aſtronomors, October the 19th, 15^h, and ſo forth.

The ſun's daily motion in longitude, which is meaſured by an arc of the ecliptic, or its daily motion in right aſcenſion which is meaſured by the correſpondent arc of the equator, being nearly equal to 59′ 8″, it follows that the above-mentioned aſtronomical day is meaſured by the ſum of the whole equator (viz. 360°), and an arc of it equal to the ſun's daily motion in right aſcenſion (viz. 59′ 8″), which ſum is equal to 360°, 59′, 8″. For at the end of a diurnal rotation of the earth, which obſervations ſhew to be equable, the meridian comes to the ſame ſtar or point of the ecliptic at which it ſtood on the preceding noon; excepting the very ſmall difference which ariſes from the preceſſion of the equinoctial points; whereas the ſun, during that period, has removed from that ſtar or point of the ecliptic to another, which has a greater right aſcenſion by 59′, 8″; therefore he muſt deſcribe ſuch an additional arc beſides a whole circle, in order to return to the ſame meridian; hence a ſidereal day, which is the interval between two ſucceſſive returns of the ſame ſtar, to the ſame meridian, is ſhorter than a mean ſolar day by 3 minutes and 56 ſeconds of time, which 3^m, 56^s, is the time employed by the ſun in percurring the additional arc of 59′, 8″; ſo that the mean ſolar day is 24 hours, whilſt the ſidereal day is 23^h, 56^m, 4^s, according to the clock, which ſhews mean time.

The ſolar days are equal, or the mean ſolar days take place when the ſun's daily motion in right aſcenſion is 59′, 8″, which takes place about the 15th of April, the 15th of June, the 1ſt of September, and the 24th of December; ſo that at thoſe times the ſun and the clock, or the ſun-dial and the clock, agree very nearly, and of courſe no equation is wanted; at other times the ſun-dial and the clock diſagree more or leſs, and an equation is required. This equation is greateſt about the 1ſt of November, when it amounts to 16^m, 14^s.

It is evident, from what has been ſaid above, that in ſeveral aſtronomical obſervations the equation of time, beſides the other corrections for parallax, refraction, &c. muſt be duly attended to.

I need not inform the reader of the names and of the number of days which form a week.

A *month*, properly ſpeaking, is the time of a lunation, or the period of time taken up by the moon in performing its courſe in the zodiac. Another month, which more properly is the *aſtronomical month*, and is nearly equal to the above, is the time in which the ſun moves along one ſign of the ecliptic. A *civil month* conſiſts of a certain number of days, which number, however, is not always the ſame for every month, nor the ſame in all countries. The names of the twelve months, together with the

the number of days in each, as are at preſent in uſe among the greateſt number of civilized nations, are ſo well and ſo commonly known, that nothing more needs be ſaid about them in this place.

What the ſidereal, the ſolar, the anomaliſtic, and the civil years, are, has been already ſhewn in another place; but in order to preſent all thoſe meaſures of time in one point of view, we ſhall briefly repeat their lengths in this place.

The *mean tropical* or *ſolar year*, conſiſts of 365^d, 5^h, 48^m, 49^s.

The *ſidereal year* conſiſts of 365^d, 6^h, 9^m, 12^s,

The *anomaliſtic year*, which is the time employed by the earth, in going from aphelion to aphelion, conſiſts of 365^d, 6^h, 14^m, 2^s.

The *common civil year*, alſo called Julian year, ſuch as is adopted by moſt nations, conſiſts of 365 days; but every fourth year is called a *biſſexſtile* or *leap year*, and conſiſts of 366 days, viz. one day more than the common year; and this day is uſually added to the end of February; excepting, however, the laſt year of every century, not diviſible by four, which is to remain a common year of 365 days. See page 61 and 62 of this volume.

The *lunar year* conſiſts of 12 revolutions of the moon, from the ſun to the ſun again, and it contains nearly 354^d, 8^h, 48^m, 36^s.

A *cycle* is a perpetual circulation of a certain fixed and determined time. Thus the *cycle of the* *ſun* is a revolution of 28 years, in which time the days of the months return again to the ſame days of the week; the ſun's place returns to the ſame ſigns and degrees of the ecliptic on the ſame months and days, ſo as not to differ one degree in 100 years; and the leap-years begin the ſame courſe over again with reſpect to the days of the week on which the days of the months fall. The *cycle of the moon*, commonly called the *golden number*, is a period of 19 years, in which time the conjunctions, oppoſitions, and other aſpects of the moon, are within about an hour and a half of being the ſame as they were on the ſame days of the months 19 years before. The *indiction* is a revolution of 15 years, uſed only by the Romans for indicating the times of certain payments made by the ſubjects of the Republic. It was eſtabliſhed by Conſtantine, A. D. 312.

The year of our Saviour's birth, according to the vulgar æra, was the 9th year of the ſolar cycle, the firſt year of the lunar cycle; and the 312th year after his birth, was the firſt year of the Roman indiction. From this we may eaſily find the correſpondence between the ſubſequent cycles.

The *olympiads* conſiſted each of four years, and the mode of reckoning by olympiads was uſed by the Greeks. The firſt olympiad began 775 years (according to other chronologiſts 777 years) before the birth of our Saviour.

Different nations and at different times various points

points or commencements of the numeration of years have been adopted. Some reckoned from the ſuppoſed time of the creation of the world. The Romans counted from the building of Rome; the Turks reckon from the flight of Mahomet, called the *hegira*, or *Turkiſh æra*; almoſt all the nations of Europe and America reckon from the birth of our Saviour, and this is called the Chriſtian æra; the modern French reckon from the abolition of their monarchical government; other nations have uſed other æras. But of all thoſe æras the *Julian period* ſeems to be the moſt uſeful, as it includes almoſt all the other æras or periods. This Julian period conſiſts of 7980 years, which number is the product of 15, 19, and 28, viz. of the Roman indiction, of the lunar cycle, and of the ſolar cycle; and the firſt year of this period was that wherein all thoſe cycles began together.

In the following ſhort table, I ſhall ſtate the commencement or the correſpondence of the principal æras, according to the more commonly received opinion; for the preciſe times of ſeveral remarkable events have been differently ſtated, and are as yet the ſubject of controverſy; I muſt therefore refer the inquiſitive reader to the profeſſed works of chronologiſts with reſpect to thoſe points.

Table of remarkable Æras, or Periods.

	Years before Chriſt.	Years of the Julian period.
The creation of the world, according to the more common opinion	4007	706
The deluge	2351	2362
The beginning of the olympiads	775	3938
The building of Rome according to Varro	753	3961
The building of Rome according to the regiſters of the Capitol	752	3962
The æra of Nabonaſſar	746	3967
The ſuppoſed true æra of Chriſt's birth	4	4709
	Years after Chriſt.	
The Dionyſian or vulgar æra of Chriſt's birth	0	4713
The Arabian or Turkiſh hegira	622	5335
The Perſian *yeſdegird*	631	5344
The Republican French æra	1792 Sept. 22	6505

CHAP. XIII.

OF ECLIPSES, OCCULTATIONS, AND TRANSITS.

WHEN our view of a celeſtial body is obſtructed by the interpoſition of another celeſtial body, or of its ſhadow, the phenomenon is called an *eclipſe*, an *occultation*, or a *tranſit*; yet not quite indiſcriminately ſo; for the word *eclipſe* is more particularly applied to the apparent obſcuration of the ſun by the interpoſition of the moon between it and the earth; to the obſcuration of the moon by its coming within the ſhadow of the earth; and to the obſcuration of the ſatellites of other planets by their coming within the ſhadows of their reſpective primaries. The word *occultation* is more commonly applied to the diſappearance of the ſtars or planets, occaſioned by the interpoſition of the moon. The word *tranſit* is more commonly uſed to denote the paſſage of the inferior planets, Venus and Mercury, over the diſc of the ſun.

Of all thoſe phenomena, the eclipſes of the ſun and of the moon, are by far the moſt ſtriking, and have at all times excited the fears of the vulgar, and the diligent attention of the moſt enlightened part of the human ſpecies. The preſent improved ſtate of aſtronomy has brought all the particulars, which relate to eclipſes, occultations, and tranſits, within the limits of calculation, whence the times, durations, and quantities of thoſe phenomena may be foretold with wonderful accuracy.

Having elſewhere ſhewn the general nature of eclipſes, we ſhall, for the ſake of perſpicuity, collect in this chapter all the moſt eſſential particulars relative to thoſe phenomena, in order that the reader may ſee the ſubject under one point of view.

As the light of the ſun falls upon the earth, a ſhadow of the latter muſt be extended in the heavenly ſpace behind it; and this ſhadow is conical, becauſe the ſun is larger than the earth. But on the ſides of this converging or conical ſhadow, there is a diverging ſhadow, the denſity of which decreaſes in proportion as it recedes from the ſides of the former conical ſhadow; this, which is uſually called the *penumbra*, is occaſioned by the partial obſtruction of the ſun's rays in the places adjacent to the denſe conical ſhadow. Thus, in fig. 1, Plate XXIX. the rays of the ſun ASB, falling upon the earth ETF, are intercepted by it, whence the conical ſhadow EFC is formed, from no part of which the ſun can be ſeen; but adjoining to and all round this cone, there is the diverging imperfect ſhadow or penumbra EFHG, from any part of which a portion only of the ſun can be ſeen; and that

that portion of the ſun's diſc is larger according as the place is farther from the conical ſhadow EFC, hence the penumbra decreaſes in intenſity; thus at Q, the portion *z y* B of the ſun can only be ſeen, but from R, the portion *v v* B is ſeen; which portions are determined by drawing ſtraight lines from the given places to the ſun and along the ſurface F of the earth. The conical ſhadow EFC of the earth is extended much farther than the diſtance of the moon, but not near ſo far as the neareſt planet which is Mars; therefore the moon alone can come within that ſhadow.

Now let O P be a portion of the moon's orbit; then as the moon, in its motion from the weſt towards the eaſt, viz. from O towards P, enters the penumbra at O, it begins to be partly obſcured on its eaſtern ſide; the obſcuration gradually proceeds towards the weſtern ſide of the moon, and increaſes in intenſity; the moon then comes within the conical ſhadow EFC, at which time the obſcuration is greateſt. After this, it begins to emerge out of the conical ſhadow EFC, with its eaſtern ſide, and as it proceeds it becomes gradually more and more illuminated, until the end of the eclipſe, viz. until the moon is got quite out of the penumbra at P. But it muſt be obſerved, that the moon is never perfectly eclipſed; or, in other words, during an eclipſe, we never loſe ſight of the moon entirely, even when ſhe is at L, in the middle of the conical ſhadow EFC; but in that ſituation ſhe appears of a dark

dark dull red colour, which is owing to the refractive power of the earth's atmoſphere (the ſame which produces the twilight), in conſequence of which ſome of the ſun's rays which paſs cloſe to the ſurface of the earth, and through its atmoſphere, are bent or refracted by the latter, ſo as to enter the cone EFC, and in ſome meaſure diminiſh the perfect darkneſs which it would have if the earth had no atmoſphere.

By inſpecting fig. 1, and by attending to the above explanation, the following particulars will be eaſily comprehended. An eclipſe of the moon can only happen at the time of full moon, when the ſun, the earth, and the moon, are in the ſame ſtraight line; but on account of the inclination of the moon's orbit to the earth's orbit, an eclipſe cannot take place at every full moon. It can only take place when the full moon happens to be in one of the nodes of the moon's orbit, or ſo near it, as that the moon's latitude does not exceed the ſum of the moon's apparent ſemidiameter and the ſemidiameter of the earth's ſhadow, where it meets the moon's orbit. And according as that latitude is more or leſs, or nothing, ſo the eclipſe may be *partial*, *total*, or *central*.

The quantity of the moon's diſc which is eclipſed (and the ſame thing muſt be underſtood of the diſc of the ſun in a ſolar eclipſe), is expreſſed by twelfth parts, called *digits*, of that diſc, viz. the diſc is ſuppoſed to be divided by twelve parallel lines: then if half the diſc is eclipſed, the quantity of the eclipſe is ſaid to be ſix digits; if one twelfth part is obſcured, then the quantity of the eclipſe is ſaid to be of one digit, and ſo forth. And when the diameter of the ſhadow, through which the moon muſt paſs, is greater than the diameter of the moon, then the quantity of the eclipſe is ſaid to be more than 12 digits; thus, if the diameter of the moon is to the diameter of the ſhadow as 4 to 5, then the quantity of eclipſe is ſaid to be equal to 15 digits; for 4 : 5 : : 12 : 15.

The eclipſes of the moon are viſible alike from all ſuch parts of the earth as have the moon above the horizon at that time; but they are not ſeen at the very ſame time from places which differ in longitude; for inſtance, if a place B be 15 degrees weſtward of another place A, the obſerver at the latter place A, muſt ſee the commencement or the end of the eclipſe an hour later than the obſerver at B, becauſe on account of their difference of longitude when it is 10 o'clock at B, it is 11 o'clock at A, or when it is 11 at B, it muſt be 12 at A, &c. Hence, from attentive obſervations, made at two different places, of the commencement, or of the end of the eclipſe, or of the arrival of the ſhadow at any particular ſpot of the moon; the difference of longitude between thoſe two places may be determined.

The moon always enters the ſhadow with its eaſtern ſide, and comes out of it with the ſame eaſtern ſide foremoſt; for the proper motion of the moon

moon being ſwifter than that of the earth's ſhadow, the moon approaches the ſhadow from the weſt, and paſſes through it with its eaſtern ſide foremoſt, leaving the ſhadow weſtward.

The duration of a lunar eclipſe is various, but it never exceeds two hours. In order to calculate the time, duration, and quantity of an eclipſe, the following particulars muſt be known, and theſe are obtained from the almanacks and other aſtronomical tables.

The true time of the moon's oppoſition, for the particular place for which the computation of the eclipſe is intended.

The apparent time of the ſame, and for the ſame place.

The ſun's place in the ecliptic.

The moon's place in the ecliptic.

The place of the moon's node.

The moon's latitude.

The moon's diſtance from the earth, or its apparent diameter, at the time.

The ſun's horary motion; and

The moon's horary motion.

The eclipſes of the ſun take place when the moon happens to be in conjunction with the ſun, or between the ſun and the earth, viz. at the time of the new moon, at which time the ſhadow of the moon falls upon the ſurface of the earth; hence, properly ſpeaking, ſuch eclipſes ſhould be called eclipſes of the earth. But the whole diſc of the earth can never

never be entirely involved in the ſhadow of the moon, becauſe the moon is much ſmaller than the earth, and the ſhadow of the moon, being conical, the ſection of that cone at the diſtance of the earth is conſiderably ſmaller than the diſc of the moon. Thus, in fig. 2, Plate XXIX. the rays of the ſun ASB, being intercepted by the moon CLD, form the conical ſhadow CDG, which falling upon the ſurface of the earth ETF, entirely deprives the portion *i o* of the ſun's light, and of courſe the inhabitants of that portion will have a total eclipſe of the ſun, the eclipſe being central at *n*. Beyond the denſe conical ſhadow CGD, there is the inverted cone of the *penumbra* CDEF, which is occaſioned by the moon's intercepting a part only of the ſun's rays from thoſe places which fall within the penumbral cone, and are out of the denſe ſhadow CDG; thus from Z, the portion YYB of the ſun can only be ſeen; conſequently the inhabitants of the parts *o* F, and *i* E, or of the zone which goes all round the denſe ſhadow, will have a partial eclipſe, the quantity of which, for any particular place, is more or leſs, in proportion as that place is nearer to the denſe ſhadow *i* O, or nearer to the borders EF of the penumbra.

Knowing the diameters of the ſun and moon, as alſo the diſtances of the ſun from the moon and from the earth, at the time of the conjunction; the extent of the conical ſhadow, and the diameter of of its ſection at the ſurface of the earth may be eaſily calculated; or it may be drawn upon paper with conſiderable accuracy, by taking the proportional dimenſions from a ſcale of equal parts. Now from ſuch computations made at different ſituations of the moon with reſpect to diſtance, it appears that, when the moon is at its greateſt diſtance from the earth (that diſtance varying from 56 to 64 ſemidiameters of the earth) the apex of the conical ſhadow CDG does not reach the earth, as is ſhewn in fig. 3, Plate XXIX.; but the penumbra EF only falls upon the ſurface of the earth; therefore the eclipſe will be partial all over the ſpace EF; but with this difference, that whilſt at one place within EF, the inhabitants loſe ſight of one part of the ſun, at another place the inhabitants loſe ſight of ſome other part of that luminary, as may be eaſily conceived by inſpecting the figure. Thoſe who happen to be at the centre H of the penumbra, will loſe ſight of the middlemoſt part *kk* of the ſun, and a ring of light all round the moon, or only the circular edge of the ſun will at that time be ſeen. The eclipſe is then ſaid to be *annular*.

So far we have deſcribed the various phenomena as if at the time of an eclipſe the ſun, the moon, and the earth, remained in the ſame line for any length of time; but ſince that is not the caſe, and ſince the proper motion of the moon, is much quicker than that of the ſun, therefore the following particulars neceſſarily take place.

The eclipſe of the ſun always begins ſomewhere on the weſtern half of the ſun's diſc, and ends at the eaſtern; for the moon moves in that direction; and

and ſo does the ſhadow move upon the ſurface of the earth; ſo that thoſe parts of the earth which are more weſtward, will ſee the eclipſe ſooner than thoſe which are more eaſtward. Since the ſhadow of the moon, and even the penumbra, is at all times much ſmaller than the half of the earth's ſurface, the ſame eclipſe of the ſun can never be ſeen by a whole hemiſpherical ſurface of the earth; and according as the different places on that ſurface are leſs or more diſtant from the line, which paſſes through the centres of the ſun and of the moon, ſo the inhabitants of thoſe places ſee the eclipſe either partial or central, or not at all; and the particular quantities of thoſe appearances, or the digits eclipſed, may be determined by computation, from the knowledge of the diameters of the ſun and moon, their diſtances, the diſtance of the moon's node from the conjunction, and the particular ſituation of the place on the ſurface of the earth. With reſpect to the time when an eclipſe of the ſun is to take place, for it doe snot take place at every new moon, the calculation may be conducted in a manner ſimilar to that uſed for the eclipſes of the moon; the particulars that are principally requiſite, and which muſt be extracted from the aſtronomical tables, are the true time of the conjunction; the longitudes both of the ſun and of the moon; the latitude of the moon, with its horizontal parallax, and its horary motion; the apparent diameters of the ſun and the moon; and the ſun's horary motion. But with reſpect to the particular mode of performing the neceſſary calculations, I muſt refer the ingenious reader to the works written profeſſedly upon the ſcience of aſtronomy*; and ſhall only add a few other particulars, which deſerve to be remarked with reſpect to ſolar eclipſes.

"The middle of a ſolar eclipſe will not be at the ſame time in all places on the ſame meridian; for the parallax of longitude will be different in different latitudes. The exceſs of the apparent diameter of the moon above that of the ſun in a total eclipſe, is ſo ſmall, that darkneſs ſeldom continues more than four minutes in the latitude of London. In moſt ſolar eclipſes, the moon's diſc is covered with a faint light, which is attributed to the reflection of the light from the illuminated part of the earth. In total eclipſes of the ſun, the darkneſs is ſometimes ſo great as to render viſible the planets that are above the horizon, and ſtars of the firſt and ſecond magnitude. In ſuch eclipſes the moon's limb is ſeen ſurrounded with a ring which appears much brighter and whiter near the moon's body than at a diſtance from it; this ring in all reſpects reſembles the appearance of an enlightened atmoſphere, viewed from a diſtance; but whether it belongs to the moon or the ſun, is not entirely decided, though it

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* See Flamſtead's Method in Sir Jonas Moore's Syſtem of Mathematics, Vol. I. Keill's Aſtronomical Lectures, Ferguſon's Aſtronomy, Vince's Aſtronomy, and Gregory's Aſtronomy, on the Subject of Eclipſes.

it is generally ſuppoſed that it belongs to the former.

"With reſpect to the *number of eclipſes* of both luminaries, it may be obſerved, that there cannot be fewer than two, nor more than ſeven, in one year; the moſt uſual number is four, and it is rare to have more than ſix. The reaſon is obvious; for the ſun paſſes by both the nodes of the moon's orbit but once in a year, unleſs he paſs by one of them in the beginning of the year, in which caſe he will paſs by the ſame again a little before the end of the year.

"Since the nodes move backwards $19\frac{1}{3}°$ every year, they would ſhift through all the points of the ecliptic in 18 years and 225 days; and this would be the regular period of the return of the eclipſes, if any complete number of lunations were performed in it, without a fraction; but this is not the caſe. However, in 223 mean lunations, after the ſun, moon, and nodes, have been once in a line of conjunction, they return ſo nearly to the ſame ſtate again, that the ſame node, which was in conjunction with the ſun and moon at the beginning of theſe lunations, will be within 28′ 12″ of the line of conjunction, when the laſt of theſe lunations is completed; and in this period there will be a regular return of eclipſes, till it be repeated about 40 times, or in about 720 years, when the line of the nodes will be $28' \times 40$ from the conjunction, and will, conſequently, be beyond the ecliptic limits:

this

this is called the *Plinian period*, or *Caldean ſaros*; it contains, according to Dr. Halley, 18 Julian years, 11^d, 7^h, 43^m, 20^s; or, according to Mr. Ferguſon, 18 years, 11^d, 7^h, 42^m, 44^s. In an interval of 557 years, 21^d, 18^h, 11^m, 51^s, in which there are exactly 6890 mean lunations, the conjunction or oppoſition coincides ſo nearly with the node, as not to be diſtant more than 11″. If therefore, to the mean time of any ſolar or lunar eclipſe, we add this period, and make the proper allowance for the intercolary days, we ſhall have the mean time of the return of the ſame eclipſe. This period is ſo very near, that in 6000 years it will vary no more from the truth, than $8\frac{1}{4}$ minutes of a degree*."

After what has been ſaid above concerning the eclipſes of the moon, we need not ſay much with reſpect to the eclipſes of the ſatellites of the other planets; for they muſt evidently be calculated after the ſame manner, and the calculations muſt be eſtabliſhed upon ſimilar particulars; as far, however, as may be obtained, conſidering that our knowledge of the irregularities of the movements of thoſe ſatellites is as yet imperfect.

In calculating the times of the eclipſes of the ſatellites of Jupiter, which indeed are, beſides the moon, the only eclipſes of ſatellites that are no-

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* Gregory's Aſtronomy, Chap. XIX.

ticed, an allowance proportionate to the diſtance of the planet from the earth, muſt be made on account of the progreſſive motion of light, as we have elſewhere noticed; but beſides this cauſe, it has been obſerved, that when viewed by different perſons and through different teleſcopes, the eclipſes of the ſatellites of Jupiter do not appear to take place exactly at the ſame time; the reaſon of which is, that as the ſatellite is progreſſively or gradually obſcured when it enters the ſhadow of the planet, and gradually enlightened when it emerges from that ſhadow, its diſappearance in the former caſe, and its reappearance in the latter caſe, muſt be ſeen ſooner or later, according to the goodneſs of the teleſcope and the acuteneſs of the obſerver's ſight. This cauſe of error in obſervation, cannot be remedied without aſcertaining the power of the teleſcope, &c. from actual experiments, and making a ſuitable allowance.

The theory of eclipſes is not a ſubject of uſeleſs curioſity; but ſeveral eſſential advantages are derived from it. From the various phenomena of the eclipſes of the ſun and moon, we derive a confirmation of the figures and ſizes of thoſe bodies, as alſo of the earth. All the eclipſes, particularly thoſe of the moon, and of the ſatellites of Jupiter, which happen much more frequently, are of very great uſe for determining the longitudes of places on the ſurface of the earth. We may laſtly add, that the knowledge of eclipſes has been of great chronological utility, as the preciſe times of ſeveral remarkable events have been aſcertained by calculating backwards the times of eclipſes, which have been ſaid in hiſtory to have accompanied, preceded, or followed thoſe events.

The occultation of the fixed ſtars by the moon, and their reappearance, are alſo of great uſe for determining the longitudes of places upon the ſurface of the earth. Their diſappearance is ſo ſudden, that the time of it may be obſerved with great accuracy. The only difficulty which attends the ſubject of occultations, is, that the movements of the moon cannot be entirely calculated with all the preciſion which might be deſired; yet it muſt be acknowledged, that the tables of thoſe movements have of late been wonderfully corrected; ſo that the occultations as are now ſtated in the nautical almanack, and elſewhere, may be depended upon as being ſufficiently uſeful for the purpoſe of determining the longitudes of different places. For inſtance, ſuppoſe that the occultation of a certain ſtar by the moon, is, according to calculation, to take place at 11 o'clock, P. M. Greenwich time; but being obſerved from another ſituation, and making the neceſſary allowances, according to the precepts, it be found to take place at half paſt eleven, the concluſion in the laſt mentioned ſituation is 7½ degrees eaſt of Greenwich; for (by converting the time into ſpace at the rate of 15° per hour), the half hour is equivalent to 7½ degrees; and at a place which is 7½ degrees eaſtward of another it muſt be 11½ o'clock, when at the latter it is only 11.

Thoſe ſtars whoſe latitude does not exceed 6°, 36′, north or ſouth, may ſuffer an occultation from the moon, ſuch as may be obſerved from ſome part of the ſurface of the earth; but their occultations may be obſerved from all parts of that ſurface which have the moon above the horizon, when their latitudes do not exceed 4°, 32′*.

With reſpect to the tranſits of Venus and Mercury over the diſc of the ſun, we have elſewhere ſhewn that they cannot take place at every conjunction, becauſe the orbit of Venus makes an angle of 3°, 23′, 35″, and that of Mercury makes an angle of 7° with the ecliptic; in conſequence of which either of thoſe planets cannot be ſeen over the diſc of the ſun, unleſs at the time of conjunction the planet be ſo near its node as that its geocentric latitude be leſs than the apparent ſemidiameter of the ſun.

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* See the method of making the calculation for an occultation, in Vince's Aſtronomy, or in Gregory's Aſtronomy.

The chief uſe of the obſervations of thoſe tranſits, which do not frequently happen, eſpecially that of Venus, is to determine the diſtance of the ſun from the earth, or its parallax; from which and the well known analogy between the periods and the diſtances of the planets, the diſtances of all the planets may be determined, as has already been done*.

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* For the method of calculating tranſits, and other particulars relative to them, the reader may conſult almoſt any of the late writers on aſtronomy.

CHAP. XIV.

OF THE ASTRONOMICAL INSTRUMENTS, AND THEIR USE.

THE number of aſtronomical inſtruments which have, at various times, been contrived for a variety of aſtronomical purpoſes; the improvements which they have received from time to time, particularly of late years, and in this country, would form the contents of a curious hiſtory, ſuch indeed as might be both agreeable and uſeful to ſcientific perſons; but ſuch an hiſtory cannot be expected, nor indeed is required in an elementary work like the preſent; yet it would be improper to let the reader remain perfectly unacquainted with thoſe inſtruments, by the uſe of which moſt of the foregoing particulars have been determined, or may hereafter be verified. I ſhall therefore briefly ſubjoin a competent deſcription of the principal inſtruments that are at preſent uſed by aſtronomers, and ſhall, at the ſame time, add very little more than the mere definitions of ſuch other inſtruments as are either not eſſentially neceſſary, or that are too common to need a deſcription.

The principal inſtruments for a fixed obſervatory, are a large fixed quadrant, or a circular divided inſtrument, chiefly for meaſuring vertical angles; a tranſit inſtrument; an equatoreal inſtrument; a chronometer, or regulator; one or more powerful teleſcopes; a fixed zenith teleſcope, and a night teleſcope.

The *quadrant*, or *quarter of a circle*, divided into 90°, and each degree ſubdivided into minutes or ſmaller parts, has been made of various ſizes; ſome of them having a radius even of 8 or 9 or more feet in length. When thoſe quadrants do not exceed one or two, or at moſt three feet in radius, they are generally fixed upon their particular ſtands, which are furniſhed with various mechanical contrivances, that are neceſſary to place the plane of the quadrant perpendicular to the horizon, and for all the other neceſſary adjuſtments. But large quadrants are fixed upon a ſtrong wall by means of proper clamps; hence they have been commonly called *mural quadrants*, and are ſituated in the plane of the meridian of the obſervatory. In either of thoſe quadrants an index, which reaches from the centre to the edge of the arch, moves round that centre, or round a ſhort axis which paſſes through that centre, ſo as to be moveable with its extremity all round that arc, and thus point out on the diviſions of the arch, the angle which it forms with the horizon, or with the vertical line, in any given ſituation. This index carries a teleſcope, through which the obſerver looks at any particular object, whoſe altitude he wiſhes to determine.

Fig. 4, Plate XXIX. repreſents a pretty ſimple conſtruction of a ſmall moveable quadrant, and fig. 5, repreſents a mural quadrant. Of the quadrant, fig. 4, CEB, is the arch divided into 90°, and generally ſubdivided into ſmaller diviſions, ſuch as half degrees, or third parts of each degree, &c. The centre of the arch is at A, and the whole is connected together by means of ſtrong metallic bars, as is ſhewn between the letters ABC in the figure, in the centre A, a ſhort axis is fixed perpendicular to the plane of the inſtrument, and to the upper part of this axis is faſtened the index AD, which carries the teleſcope. This index generally has a ſmall lateral projection, as at E, upon which the nonius is marked, by which means the minutes or ſmaller parts of each degree may be diſcerned *. The ſcrew P, commonly called the *tangent ſcrew,* with a nut that may be faſtened to any part of the arch BC, ſcrews likewiſe into the extremity of the index, and is uſeful for moving the index gently or more accurately than by the immediate application of the hand to the index itſelf.

Since the index is ſuſpended at one end, viz. at A, if the other end D happens to be diſengaged from the ſcrew P, that lower end D of the index

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* With reſpect to the nature of the nonius or vernier, ſee page 461 of the ſecond volume of this work.

will naturally come down to C, on account of its own weight, and that of the teleſcope. Now, in order to avoid this tendency downwards, an arm Y of braſs or iron, is frequently affixed to the upper part of the index, which carries the leaden weight Z, ſufficient to balance the weight of the index and teleſcope; ſo that by this means, even when diſengaged from the ſcrew P, the index will remain in any ſituation in which it may be left. The whole frame ABC is ſupported upon a ſtrong vertical axis FS, the lower part of which turns into the pedeſtal QK*m*, and carries an index S*x*, which moves upon the divided horizontal circle Q, fixed to the pedeſtal. This ſerves to fix the plane of the quadrant in any azimuth that may be required. The lower part of the pedeſtal has three claws, with a ſcrew *m* in each; by which means the axis FS may be ſet truly perpendicular. The plummet AO, ſuſpended at A, ſerves to ſhew when the edge AC of the inſtrument is truly perpendicular, or when the firſt diviſion of the arch at C is exactly in the vertical which paſſes through the centre A of the quadrantal arc BC. The weight I of the plummet generally moves in a glaſs of water, which is fixed upon the arm GR; the object of which is to check the vibrations of the pendulum; which otherwiſe would be eaſily moved by every breath of air, and would continue to move for a conſiderable time after. I omit to mention the lenſes or microſcopes that are applied to read off the diviſions at E, and at *x*, or to ſee the coincidence of the

plummet-

plummet-line, with a dot marked upon the arc at C, as matters that need no particular deſcription.

In the eye-tube of the teleſcope AD, there are certain ſlender wires, placed in the focus of the eye-lens, and perpendicular to the axis of the teleſcope, which enable the obſerver to diſtinguiſh more accurately when an object, that is ſeen through the teleſcope, reaches the axis of the teleſcope, or as it is more commonly called, the *line of collimation*, &c. Now when the ſtars or planets are obſerved at night, thoſe wires in the eye-tube cannot be ſeen; therefore, to render them viſible, an arm or wire is fixed occaſionally at the end of the teleſcope, which arm holds a ſmall piece of ivory or card *z*, ſet aſlant to the axis of the teleſcope; for when a lighted candle or lantern is ſituated at a little diſtance, and is directed ſo as to ſhine upon the above-mentioned ivory or card, the reflection of the light from it into the tube of the teleſcope will enable the obſerver to diſtinguiſh the wires at the ſame time that he beholds the celeſtial object.

The mural quadrant, fig. 5, Plate XXIX. is a larger inſtrument like the above, excepting that it has no ſtand; and its index is prevented from bending on account of its great length, by means of metallic bars *d*, *f*, *b*, *c*. This inſtrument is firmly fixed upon a wall exactly in the plane of the meridian of the obſervatory, for which purpoſe it has

clamps,

clamps, ſcrews, and other adjuſtments. It has likewiſe a plummet.

This undoubtedly is the principal inſtrument of an obſervatory; for by obſerving the times by the clock, of the arrival of any celeſtial object to the meridian, the right aſcenſion of that object is had immediately; and its declination is ſhewn at the ſame time by the index of the quadrant upon the divided arch; deducting the inclination of the equator, which is given by the latitude once aſcertained of the obſervatory. It is by this means that exact catalogues of the places of the fixed ſtars have been made.

The principal defects of thoſe quadrants are the change of ſhape, which they frequently ſuffer from the weight and ſtreſs of their own parts, and the difficulty of determining the error which is introduced amongſt the diviſions of the arch from that change of ſhape.

Principally with a view of remedying thoſe defects, the late improved ſtate of mechanics has introduced whole circles inſtead of quadrants; and theſe are fixed upon their own particular ſtands, quite independent of a wall. The index, with the teleſcope, of thoſe circular inſtruments is as long as the diameter of the divided circle, and has two nonius diviſions at its two extremities, which point to the like diviſions on two oppoſite parts of the circle, provided the inſtrument be exact; otherwiſe by by their pointing to diſſimilar diviſions, they inſtantly manifeſt the incorrect ſtate of the diviſions, or the derangement of the parts of the inſtrument.

I ſhall not ſubjoin a particular deſcription of ſuch circular inſtruments, firſt, becauſe it is not eſſentially neceſſary for our preſent purpoſe; and, ſecondly, becauſe it would take up more room than we can conveniently allow it in this work. A very good deſcription, by the Rev. F. Wollaſton, of an excellent inſtrument of this ſort made by Mr. Cary, is to be found in the ſecond part of the volume of the Philoſophical Tranſactions for the year 1793.

The *tranſit inſtrument* conſiſts of a teleſcope of any convenient length, fixed at right angles to an horizontal axis, which axis is ſupported at its two extremities; and the inſtrument is generally ſituated, ſo that the line of collimation of the teleſcope may move in the plane of the meridian. The uſe of this inſtrument is to obſerve the preciſe time of the celeſtial bodies paſſage acroſs the meridian of the obſervatory.

Fig. 6, Plate XXIX. exhibits a tranſit inſtrument. NM is the teleſcope, in the eye-tube of which a ſyſtem of parallel wires, ſuch as is repreſented at NI is ſituated in the focus of the eye-lens. FE is the horizontal axis, in the middle of which the teleſcope is ſteadily fixed; ſo that by moving the teleſcope, the axis is forced to turn round its two extremities E and F, which reſt in the notches of two thick pieces, T, S, of bell metal, ſuch as are delineated ſeparately, and magnified at N. II. and III. Thoſe pieces are generally fixed upon two pillars, either of caſt iron, or, which is better, of ſtone, as are ſhewn in the figure; and they are conſtructed ſo as to be ſuſceptible of a ſmall motion by means of ſlides and ſcrews, viz. the piece T backwards and forwards, and the piece S upwards and downwards; by which means the axis EF of the inſtrument may be ſet, and cauſed exactly horizontal, to move perpendicular to the plane of the meridian. In order to verify the firſt of thoſe requiſites, viz. to ſee whether the axis is truly horizontal, the long ſpirit-level PQ is ſuſpended upon it by means of the metallic branches PO, and QR; and the ſituation of the bubble in it will immediately ſhew whether the axis be truly horizontal, or which way it inclines, and of courſe where it muſt be raiſed or depreſſed. The other requiſite, viz. whether the axis be perpendicular to the plane of the meridian, or not, may be verified by various means, the beſt of which is by obſervations on thoſe circumpolar ſtars, which never go below the horizon of the obſervatory. Thus, obſerve the times by the clock, when a circumpolar ſtar, ſeen through the teleſcope NM, croſſes the meridian both above and below the pole; and if the times of deſcribing the eaſtern and weſtern parts of its circuit are equal, the teleſcope is then in the plane of the meridian, conſequently the axis EF is perpendicular to that plane; otherwiſe the notched pieces T and S, which ſupport the extremities E, F, of the axis, muſt be moved accordingly, or until upon obſervation it be found that the above-mentioned times of the ſtars' ſemi-revolutions be equal*.

The cylindric extremity F is perforated, and the perforation paſſes through the half of the axis, and reaches the inſide of the teleſcope; that ſide of the teleſcope tube, which is exactly facing F, being alſo perforated. Within the ſaid tube, and directly oppoſite to the perforation of the end F, a plane reflector, or a flat piece of ivory, is fixed, making an angle of 45°, with the axis of the teleſcope, and having an hole through it large enough to admit all the rays paſſing from the object-glaſs to the eye-glaſs of the teleſcope.

When ſtars or other celeſtial objects are to be obſerved in the night time, a ſmall lantern Y is ſet upon a ſtand juſt before the perforation of the extremity F, ſo as to throw the light within the axis, and upon the ſlant reflector within the tube of the teleſcope, whence it is reflected upon the wires in the eye-tube M, and renders them viſible. By placing the lantern nearer to, or farther from the

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* When the inſtrument has been once ſo adjuſted, a mark may be made upon a houſe, or rock, or poſt, at ſome diſtance from the obſervatory, ſo that when viewed through the teleſcope, this mark may appear to be in the direction of the axis of the teleſcope; by which means the correct ſituation of the inſtrument may afterwards be readily verified.

extremity F, the obſerver may illuminate the wires ſufficiently for the purpoſe, and not too much.

To the other extremity E, of the axis, a divided circle, or ſometimes a ſemi-circle, is fixed, which turns with the axis; the index being fixed to the pillar which ſupports the axis. Sometimes the ſituation of thoſe parts is reverſed; viz. the circle is faſtened to the pillar, or to the braſs piece which ſupports the axis, and the index is faſtened to the extremity E of the axis. The uſe of this circle is to place the teleſcope in the direction of any particular celeſtial body, when that body croſſes the meridian; which inclination is equal to the collatitude of the place, more or leſs the declination of the celeſtial body, according as that declination is north or ſouth.

The *equatorial inſtrument* is not ſo generally to be found in aſtronomical obſervatories; yet, when properly conſtructed, it anſwers ſeveral uſeful purpoſes; it ſerves almoſt inſtead of all other inſtruments, and ſaves a good deal of calculation in ſeveral caſes; hence the portable equatorial inſtruments, have frequently been called *portable obſervatories.*

The principal parts of an equatorial inſtrument, are an axis fixed in a proper frame, ſo as to ſtand parallel to the axis of the world, and to turn round its two extremities, as if it were the axis of the earth upon its two poles. A circle divided into degrees,

degrees, and likewiſe into 24 equal parts or hours, with the ſubdiviſions, &c. is fixed perpendicularly to, and about the middle of the axis. Therefore, this circle is in the plane of the equator, and it is on this account that the inſtrument has been called an *equatorial*. Upon the ſame or principal axis there is another circle, or a ſemi-circle, which moves in the plane of the axis, conſequently perpendicular to the equatorial circle. This vertical circle carries the teleſcope, and is called the *declination circle*. Now if a celeſtial body move in the equator, then the declination circle muſt be ſet at 0°; viz. the teleſcope is ſet parallel to the equatorial circle; and turning the whole inſtrument round its principal axis, ſo far from the meridian as the celeſtial body in queſtion is from it, you will ſee that object directly through the teleſcope. But if the given body have any declination, viz. if it be not exactly in the equator, then the declination circle with the teleſcope muſt be ſet accordingly, &c. Such, in ſhort, are the principal parts of an equatorial inſtrument for a fixed obſervatory, where thoſe parts are adapted to maſonry work, or to other ſteady ſupports. But a portable equatorial muſt have ſome other parts, which are neceſſary for rectifying it according to the latitude of any required place, for holding the whole machine ſteadily, &c.; hence it is furniſhed with a ſtand, an horizontal circle with ſpirit levels, &c. I do not

not attempt to delineate or to deſcribe all the uſes of an equatorial, as our limits do not admit of it.

Various arrangements of the above-mentioned parts have been adopted by various artiſts; but the beſt inſtruments of the ſort, both portable and for a fixed obſervatory, were unqueſtionably contrived and executed by that great mechanical genius, the late Mr. Jeſſe Ramſden. A ſhort deſcription of his portable equatorials was ſome years ago publiſhed by itſelf, and has been tranſcribed in various dictionaries of arts and ſciences. The beſt large inſtrument of the kind, as far as I know, which was likewiſe conſtructed by Ramſden for Sir George Shuckburgh, is now in the poſſeſſion of the ſame, who has publiſhed a very accurate deſcription, and a delineation of it in the Philoſophical Tranſactions for the year 1793.

Of all the different ſorts of chronometers, or time-keepers, a pendulum-clock, when properly conſtructed, is undoubtedly capable of the greateſt accuracy; it being liable to fewer cauſes of obſtruction or irregularity; therefore ſuch machines are moſt recommendable for an obſervatory. The ſituation of this clock muſt be near the quadrant, and near the tranſit inſtrument; ſo that the obſerver, whilſt looking through the teleſcope of any of thoſe inſtruments, may hear the beats of the clock and count the ſeconds.

I need hardly obſerve with reſpect to teleſcopes, that they are of very great uſe in an obſervatory. Indeed a teleſcope for the ſame can never be too good or too large; and it ſhould be furniſhed with micrometers, with different eye-pieces, &c.; but as a large inſtrument of that ſort is not eaſily managed, nor is always required, ſo there ſhould be two or three teleſcopes of different ſizes and different powers in every obſervatory. With reſpect to the conſtruction of teleſcopes enough has been ſaid in the third volume of this work; but I ſhall only obſerve in this place, that one at leaſt of the teleſcopes ought to be fixed upon an axis which may move parallel to the axis of the earth; for in this conſtruction the celeſtial bodies may, with the teleſcope, be eaſily followed in their movements, as the hand of the obſerver is, in that caſe, obliged to move the teleſcope in one direction only.

A pretty good teleſcope, placed truly vertical in an obſervatory, is likewiſe a very uſeful inſtrument; as the aberration of the ſtars, latitude of the place, &c. may be obſerved and determined by the uſe of ſuch an inſtrument, with great eaſe and accuracy.

The night teleſcope is a ſhort teleſcope, which magnifies very little; but it collects a conſiderable quantity of light, and has a very great field of view; it therefore renders viſible ſeveral dim objects, which cannot be diſcovered with teleſcopes of conſiderably

ſiderably greater magnifying powers; and hence it is very uſeful for finding out nebulæ, or ſmall comets, or to ſee the arrangement of a great number of ſtars in one view.

The principal inſtruments that are at preſent uſed for marine aſtronomy, or for the purpoſes of navigation, are that incomparably uſeful inſtrument called *Hadley's ſextant*, or *quadrant*, or *octant*; a portable chronometer; and a pretty good teleſcope. With thoſe few inſtruments, the latitudes, longitudes, hours of the day or night, and ſeveral other problems uſeful to navigators, may be accurately ſolved. The deſcription and the various uſes of Hadley's ſextant, may be found in all the works on navigation of the laſt 30 or 40 years, as alſo in all the modern dictionaries of arts and ſciences. I ſhall not ſay any thing with reſpect to other inſtruments of leſs eſſential uſe; ſuch as a zenith ſector, an equatorial ſector, an equal altitude inſtrument, ſun-dials, &c.*

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* With reſpect to ſun-dials, I muſt not omit to recommend the uſe of what is called the univerſal ring-dial, to thoſe gentlemen who, in travelling, wiſh to ſet their watches within four or five minutes of common time, for common purpoſes; which in moſt country places, where even the church-clock is much out of the true time, cannot be eaſily accompliſhed. The ring-dial when properly conſtructed, and from four to ſix inches in diameter, is eaſily uſed in any part of the world; is a cheap, very portable, and durable inſtrument; and, when the ſun ſhines, it ſhews the time of the day within leſs than five minutes; allowing for the equation of time, which is ſtated in almoſt every almanack.

Under the title of aſtronomical machines, ſome writers do alſo reckon orreries, planetariums, globes, machines for ſhewing eclipſes or tranſits, &c. but thoſe only ſerve to illuſtrate the theory of aſtronomy, and as ſuch they are undoubtedly of uſe in a lecture room, or to inſtruct novices. For this purpoſe I would give the preference to a pair of globes; for theſe are neither very expenſive, nor eaſily put out of order; and are, at the ſame time, uſeful for the ſolution of a great many problems, as will be ſhewn in the next chapter.

An orrery is a very fit machine to ſhew the ſyſtem of the world, and ſome of them have been made at an enormous expence, with a great complication of wheels and other parts, by which means they have imitated the principal movements of the celeſtial bodies; but even the beſt of them fall very ſhort of real accuracy; and of courſe they are quite unfit for the purpoſes of calculating the future ſituations of the celeſtial bodies. With reſpect to the deſcription of orreries, planetariums, &c. I muſt refer the reader to the works of other authors, eſpecially to Ferguſon's Aſtronomy, and to his Lectures; as alſo to the various tracts of Benjamin Martin.

CHAP. XV.

THE USE OF THE GLOBES, AND THE SOLUTION OF VARIOUS ASTRONOMICAL PROBLEMS.

TWO globes, one to repreſent the celeſtial ſphere, and the other to repreſent the ſurface of the earth, are commonly made for the purpoſe of inſtructing ſtudents in aſtronomy and geography. They are made of various ſizes, and have been variouſly mounted in frames furniſhed with magnetic needles, and a variety of extra pieces, intended by the workmen to anſwer different purpoſes. Thoſe which are delineated in fig. 7 & 8, Plate XXIX. are of the moſt uſual form, and ſuch as are quite ſufficient for the purpoſe of illuſtration, and for the ſolution of the problems which may be expected to be ſolved by means of the globes. And here I muſt once more requeſt the reader to recollect that the circles, poles, &c. which are either delineated upon, or annexed to the frames of thoſe globes, are by no means exiſting in nature; but they are ideal circles, or lines, or points, or zones, which are of uſe only for expreſſing our ideas, or meaſures, &c. On the real globe of the earth there is only the diſtinction of of land and water. In the heavens we perceive the ſun, the moon, the fixed ſtars, the planets, and now and then a comet; which bodies are undoubtedly at different diſtances from us; but ſince to common ſight they appear to be all equally diſtant, therefore they are delineated upon the ſurface of a globe; and, if conveniency would allow it, they ought to be delineated on a concave ſpherical ſurface.

With reſpect to the aſtronomical problems, which muſt be ſolved by calculation, or by the uſe of inſtruments, I ſhall add in the note a few of them only that are of more common uſe and leſs operoſe. It would be impracticable to inſert a complete collection of ſuch problems in this work, and the reader, who is deſirous of going deeper into the ſcience of aſtronomy, will find abundance of them in the works written profeſſedly upon that ſcience, ſuch as De la Lande's, De la Caille's, Vince's, Gregory's, and others (1).

The

(1.) I. *To find the Meridian of the Place of Obſervation, or to draw a Meridian Line.*

A line drawn from the floor of a room or elſewhere, and in the plane of the meridian, ſo that the rays of the ſun coming along the edge of a window, or through a hole in the adjoining wall perpendicularly above one end of the line, may be upon that line whenever the ſun is in the meridian at

The ſtands, with the frames which ſupport the globes, are ſo ſimple, and ſo evident in the figure, as

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at noon, is of great uſe for rectifying a globe, for ſituating a moveable quadrant in certain caſes, for regulating a common watch, &c.

The eaſieſt method of delineating it is as follows: On an horizontal plane deſcribe three or four concentric circles; and placing a convenient ſtand near thoſe circles, let a plummet, as BC, fig. 9, Plate XXIX. conſiſting of a thread, with a leaden ſhot at its lower extremity, be ſuſpended from a projection AB of the ſaid ſtand, ſo that its lower extremity C may be juſt over, but not touch, the common centre of the circles. A knot muſt be made ſomewhere, as at K, in the thread of this pendulum. When the ſun ſhines in the morning, obſerve where the ſhadow of the knot K touches one of the circles, as for inſtance at D, and draw the line D C, viz. from the centre C to the mark D. After this time, the ſhadow of the knot will be found to fall within the circle until a certain time, after which, viz. in the afternoon, it will again approach that circle. Now when you find that the ſaid ſhadow falls upon the ſame circle, as at F, mark that place, and draw another line CF from the centre C to it. Laſtly, biſect the angle DCF, and the line of diviſion CE is the meridian line, or line in the plane of the meridian of the place; for the projection of the ſhadow of CK upon the horizontal plane, is longer or ſhorter, according to the various elevations of the ſun; conſequently it muſt be equally long when the ſun is at equal altitudes, viz. equally diſtant from the meridian. Therefore the middle ſituation CE between the two ſituations DC, FC, muſt be the true meridian line. This operation proceeds upon the ſuppoſition as to require no particular deſcription. Each of thoſe ſtands ſupports, and is firmly fixed to, the broad

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poſition that the ſun is equally high above the horizon, at equal times from noon, which is not exactly the caſe, becauſe the ſun is continually changing its declination; yet that change is not ſo great as to occaſion any ſenſible error in the above-mentioned operation. The beſt time of the year for drawing a meridian line is about Midſummer; the daily or hourly change of the ſun's declination at that time, being very little.

When a meridian line has thus been drawn, another meridian line, in a more convenient ſituation near the ſame place, may be eaſily drawn. Thus ſuſpend a thread and plummet juſt over the ſouth end of the known meridian line, and ſuſpend another plummet over the ſouth end of the intended meridian line. When the ſun ſhines, let an obſerver give notice when the ſhadow of the firſt mentioned plummet line falls exactly upon the known meridian line, and at the ſame inſtant let another perſon mark two points in the ſhadow of the ſecond pendulum, viz. upon the plane where that other ſhadow is projected. Then a line drawn through thoſe two marked points, is the other meridian line ſought. A meridian line thus drawn, may be corrected by repeating the above-mentioned operation at other opportunities.

II. *To find the Latitude of the Place of Obſervation, and conſequently the Elevation of the Pole for that Place.*

By means of a quadrant, find the ſun's apparent meridional altitude; viz. the greateſt altitude above the horizon that the ſun does reach on the day of obſervation; and in order to deduce broad circular piece H *b*, which repreſents the horizon. M*m* is a braſs circle, which fits two notches made

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deduce the true altitude from this, which is the apparent altitude, you muſt apply the following corrections, viz. 1ſt, If you have obſerved the altitude of the ſun's upper or lower limb, you muſt accordingly add or ſubtract the ſemi-diameter of the ſun's diſc (which is given in the nautical almanack for every day) ſo as to have the altitude of the ſun's centre. 2dly, Subtract the refraction correſpondent to the obſerved altitude; and, 3dly, add the ſun's parallax in altitude (which particulars are to be had from the nautical almanack, and from the tables requiſite to be uſed with it, from which ſome of the following problems are taken), and the reſult is the correct meridional altitude of the ſun's centre. Subtract this corrected altitude from 90°, and the remainder is the true diſtance of the ſun's centre from the zenith; which is to be called north or ſouth, according as the zenith of the place is north or ſouth of the ſun's centre. Take the ſun's declination for the day of obſervation, out of the almanack, obſerving if it be north or ſouth declination. Then if the zenith diſtance and the declination be both north or both ſouth, add them together; but if one be north, and the other ſouth, ſubtract the leſs from the greater; and the ſum in the firſt caſe, or the difference in the ſecond caſe, is the latitude of the place, of the ſame name with the greater, viz. north or ſouth.

In correcting the apparent or obſerved altitude, ſome other correction is ſometimes neceſſary to be applied, which muſt be derived from the nature of the inſtrument with which the altitude is taken; for inſtance, if the obſervation be made with an Hadley's ſextant, and an artificial horizon, you muſt take made in the horizon H *h*. It is fixed perpendicularly to it, and may be moved vertically, ſo that any

part

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take the half of the angle which is ſubtended at the eye by the ſun and by its reflected image. If you obſerve the altitude at ſea, and make uſe, according to cuſtom, of the apparent horizon or boundary of the ſea, you muſt ſubtract what is called the *dip of the horizon* (the quantity of which is found in the table requiſite to be uſed with the nautical almanack); for according as the deck of the ſhip is more or leſs elevated above the ſurface of the ſea, ſo the horizon appears to be more or leſs depreſſed.

Example. On the 13th of Auguſt 1802, the obſerved meridional altitude of the ſun's upper limb was	53°	54′	1″
The ſun's ſemi-diameter, which muſt be ſubtracted - - - -	0°	15′	51″
	53°	38′	10″
The refraction, which muſt be ſubtracted	0°	0′	43″
	53°	37′	27″
The parallax in altitude, which muſt be added - - - - -	0°	0′	6″
and the ſum, viz. 53° 37′ 33″, is the corrected elevation, which being ſubtracted from 90°, leaves the north zenith diſtance equal to - - - -	36°	22′	27″
The declination, which, being likewiſe north, muſt be added - - -	14°	33′	10″
and their ſum is the north latitude of the place of obſervation, viz. - - -	50°	55′	37″

III. *To*

part of it may be placed above the horizon; one half always remaining below the horizon. The globe is furniſhed with an axis, the extremities of which, or poles, N, S, paſs through two ſockets, or holes, made in the braſs circle M *m*; and as the globe may be turned round that axis, and of courſe any part of its ſurface may be ſituated under the braſs

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III. *To find the Latitude of the Place from the obſerved meridional Altitude of a fixed Star.*

The meridional or greateſt altitude of a ſtar above the true horizon, is to be obſerved in the ſame manner as the altitude of the ſun; but as the fixed ſtars have no apparent diameter, nor any ſenſible parallax, therefore the only correction that can be applied to the apparent, in order to obtain the corrected altitude, is the effect of refraction. Then proceed as has been ſaid in the preceding problem, viz. ſubtract the corrected altitude from 90°, and the remainder is the zenith diſtance, which is north or ſouth, according as the zenith is to the north or to the ſouth of the ſtar at the time of obſervation. Take the ſtar's declination out of the tables requiſite, &c. obſerving whether it be north or ſouth. Then if the zenith diſtance and declination be both north or both ſouth, add them together; but if one be north, and the other ſouth, ſubtract the leſs from the greater, and the ſum or difference will be the latitude of the place of obſervation.

Example. The meridional altitude of the ſtar Procyon was obſerved at ſea with an Hadley's ſextant, and it appeared to be 77° 27′ 15″, the zenith of the place being ſouth of the braſs circle M *m*; therefore this circle is called the *univerſal meridian*, or *the brazen meridian*, in diſtinction from the meridians which are delineated on the ſurface

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the ſtar, and the height of the obſerver's eye being 22 feet above the ſurface of the ſea. What was the latitude?

Apparent meridional altitude of Procyon -	77°	27′	15″
For the dip of the horizon, correſpondent to 22 feet of the obſerver's altitude, ſubtract	0°	4′	28″
and there remains - - -	77°	22′	47″
Refraction, which muſt be ſubtracted -	0°	0′	13″
and there remains the true altitude of Procyon - - - - =	77°	22′	34″
which being ſubtracted from 90°, leaves the true ſouth zenith diſtance of Procyon =	12°	37′	26″
The declination of Procyon, which being north, muſt be ſubtracted - -	5°	46′	39″

and the remainder, viz. 6° 50′ 47″, is the latitude ſouth of the ſhip at the moment of taking the ſtar's meridional altitude.

IV. *To find the apparent Time by means of celeſtial Obſervations.*

This uſeful problem may be ſolved various ways, of which however I ſhall ſubjoin ſuch only as are leſs operoſe.

With a fixed inſtrument, ſuch as a quadrant or a tranſit-inſtrument duly ſituated in the plane of the meridian, the exact time of apparent noon may be readily aſcertained; for you need only obſerve, when the centre of the ſun is exactly in the axis of the teleſcope. Alſo other times of the day, or of ſurface of the globe itſelf, and which are the meridians of thoſe places only over which they are drawn.

The

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the night, may be aſcertained by obſerving the meridian paſſage of ſome fixed ſtar or planet, whoſe diſtance from the ſun is known.

Though to obſerve the arrival of the ſun's centre to the axis of the teleſcope may at firſt ſight appear to be an operation ſufficiently ſimple; yet as the practitioner will probably meet with ſome difficulty, I ſhall add the following directions:

In the eye-tubes of the teleſcopes of quadrants, circular inſtruments and tranſits, there always are certain perpendicular and parallel wires (generally five), by means of which the time of the approach of the ſun's limb may be accurately obſerved; whence the time of the ſun's centre being in the meridian may be determined. This time muſt be eſtimated by means of a clock or chronometer; or, in other words, the obſerver is to find what hour, minute, ſecond, and part of a ſecond, is ſhewn by the clock when the ſun's centre is upon the meridian; then, by applying the equation of time for that day, in which the obſervation is made, he will aſcertain whether the clock is right, or how much it deviates from mean time. In order to make the obſervation, ſet the teleſcope of the tranſit-inſtrument to the proper altitude, *viz.* the altitude which the ſun muſt have at noon on that day, and which is had by taking the ſum or difference of the colatitude of the place and the ſun's declination for that day, according as they are of the ſame or of different denomination. Then a few minutes before noon apply your eye (defended

The brazen meridian, being of a conſiderable thickneſs, cannot repreſent a real meridian, which is not more than a line; therefore one ſurface or one

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(defended by a dark glaſs) to the teleſcope, and wait till you ſee the firſt limb of the ſun enter it; which will be apparently on the weſt ſide, becauſe thoſe teleſcopes, being of the aſtronomical kind, invert the objects. When this happens, let your aſſiſtant attend to the watch; and, when the firſt limb of the ſun touches the firſt wire, bid him mark the ſecond and part of a ſecond, which is ſhewn by the watch; and which muſt be ſet down in the firſt column of a paper that contains five columns, ready ruled for the purpoſe. He muſt then prefix the minute, and attend again to the watch. When the ſun's firſt limb arrives at the ſecond wire, bid him again to mark the ſecond, &c. which muſt be ſet down in the ſecond column of the paper, and after having prefixed the minute, he muſt attend again to the watch. And in this manner the times, when the ſun's firſt limb arrives at every one of the wires, muſt be obſerved and noted down in its proper column. The times when the ſecond limb arrives at each of the five wires muſt be obſerved in the ſame manner, and written in the proper columns under thoſe of the firſt. If the wires in the focus of the teleſcope be ſo diſpoſed, that there is not time to obſerve the firſt limb at all the five wires, before the ſecond limb arrives at the firſt wire, the obſervation of the firſt limb at the fifth wire muſt be omitted; and, in this caſe, the obſervation of the ſecond limb at the firſt wire may be omitted alſo, as it will be of no uſe.

The mean of the times, when the two limbs of the ſun were at the middle wire, will be the time of apparent noon by one ſide only of it muſt be conſidered as the meridian; and, in fact, the holes for the extremities of the axis are not made in the middle of the thickneſs

of

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by the watch; and if the wires are equi-diſtant (as they ought to be), the mean of the two times, when the firſt limb was at the firſt wire, and the latter limb at the fifth wire, will alſo be the time of noon. Alſo the mean of the two times, when the firſt limb was at the ſecond wire, and when the latter limb was at the fourth wire, will be the time of noon. Likewiſe the mean of the times when the firſt limb was at the fourth wire, and the latter limb was at the ſecond wire, will be the time of noon. If the firſt limb was obſerved at the laſt wire, and the latter limb at the firſt, the mean of theſe two obſervations will alſo be the time of apparent noon: and the mean of all theſe reſults, if they differ as they moſt likely will, is the time of apparent noon by the watch. This done, take the equation of time for the day of obſervation from the almanack, and add or ſubtract it, according as is mentioned in the almanack, to the above-mentioned noon time, and the difference of the reſult from the 12 o'clock hour is the acceleration or retardation of the watch. Thus, if by the obſervation of the tranſit the apparent noon be at $12^{h}\ 3'$ by the watch, and the equation to be ſubtracted is $2'\ 30''$, you muſt ſubtract $2'\ 30''$ from $12^{h}\ 3'$, and the remainder is $12^{h}\ 0'\ 30''$, which ſhews that the watch is $30''$ too faſt.

The above-deſcribed obſervation may be performed by a ſingle perſon without any aſſiſtant, provided he has a clock ſo near the inſtrument as to hear the beats of its pendulum, and count the ſeconds whilſt he is looking through the teleſcope; for he will have quite time enough to mark down the times of the ſun's approach to the different wires.

A ſecond

of the circle M *m*, but by means of two projections of braſs, they are made ſo as to be even with the above-mentioned ſurface. This ſame ſurface of the braſs

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A ſecond method of finding the time of the day when the latitude and longitude of the place of obſervation, the ſun's declination at noon, and its altitude as taken by a quadrant, at any time, are known, is as follows:

Correct the obſerved altitude for the effects of refraction and ſemidiameter of the ſun (according as the altitude of its upper or lower limb has been obſerved), ſubtract the natural ſine of the corrected altitude from the natural ſine of the meridian altitude (the meridian altitude of the ſun is the ſum or the difference of the colatitude of the place and the ſun's declination, according as they are of the ſame or of different denomination); find the logarithm of the remainder, to which add the logarithmic ſecant of the latitude of the place, and the logarithmic ſecant of the ſun's declination; their ſum, rejecting 20 from the index, muſt be ſought for in table XVI. of the table requiſite to be uſed with the nautical almanack, under logarithmic riſing, and the time correſponding to it, is the apparent time from the neareſt noon, when the ſun's altitude was obſerved; conſequently, if the obſervation be made in the forenoon, the time, thus found, muſt be taken from 24 hours, and the remainder will be the apparent time from the noon of the preceding day.

Example. On the 5th of March 1780, in the afternoon, in latitude 16° 24′ north, and longitude 138° eaſt, the altitude of the ſun's lower limb was obſerved to be 47° 8′ 44″. What was the apparent time when the obſervation was made?

The

braſs circle, M*m*, is divided into four quadrants of 90° each; two of which are reckoned from M, viz. from the middle, or where the equator cuts the meridian,

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The ſun's obſerved altitude - -	47° 8′ 44″
Refraction to be ſubtracted - -	0° 0′ 53″
	47° 7′ 51″
The ſun's ſemidiameter to be added -	0° 16′ 9″
The true altitude of the ſun - -	47° 24′ 0″

Now with reſpect to the declination, it muſt be remarked that in the nautical almanack, the declination is given only for the noon of each day at the meridian of Greenwich; but as the ſun's declination is altering continually, therefore the declination, as given in the almanack, muſt be altered according to the longitude of the place of obſervation, and the time of the day nearly. In order to facilitate this reduction of the declination, a table, viz. table VI. is given in the tables requiſite, &c. by means of which the declination, as given in the nautical almanack for noon at Greenwich, may be reduced to the declination for any time under any other meridian.

From this table, the declination for the meridian of the place of obſervation, and for the time of making the obſervation (which was eſteemed to be nearly 2½ P. M.) was ſouth 5° 48′ 7″.

Now, as the declination is ſouth, and the colatitude north, the leſſer muſt be ſubtracted from the greater, viz.

	73° 36′
	5° 48′
and you have the meridional altitude - -	67° 48′

The

ridian, towards each pole; the other two quadrants are reckoned from the poles towards the other interſection *m*, with the equator. When the globe is rectified

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The natural ſine of the meridional altitude, viz. of 67° 48′ is	92587
from which ſubtract the natural ſine of the correct altitude, viz.	73610
and the remainder is	18977
whoſe logarithm is	4,27823
to which add the logarithmic ſecant of the declination	10,00223
and the logarithmic ſecant of the latitude	10,01804
	24,29850

Reject 20 from the index of the ſum, and the remainder, viz. 4,29850, muſt be ſought for in table XVI. of the requiſite tables, under the column of logarithms riſing, and againſt it you will find the correſpondent time, which is the time of making the obſervation, viz. $2^h\ 27'\ 2''$.

V. *Having the Latitude of the Place of Obſervation, to find its Longitude.*

It has been mentioned in the preceding chapters of this volume, that the longitude of one place from another may be aſcertained by various methods. Thoſe methods may be reduced to four, viz. it may be aſcertained, 1ſt, by obſerving the time of an eclipſe of a ſatellite of Jupiter; but this can only be done on land, when ſuch eclipſes take place, and the weather is ſufficiently clear; 2dly, by obſervations made at the time of an eclipſe of the ſun or of the moon; 3dly, by means rectified for experiment, this divided ſide is uſually turned towards the eaſt, and the north pole, N, towards the real north.

The

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means of a time-keeper or chronometer; and 4thly, by lunar obſervations, viz. by obſerving the diſtance of the moon from the ſun or from ſome fixed ſtar; which two laſt methods may be uſed almoſt at all times.

Reſpecting the firſt and ſecond method, enough has been ſaid in the preceding chapters. With reſpect to the fourth, which is the moſt difficult and operoſe, I muſt refer the reader to the modern aſtronomical works, and eſpecially to the tables requiſite to be uſed with the nautical almanack, where he will find the lunar method clearly and correctly deſcribed; whilſt I ſhall only briefly deſcribe the third method, viz. by the uſe of a time-keeper.

"If a chronometer or time-keeper be regulated to keep mean time exactly, and be ſet to the mean time at the meridian of one of the two places, whoſe difference of longitude is required; for inſtance, be ſet to mean time at the meridian of Greenwich obſervatory. It is evident that ſuch a chronometer will continue to ſhew the mean time at that meridian as long as it continues to go at the ſame rate, whatever place it may be carried to; conſequently, if a watch ſo regulated, be kept on board a ſhip, it will always ſhew the mean time at the firſt meridian. Hence, if the mean time be found in the ſhip, under any other meridian, by the preceding problem, the difference between it and the time ſhewn by the chronometer, when the ſun's altitude was obſerved, being turned into degrees and minutes, at the rate of 15° to an hour, will be the longitude of the place where the ſun's altitude was obſerved."

It

The horizon H *b*, which is generally of wood covered with paper, has its upper ſide divided with ſeveral circles; the innermoſt of which is divided into 360°; then come the twelve ſigns of the zodiac, diſtinguiſhed by their names and characters, and each ſign is divided into 30°.

It is not, however, abſolutely neceſſary that the chronometer ſhould either be ſet preciſely to mean time at the firſt meridian, or be regulated to keep exactly mean time; both of which might, perhaps, be difficult, or, at leaſt, tedious to effect. The only thing which is abſolutely requiſite in a watch, to render it equal to the taſk of finding the longitude, is, that it will go uniformly at ſome known rate; for inſtance, that it will accelerate or retard its going by a ſecond or two, or more, every day; which acceleration or retardation is commonly called the *rate of the watch*, and being known, the mean time at the firſt obſervatory may be known by the chronometer, as well as if that machine ſhewed that mean time exactly. Thus, if the watch accelerates 10″ each day, three days after the ſetting of the chronometer, I know that the noon at the meridian, where the chronometer was ſet, is when that machine ſhews 12^h and 30″.

The few problems which are given in this note, are intended merely to give the ſtudent an idea of ſuch operations. If he wiſhes to proceed farther in the ſcience of practical aſtronomy, he is referred to the recent works written profeſſedly on the ſcience, and which have been frequently quoted in the preceding pages of this volume. A complete ſet of all the neceſſary aſtronomical problems, together with their demonſtrations and examples, being abſolutely incompatible with the limits of this work.

Next to this circle there is the calendar, viz. the names of the twelve months with the diviſions of the days correſpondent with the ſigns of the zodiac. The outermoſt circle contains all the points of the compaſs, and the winds as they are denominated by the ſeamen.

On the meridian and round the north pole N, there is a circle C faſtened to the meridian. This is called the *horary circle*, and is divided into twice twelve hours; the 12th hour at noon being on the upper part of the meridian; and the 12th hour at night being on the lower ſide of the meridian or towards the horizon. The extremity of the axis at N projects a little above the plane of this horary circle, and carries an index, which turns with the globe when the globe is turned round its axis, and indicates the hours, or how much a given part of the ſurface of the globe is removed from the meridian; ſince the time of a whole revolution is divided into 24 equal parts or hours.

The index is ſlipt upon the end of the axis, and may be eaſily moved; F is a flexible ſlip of braſs, divided into 90°, and having a little clamp B, with a ſcrew at one end, by which means it may be faſtened to the meridian. This muſt be faſtened always to the upper or middlemoſt part of the meridian, and its lower extremity is ſlipt in between the horizon and the globe, and may be placed in any azimuth. This ſlip of braſs having the 90° numbered from the horizon up to the zenith, ſerves to to ſhew the altitude of an object on the ſurface of the globe; and hence it is called the *quadrant of altitude.*

There frequently is another appendage to the globes, which is called the *ſemicircle of poſition.* It is a pretty ſlender wire, whoſe extremities are fixed to the points of north and ſouth on the horizon, ſo that the wire or ſemicircle can be moved freely from the horizon to the meridian, and may be raiſed to any poſition.

The principal circles marked upon the ſurfaces of the globes, and which, having already been deſcribed, need only be mentioned, are the following. The equator, divided into 360°, the numeration commencing at the vernal interſection with the ecliptic, which croſſes the equator at the vernal and at the autumnal equinoctial points, viz. firſt degree of Aries, and firſt degree of Libra. The ecliptic is divided into 12 equal parts or ſigns, and each ſign into 30°.

If on each ſide of the ecliptic we add a broad ſpace of about 8°, we have the zodiac, and this is actually drawn upon the celeſtial globe, with its 12 conſtellations.

The two tropics, viz. that of Cancer being on the northern, and that of Capricorn on the ſouthern ſide of the globe.

Near the poles are ſeen the two polar circles, viz. the north, or the arctic polar circle, near the north pole;

pole; and the ſouth or the antarctic, near the ſouth pole.

Beſides thoſe, there are other circles, which however are not common to both the globes. Thus the celeſtial globe has the two colures and the circles of latitude; it has alſo the conſtellations with the ſtars repreſented in their proper ſituations and magnitudes. The terreſtrial globe has the meridians, the parallels of latitude, and the rhumbs; it has alſo the repreſentations of countries, coaſts, iſlands, ſeas, and generally the tracks of the moſt renowned circumnavigators. The principal problems which may be ſolved by means of the globes, are as follows:

I. *A particular place upon the terreſtrial globe being given, to find its latitude and longitude.*

Turn the globe round its axis, until the given place comes juſt under the brazen meridian CBM, (viz. under the edge of its divided ſide, which ſide muſt always be underſtood when the meridian is mentioned), and the degree of the meridian which is juſt over the place (meaning the degrees of the two quadrants, which are numbered from the equator) is the latitude ſought; and it is north or ſouth, according as it is on the northern or on the ſouthern ſide of the equator. At the ſame time the degree of the equator, which is juſt under the brazen meridian, is the longitude of the place in queſtion.

N. B. In old globes, the longitude is reckoned from the iſland of Ferro, one of the Canary Iſlands. At preſent the longitude on the globes that are made in this country, begins to be reckoned from the meridian of the Royal Obſervatory at Greenwich.

II. *The latitude and longitude of a place being given, to find that place on the terreſtrial globe.*

This is the reverſe of the preceding problem, and is eaſily ſolved. Find on the equator the known degree of longitude, and turn the globe ſo as to bring that degree juſt under the braſs meridian; then find the degree of the given latitude upon the meridian, obſerving whether it be north or ſouth latitude, and exactly under it you will find the place in queſtion.

III. *To rectify the globe for any particular place.*

If the latitude of the place be north, elevate the *north* pole as many degrees above the horizon H *h*. If the latitude be ſouth, elevate the *ſouth* pole above the horizon an equal number of degrees; for according to the lower or higher latitude of any particular place, ſo does the pole appear to be higher or lower at that place. The degrees of this elevation of the pole are counted upon the meridian. Thus in the figure, the north pole is elevated 51½° above the horizon, the globe being rectified for the latitude of London.

Turn the globe till the given place comes to the meridian; and that part of the meridian, which is juſt over it, and which is 90° diſtant from the horizon on either ſide, repreſents the zenith. To this point of the meridian the quadrant of altitude muſt be faſtened, which ſerves to ſolve certain problems that will be deſcribed hereafter. Laſtly, turn the whole frame of the machine, ſo that the north pole be directed towards the real north, and of courſe the ſouth ſide towards the real ſouth. Then the globe is ſituated juſt as the real earth is ſituated with reſpect to the given place. In order to place the inſtrument duly north and ſouth, a magnetic needle is affixed to ſome globes; but you muſt then allow for the magnetical variation.

IV. *Two places being given upon the ſurface of the globe, to find their difference of latitude and difference of longitude.*

Turn the globe until one of the places comes under the brazen meridian, and mark the degree of latitude which is juſt over it, obſerving whether it be north or ſouth; then turn the globe until the other place comes under the meridian, and mark likewiſe the degree of this place's latitude. Now, if both thoſe latitudes be north, or both ſouth, their difference is the difference of latitude between the two places; but if one be ſouth and the other north, then their ſum is the difference of latitude between the two places. To find their difference of longitude, when one of the places is under the meridian, mark the point or degree of the equator, which is at the ſame time under the equator; then turning the globe until the other place comes under the meridian, mark likewiſe the point of the equator which is cut by the meridian; and the number of degrees which lie between thoſe two marks, is the difference of longitude ſought.

If this number of degrees be turned into time at the rate of 15° per hour, you will have the difference between the apparent time at thoſe places; for inſtance, if the difference of longitude be 35°, then the difference between the apparent times at the two places is 2 hours and 20 minutes; ſo that when it is noon at one of thoſe places, it muſt be 2 o'clock and 20 minutes in the afternoon, or 2 hours and 20 minutes before noon, at the other place, according as the latter is eaſtward or weſtward of the former. But this difference of apparent time may be had likewiſe by the horary circle C; for if when one of the places is under the meridian, you place the index at the 12th hour on the horary circle, and then turn the globe until the other place comes under the meridian, you will find the index directed to the proper difference of time. Thus in the above-mentioned inſtance the index will be found directed either to 9^h, 40^m, or to 2^h, 20^m.

V. *To*

V. *To find the direct diſtance between two given places.*

The eaſieſt and general way of performing this operation is by ſeparating the quadrant of altitude from the meridian, and applying it to the two places on the ſurface of the globe. Then the number of degrees which are ſhewn by that quadrant to be between the two places, being converted into miles at the rate of 69¼ miles per degree, will give the diſtance in miles between the two places. Should the two places be farther aſunder than the quadrant can reach, the operation may be performed by two meaſurements, viz. make a mark ſomewhere between the two places, and as nearly as you can in their direction; then apply the quadrant, and take the diſtance between one of the places and the mark, and in the ſame manner take the diſtance between the mark and the other place. Then the ſum of thoſe two diſtances is evidently the diſtance between the two places.

VI. *To find the ſun's place in the ecliptic for any given day of the year.*

Find on the wooden horizon H*b*, the given day of the month, and in the circle of the ſigns which is cloſe to it, you will find the degree of the ſign correſpondent to it: now find that degree of that ſign on on the ecliptic, which is marked upon the globe, and that is the place of the ſun for the given day; where you may make a mark, or fix a bit of paper by means of a bit of wax, as this will be uſeful for the ſolution of other problems.

If you move the globe until the above-mentioned marked place of the ſun comes under the meridian, then the number of degrees which are found on the brazen meridian to be between it and the equator, is the declination of the ſun for that day, and it is north or ſouth, according as the marked place is on the northern or on the ſouthern ſide of the equator.

If you rectify the globe for any particular place, and then turn it until the marked place of the ſun comes to the meridian, the number of the degrees, which are ſhewn by the meridian to be between the horizon and that marked place of the ſun, is the meridian altitude of the ſun for that place on the given day.

VII. *To find the time of ſun-riſing, and of ſun ſetting, at any given place, and for any given day of the year.*

Find and mark the ſun's place in the ecliptic for the day given (by the preceding problem). Rectify the globe for the latitude of the given place; and turn the globe ſo as to bring the ſun's place to the meridian. In this ſituation keep the globe ſteady, and direct the index of the horary circle to the 12 o'clock hour; then turn the globe until the ſun's place comes to the horizon on the eaſtern ſide of the machine, and the index of the horary circle will point to the hour and part of the hour, at which the ſun will be ſeen to riſe on that day from the given place. If you turn the globe until the ſun's place comes to the horizon on the weſtern ſide of the machine, the index of the horary circle will ſhow the time of ſun ſetting for the day and place in queſtion; whence you have the length of the day.

VIII. *To find the beginning and the end of the twilight for any place and day given.*

Find the latitude of the place, and rectify the globe (by problem 1ſt and 3d); put the index of the horary circle to the 12th hour, the ſun's place being in the meridian; then take the point of the ecliptic oppoſite to the ſun's place, and turn the globe weſtward, as alſo the quadrant of altitude, till the point oppoſite to the ſun's place cuts the quadrant of altitude in the 18° above the horizon. Then the index on the horary circle will ſhew the time when twilight begins in the morning. If you take the point oppoſite to the ſun, and bring it to the eaſtern hemiſphere, and turn it until it meets with the 18th degree on the quadrant of altitude, the index will ſhew when the twilight ends in the evening.

IX. *To find the length of the longeſt and ſhorteſt day in any given place.*

Rectify the globe for the latitude of the place; bring the ſolſticial point of that hemiſphere (viz. the firſt point of Cancer, if the place have north latitude; or the firſt point of Capricorn, if the place have ſouth latitude) to the eaſtern part of the horizon, ſet the index to the 12 o'clock hour at noon; turn the globe until the ſolſticial point comes to the weſtern ſide of the horizon; and the hours paſſed over by the index give the length of the longeſt day or night at that place. The complement of which time to 24 hours, is the length of the ſhorteſt day or ſhorteſt night.

X. *To find on what day the ſun will be vertical at any given place in the torrid zone.*

Find the latitude of the place on the brazen meridian; turn the globe, and obſerve the two points of the ecliptic that paſs under the above-mentioned degree of the brazen meridian. Then ſeek for thoſe points of the ecliptic in the circle of the twelve ſigns that are marked upon the horizon H *h*, and againſt them you will find the days of the month in which the ſun will be vertical to the given place.

XI. *At*

XI. *At any given time to find all thoſe places of the earth where the ſun is then riſing or ſetting, and where it is noon or midnight.*

Find the place where the ſun is vertical at the given time; rectify the globe for the latitude of that place, and bring the place to the meridian. Then all thoſe places, that are in the weſtern half of the horizon, have the ſun riſing, and thoſe which are in the eaſtern half of the horizon, have the ſun ſetting; thoſe who are under the meridian above the horizon have noon or the ſun culminating, and thoſe who are under the meridian below the horizon, have midnight; thoſe who are above the horizon, have day, and thoſe who are below it, have night.

XII. *A place being given within either of the polar circles, to find the time when the ſun begins to be ſeen, and when it departs from that place; alſo how long he will continue to be ſeen, and how long he will be abſent from that place.*

" Rectify the globe for the latitude of the place; turn it, and obſerve what degrees in the firſt and ſecond quadrants of the ecliptic are cut by the north point of the horizon (the latitude of the place being ſuppoſed to be north). Find thoſe degrees in the circle of the ſigns on the horizon, and their correſponding

reſponding days of the month; and all the time between thoſe days the ſun will not ſet in that place."

"Again, obſerve what degree in the third and fourth quadrants of the ecliptic will be cut by the ſouth point of the horizon, and the days anſwering; then the ſun will be quite abſent from the given place during the intermediate days; that day in the third quadrant ſhews when he begins to diſappear; and that in the fourth quadrant ſhews when he begins to ſhine in the place propoſed."

XIII. *The latitude of the place, and the day of the month, being given, to find the ſun's declination, meridian altitude, right aſcenſion, amplitude, oblique aſcenſion, aſcenſional difference; and thence the time of riſing and ſetting, with the length of the day and night.*

"Rectify the globe for the latitude of the place, and noon (viz. bring the place under the meridian); then the degree of the meridian over the ſun's place is the declination. The meridian altitude is ſhewn by the degree the ſun is above the horizon, and is equal to the ſum or difference of the colatitude and declination. The ſun's right aſcenſion is that degree of the equator which is under the meridian."

" Bring the ſun's place to the eaſtern part of the horizon; then the amplitude is that degree of the horizon which is oppoſite to the ſun. The oblique aſcenſion is that degree of the equator which is cut by the horizon. The aſcenſional difference is the difference between the right and oblique aſcenſions. The aſcenſional difference converted into time, will give the time the ſun riſes before or after the hour of ſix, according as his amplitude is to the northward or ſouthward of the eaſt point of the horizon."

XIV. *The latitude of the place, day of the month, and the ſun's altitude being given, to find the azimuth and hour of the day.*

Rectify the globe for the latitude of the place; bring that place under the meridian; fix the index to the 12 o'clock hour at noon; and fix the clamp of the quadrant of altitude to the zenith. This done turn the globe, and move the quadrant of altitude until the ſun's place coincides with the given altitude on the graduated edge of the quadrant; then that edge of the quadrant will cut the degrees of azimuth on the horizon H *b*, reckoned from the north; and at the ſame time the index will ſhew the hour of the day on the horary circle.

XV. *To diſpoſe the celeſtial globe, ſo as to ſhew the actual appearance of the heavens at any given time and place.*

Rectify the celeſtial globe for the latitude of the place. Take the place of the ſun for the given time, and bring it to the meridian; alſo ſet the index to the twelfth hour on the horary circle; then turn the globe until the index points to the given hour; then the globe will be ſituated like the celeſtial ſphere, and every ſtar upon the globe will point towards the real ſtar in the heavens. The ſtars which are in the eaſtern half of the horizon, are riſing; thoſe in the weſtern half, are ſetting; and thoſe which are under the meridian, are culminating. If the quadrant of altitude be ſet to any given ſtar, it will ſhew the altitude of that ſtar, and its lower extremity will ſhew the azimuth of that ſtar upon the horizon. If you turn the globe quite round, you will eaſily perceive thoſe ſtars which are within the circle of perpetual apparition, as alſo thoſe which are within the limits of perpetual occultation, viz. thoſe which never go below the horizon, and thoſe which never riſe above the horizon, of the given place.

XVI. *To repreſent the ſituations of the planets.*

The celeſtial globe repreſents the fixed ſtars; but the planets cannot be delineated upon it, becauſe the latter are always ſhifting their places amongſt the former. Therefore, when the planets are to be repreſented for any particular time, they muſt be ſtuck on occaſionally; viz. little round pieces of paper, each having the mark or character of a particular planet on one ſide, and a bit of wax on the other (the philoſophical inſtrument makers ſell papers with the characters of the planets ready ſtamped for this purpoſe) are lightly ſtuck upon the globe in their proper places, which places are given in the ephemeris for every day of the year; then if you perform the preceding problem, you will have the repreſentaion of the planets in their proper places, as well as of the ſtars.

XVII. *To find the latitude and longitude of any given ſtar.*

Place one extremity of the quadrant of altitude upon one of the poles of the ecliptic, viz. that pole which is nearer to the given ſtar; and let its graduated edge fall upon the given ſtar. Then the number of degrees which the quadrant ſhews to be between the ecliptic and that ſtar, is the latitude of the ſame. The longitude is the degree on the ecliptic, which is cut at the ſame time by the quadrant of altitude.

XVIII. *To find the right aſcenſion and declination of a fixed ſtar.*

Move the globe ſo as to bring the ſtar to the meridian; then the degree of the meridian, which is juſt over it, is its declination; and the degree of the equator, which is cut by the meridian in that ſituation, is its right aſcenſion.

XIX. *To find when a given ſtar riſes, ſets, or culminates on any given place and day of the year.*

Rectify the globe for the latitude of the place, bring that place to the meridian, and ſet the index to the 12 o'clock hour at noon. Then move the globe until the given ſtar coincides with the horizon on the eaſtern ſide, and the index will ſhew the time of its riſing. If you turn the globe until the ſame ſtar coincides with the horizon on the weſtern ſide, the index will ſhow the time of its ſetting, and if you bring the ſtar to the meridian, the index will ſhew the time of its culminating.

The meridian altitude of the ſtar, as alſo its oblique aſcenſion and aſcenſional difference, are found in the ſame manner as for the ſun. See problem the 13th.

XX. *To find the apparent angular diſtance between two given ſtars.*

Lay the quadrant of altitude flat upon the globe, ſo that its graduated edge may paſs over the two ſtars; then the number of degrees that appear to be between thoſe ſtars, is the angular diſtance ſought.

ELEMENTS OF

NATURAL PHILOSOPHY.

PART V.

CONTAINING A FEW UNCONNECTED SUBJECTS.

A FEW particular ſubjects, uſeful to the ſtudent of natural philoſophy, but which could not, with propriety, be inſerted in the preceding volumes, will form the contents of the preſent or fifth part of this work; which, therefore, will be divided into ſections that are quite unconnected with each other. The ſubject of aeroſtation will be briefly treated of in the firſt ſection. The next will contain an abridgment of facts and conjectures relative to meteors, and to the fall of ſtones from the atmoſphere. The third ſection will exhibit a compariſon of weights and meaſures. The laſt ſection will contain ſeveral additional facts, diſcoveries, obſervations, &c. relative to the different branches of natural philoſophy, which have either been made, or come to notice, ſubſequent to the printing of the preceding parts of theſe elements.

SECTION I.

OF AEROSTATION.

CHAPTER I.

DISCOVERY OF AEROSTATIC MACHINES.

THE art of flying, or of imitating the feathered tribe, has long been the object of earneſt deſire amongſt men. The fanciful ideas of poets, the tales of amuſement, the pretended diſcoveries of impoſtors, and the projects of mechanicians, relative to this art, have not been deficient in every age, and almoſt in every country. Cars, artificial birds, wings, and other mechaniſms for flying, generally abſurd, and always inſufficient, have frequently been exhibited to the undiſtinguiſhing eye of the vulgar; but the ſtricteſt enquiry into the accounts of authentic hiſtory, finds no mention of any ſucceſs having ever attended the attempts of this nature previous to the year 1782. The recent diſcoveries made on the nature and properties of aërial fluids, by the induſtry of Black, Prieſtley, Cavendiſh,

Cavendiſh, and others, ſuggeſted, ſome time before the above-mentioned year, the practicability of forming machines ſufficient to elevate conſiderable weights into the regions of the atmoſphere. Mr. Cavendiſh was the firſt who aſcertained the ſpecific gravity of hydrogen gas, (then called inflammable air) and found it to be a vaſt deal lighter than common air. His experiments on this ſubject are publiſhed in the Philoſophical Tranſactions for the year 1766. In conſequence of this diſcovery, it was natural to conclude, that if a large bladder, or bag, or envelope, were filled with hydrogen gas, and that if the weight of the envelope added to that of the contained gas, did not exceed the weight of an equal bulk of common air; the apparatus would mount up into the atmoſphere for the ſame reaſon, and in the ſame manner as a cork would riſe from the bottom towards the ſurface of the ſea, ſuppoſing the cork were left at liberty in the former place.

Dr. Black of Edinburgh thought of filling the allantois of a calf with hydrogen gas, for the purpoſe of ſhewing at his lectures that ſuch a body would aſcend into the atmoſphere; but he never put the project to the teſt of actual experience.

Early in the year 1782, I made the firſt attempts to elevate a bag full of hydrogen gas into the ambient air, and an account of my experiments was read at a meeting of the Royal Society on the 20th of June 1782.

The

The weight of hydrogen gas, the mean weight of atmoſpherical air, and the weight of the ſubſtance of which the veſſel or bag is to be formed, being aſcertained, it is eaſy from thoſe particulars to determine by calculation, the dimenſions of a veſſel, which, when filled with hydrogen gas, might be lighter than an equal bulk of common air; for the ſurfaces of ſimilar bodies are as the ſquares of their ſimilar ſides, or of their diameters, whilſt their capacities are as the cubes of thoſe ſides or diameters; ſo that if the diameter of the globe A be 2 feet, its contents will be equal to 3 cubic feet nearly, and its ſurface will be equal to 6 ſquare feet nearly; but if we increaſe the diameter of the globe, for inſtance, we make it 4 feet, then the contents or capacity will be 8 times what it was before, and its ſurface will be only 4 times what it was before; hence, let the thickneſs or weight of the ſubſtance, which forms the bag, be what it may, by increaſing the diameter of the globe, one may always render it ſo that, when filled with hydrogen gas, the weight of the whole may be leſs than the weight of an equal bulk of atmoſpherical air.

Upon thoſe principles, and for the above-mentioned purpoſe, I tried bladders, the thinneſt and largeſt that could be procured. Some of them were cleaned with great care, removing from them all the ſuperfluous membranes, and other matter that could be poſſibly ſcraped off; but notwithſtanding all

all thoſe precautions, I found the largeſt and lighteſt of thoſe prepared bladders to be ſomewhat too heavy for the purpoſe. Some ſwimming bladders of fiſhes were alſo found too heavy for the experiment; nor could I ever ſucceed to make any durable light balls by blowing hydrogen gas into a thick ſolution of gums, thick varniſhes, and oil paint. In ſhort, ſoap-balls, inflated with hydrogen gas, were the only things of this ſort which I could ſucceed to elevate into the ambient air; and theſe, as far as I know, are the firſt ſort of air balloons that were ever conſtructed.

After thoſe trials I endeavoured to make bags or balloons of the fineſt ſort of China paper, and to inflate them with hydrogen gas. The ſize of thoſe bags was ſuch, that had it been poſſible to fill them with the gas, they muſt have undoubtedly aſcended into the atmoſphere; but I had the mortification to find that though common air did not, yet the hydrogen gas paſſed through the pores of paper exactly like water through a ſieve. After a variety of ſimilar trials, being at laſt tired with the expence and loſs of labour, I deferred the proſecution of ſuch experiments to a future opportunity, and contented myſelf with giving an account of my attempts to the Royal Society.

Not long after this, news was received from France of the ſucceſs which had attended an experiment of a ſimilar nature made at Avignon, by Stephen Montgolfier; but the bag was not filled with hydrogen

hydrogen gas. It was filled with air rarefied by heat, which of courſe was lighter than an equal bulk of common air, of the uſual temperature.

It is ſaid that the two brothers, Stephen and John Montgolfier, began to think on the experiment of the aeroſtatic machine as early as the middle or latter end of the year 1782. The natural aſcenſion of ſmoke, and of the clouds in the atmoſphere, ſuggeſted the firſt idea; and to imitate thoſe bodies, or to encloſe a cloud in a bag, ſo that the latter might be elevated by the buoyancy of the former, was the firſt project of thoſe celebrated gentlemen.

Stephen Montgolfier, the eldeſt of the two brothers, made the firſt aeroſtatic experiment at Avignon, towards the middle of November 1782. The machine conſiſted of a bag of fine ſilk, in the ſhape of a parallelopipedon, open on one ſide, the capacity of which was equal to about 40 cubic feet. Burning paper, applied to its aperture, ſerved to rarefy the air, or to form the cloud; and, when ſufficiently expanded, the machine aſcended rapidly to the ceiling of the room. Thus the original diſcovery was made, which was afterwards confirmed, improved, and diverſified by different perſons in different parts of the world.

As ſoon as the news of Mr. Montgolfier's ſucceſsful experiment reached Paris, the ſcientific perſons of that capital, juſtly concluding that a ſimilar experiment might be made by filling a bag with hydrogen gas, immediately attempted to verify the

ſuppoſition.

ſuppoſition. A ſubſcription for defraying the expences which might attend the accompliſhment of the project, was immediately opened; perſons of all ranks ran with eagerneſs to ſign their names, and the neceſſary ſum was ſpeedily raiſed. Meſſrs. Roberts were appointed to conſtruct the machine, and Mr. Charles, profeſſor of experimental philoſophy, was appointed to ſuperintend the work.

The obſtacles, which oppoſed the accompliſhment of this firſt attempt, were many; but the two principal difficulties were to produce a large quantity of hydrogen gas, and to find a ſubſtance ſufficiently light to make the bag of, and at the ſame time impermeable to the gas. At laſt they conſtructed a globular bag of a ſort of ſilk ſtuff, called *luteſtring*; which, in order to render it impervious to the gas, was covered with a certain varniſh, ſaid to conſiſt of diſſolved elaſtic gum (caoutchouc). The diameter of this bag (which, from its ball-like ſhape, was called a *balloon*, and gave the name of *air-balloons* to thoſe machines in general) was 12 feet 2 inches French, or about 13 feet Engliſh. It had only one aperture, like the neck of a bladder, to which a ſtop-cock was adapted. The weight of the balloon, when empty, together with the ſtop-cock, was 25 pounds.

The attempts to fill this bag commenced on the 23d of Auguſt 1783. But the operators met with many difficulties and diſappointments, from inadvertences, want of materials, want of precautions,

&c. ſo much ſo, that the accompliſhment of the experiment, viz. the actual aſcent of the balloon, did not take place before the 26th of the ſame month. On the morning of that day, the inflated balloon, having a ſmall cord faſtened to its neck, was permitted to riſe only to the height of about 100 feet; but at five o'clock in the afternoon of the 27th, the balloon was diſengaged from its faſtenings, in the *Camp of Mars*, and roſe majeſtically in the atmoſphere before the eyes of a great many thouſand ſpectators, and amidſt a copious ſhower of rain. In about two minutes time it roſe to the height of about 3123 feet. After remaining in the atmoſphere only ¾ of an hour, this balloon fell in a field near *Goneſſe*, a village about 15 miles from Paris. Its fall was attributed to a rupture that was found in it, and it was reaſonably imagined that the expanſion of the hydrogen gas, when the balloon had reached a much leſs denſe part of the atmoſphere, had burſt it. When this balloon went up, it was found upon trial to be 35 pounds lighter than an equal bulk of common air.

Thus in the years 1782 and 1783, it was aſcertained that bags full of hydrogen gas, or of rarefied common air (either of which is lighter than common air in its uſual ſtate), would aſcend into the atmoſphere, and that they might take up conſiderable weights. The principal experiments and improvements that were made in purſuance of thoſe diſcoveries, will be mentioned in the next chapters; but it will be previouſly neceſſary to make the following remark; namely, that this diſcovery, though in itſelf very remarkable, is far from amounting to the art of flying. The only effect that an aeroſtatic machine can produce, is to elevate, and to keep ſuſpended, a certain weight in the atmoſphere; but with reſpect to its progreſſive motion, it can only follow the courſe of the wind; nor has any method been diſcovered by means of which the balloon may be cauſed to deviate from that courſe in any uſeful degree.

CHAP. II.

PROGRESS OF AEROSTATION.

SOON after the ſucceſs of the firſt attempt, the Montgolfiers repeated the experiment in the open air, and with bags of different ſizes; but their firſt grand and public exhibition in the preſence of a very reſpectable and numerous aſſembly, was made on the 5th of June 1783, with an aeroſtatic machine or bag that meaſured 35 feet in diameter. The machine inflated by the rarefied air, aſcended to a conſiderable height, and then fell at the diſtance of 7668 feet from the original place of aſcenſion. This experiment was deſcribed and recorded with great accuracy; and accounts of it were immediately forwarded to the court of France, to the academy of ſciences, and almoſt as far as literary and entertaining correſpondence could reach. The youngeſt Montgolfier, arriving at Paris not long after the above-mentioned public exhibition, was invited by the Academy of Sciences to repeat his ſingular aeroſtatic experiment; in conſequence of which invitation, that gentleman began to conſtruct an aeroſtatic machine of about 72 feet in height, at the

the expence of the academy. But while this operation was going on, and as a ſucceſsful experiment with an inflammable air balloon, had already been performed on the 27th of Auguſt, the project of making balloons became general, and thoſe who wiſhed to make the experiment on the ſmalleſt ſcale, ſoon calculated the neceſſary particulars, and found that the performance of the experiment was far from being either difficult or expenſive. The baron de Beaumanoir, at Paris, by the ſuggeſtion of a Mr. Deſchamps, was induced to try gold-beater's ſkin, and ſoon made a balloon by glueing ſeveral pieces of that ſkin together. This balloon was no more than 19 inches in diameter; it was of courſe eaſily filled with hydrogen gas, and on the 11th of September 1783, it mounted with rapidity into the atmoſphere.

In conſequence of this experiment of the baron, ſeveral perſons endeavoured to make balloons ſtill ſmaller than his, and ſome ſucceeded to make them of not more than ſix inches in diameter, which weighed between 30 and 40 grains. Theſe were filled with the utmoſt facility, and ſerved well enough to ſhew the experiment in a room; but as they were neceſſarily formed of ſkins extremely fine, conſequently more porous than the uſual thicker ſkins, the gas ſoon eſcaped from them, and the diminutive balloons hardly floated longer than a minute or two.

Mr. Montgolfier, having completed his large aeroſtat, agreeable to the deſire of the academy, made a private experiment with it on the eleventh of September, which ſucceeded. On the following day another experiment was made with the ſame, before the commiſſaries of the academy, and a vaſt number of other ſpectators; but this experiment, in conſequence of a violent ſhower of rain, was attended with partial ſucceſs; and the aeroſtat was thereby conſiderably damaged.

Another ſimilar machine was ſpeedily conſtructed by the ſame Mr. Montgolfier, with which the experiment was performed at Verſailles on the 19th of September, before the royal family of France, and an innumerable concourſe of ſpectators. The preparation for filling the machine with rarefied air conſiſted of an ample ſcaffold, raiſed ſome feet above the ground; in the middle of which there was a well or chimney, about 16 feet in diameter; in the lower part of which, near the ground, the fire was made. The aperture of the aeroſtat was put round the chimney or well, and the reſt of it was laid down over the well and the ſurrounding ſcaffold. As ſoon as the fire was lighted, the machine began to ſwell; acquired a convex form, ſtretched itſelf on every ſide, and in 11 minutes time, the chords being cut, the machine aſcended, together with a wicker baſket or cage, which was faſtened to it by means of a rope, and in which a ſheep, a cock, and a duck had been placed. Theſe were the firſt animals that ever aſcended with an aeroſtatic machine. The apparatus roſe to the height of about 1440 feet, and remained in the atmoſphere during 8 minutes; then fell at the diſtance of about 10200 feet from Verſailles, with the animals ſafe in the baſket.

After the ſucceſs of this experiment with the animals, &c., and when ten months had ſcarcely elapſed ſince Mr. Montgolfier made his firſt experiment of this ſort, Mr. Pilatre de Rozier publicly offered himſelf to be the firſt adventurer in the newly invented machine. His offer was accepted, his courage remained undaunted, and on the 15th of October 1783, he actually aſcended into the atmoſphere, to the aſtoniſhment of a gazing multitude. The aeroſtat with which he aſcended, was of an oval ſhape, its height being about 74, and its horizontal diameter 48 feet. The aperture or lower part of the machine had a wicker gallery about 3 feet broad, with a baluſtrade both within and without, about 3 feet high. The inner diameter of this gallery, and of the neck of the machine which paſſed through it, was nearly 16 feet. In the middle of this aperture an iron grate, or brazier, was ſupported by means of chains, which came down from the ſides of the machine. In this conſtruction, when the machine was up in the air, with a fire lighted in the grate, it was eaſy for a perſon who ſtood in the gallery, and had fuel with him, to keep up the fire in the opening of the machine, by throwing the fuel on the grate through port-holes made in the neck of the machine. By which means the machine might be kept up as long as the perſon in its gallery thought proper, or till he had fuel to ſupply the fire with.

After this Mr. de Rozier repeated the experiment with the ſame and with other ſimilar machines, and his ſucceſs ſhewed to the world that human beings might ſafely aſcend with thoſe machines. In fact, the experiment was afterwards repeated by a variety of people of both ſexes; and it is remarkable, that in thoſe aërial excurſions, no giddineſs, nor ſickneſs was experienced by the travellers.

The firſt aërial voyage, with an inflammable air balloon, was performed ſubſequent to the abovementioned experiment, viz. on the 1ſt of December 1783. Mr. Charles and Mr. Robert, who had conſtructed the firſt balloon of this ſort, as has been mentioned in this chapter, were the firſt adventurers. The balloon was globular, its diameter being 27½ feet. A net went over the upper hemiſphere, and was faſtened to a hoop, which went round the middle of the balloon. From this hoop ropes proceeded, and were faſtened to a boat which ſwung a few feet below the balloon. In order to prevent the burſting of the machine by the expanſion of the gas, in an elevated region, a valve was made on the upper part of it, which, by pulling a ſtring, would

would open and let out part of the gas. There was likewiſe a long ſilken pipe, through which the balloon was filled.

The apparatus for filling it conſiſted of ſeveral wooden caſks placed round a large tub full of water, every one of which had a long tin tube, which terminated under a veſſel or funnel, that was inverted into the water of the tub. A tube then proceeded from this funnel, and communicated with the balloon, which ſtood juſt over it. Iron filings and diluted ſulphuric acid were put into the caſks; and the gas which was extricated from thoſe materials, paſſed through the tin tubes, then through the water of the tub, and, laſtly, through the tube of the funnel into the balloon.

When Meſſrs. Charles and Robert placed themſelves in the boat, they had with them proper philoſophical inſtruments, proviſions, clothing, and ſome bags full of ſand, by way of ballaſt. With this preparation they aſcended at ¾ after one o'clock, At the time they went up, the thermometer, Fahrenheit's ſcale, ſtood, at 52°, the mercury in the barometer ſtood at 27 inches, from which they deduced their altitude to be nearly 600 yards. During the reſt of their voyage, the mercury in the barometer moved generally between 27 inches, and 27,65; riſing and falling according as part of the ballaſt was thrown out, or ſome gas eſcaped from the balloon. The thermometer ſtood generally between 53° and 57°.

Soon after their aſcent, they remained ſtationary for a ſhort time; then they went horizontally, in the direction of N. N. W. They croſſed the Seine, and paſſed over ſeveral towns and villages, to the great aſtoniſhment of the inhabitants, who did not expect to ſee ſuch a ſpectacle, and who had perhaps never heard of this new ſort of experiment. This delicious aërial voyage laſted one hour and three quarters. At laſt they deſcended in a field near *Neſle*, a ſmall town, about 27 miles diſtant from Paris; ſo that they had gone at the rate of about 15 miles per hour, without feeling the leaſt inconvenience; and the balloon underwent no other alteration, than what was occaſioned by the dilatation and contraction of the gas, according to the viciſſitudes of heat and cold.

The ſucceſs of the experiments, which have been already deſcribed, ſpread a univerſal enthuſiaſm throughout Europe, and the aeroſtatic experiments, both in the diminutive, and in the large way, were ſoon undertaken in different countries. The firſt experiment of this ſort was ſhewn in London on the 25th of November 1783, with an inflammable air-balloon of 10 feet in diameter, by Count Zambeccari, an Italian gentleman. The firſt aërial voyage undertaken in England, with an inflammable air-balloon, of 33 feet in diameter, made of oil ſilk, was performed by Mr. Lunardi, another Italian, on the 15th of September 1784.

During

During the above-mentioned and the three following years, the daily papers, and other periodical publications, gave frequent accounts of aërial voyages having been performed in various parts of Europe, and even in America. The ſmall inflammable air-balloons were exhibited at public lectures, and almoſt in every private aſſembly. Small aeroſtatic machines of fine paper, to be elevated by rarefied air, were publicly ſold in great plenty, ſome of them even for the trifling price of a ſingle ſhilling; and as theſe formed a pretty ſpectacle in the night time, on account of the burning combuſtible which was appended to their aperture for the purpoſe of rarefying the air, a great many of them were every night ſeen to move over London, in the direction of the wind.

The ſimple conſtruction of thoſe diminutive aeroſtatic machines for rarefied air, is as follows. Pieces of that ſort of fine paper, which is ſold in London under the name of *fan paper*, or *ſilver paper*, are cut in an oblong ſhape, gradually tapering at the two extremities. Thoſe pieces are ſtuck together ſucceſſively, edge to edge, ſo as to form a globular paper bag. Part of this globe is then cut off ſo as to leave a circular aperture of about 10 or 12 inches in diameter, to the edge of which a fine iron or braſs wire is adapted by way of ſtrength, and is fixed by turning and paſting a little of the edge of the paper over it. Two ſtraight and pretty thin iron wires are alſo to be placed acroſs each other in the above-mentioned aperture, and their extremities are faſtened to the circular wire, which goes round the aperture. This croſs of wire ſerves to ſupport the fuel, viz. in the middle of it a ball of ſpun wool is faſtened alſo by means of fine iron wire, which when the experiment is to be performed, muſt be ſoaked in ſpirit of wine, or in ſpirit of turpentine, and then lighted, whilſt an aſſiſtant holds the balloon (which need not be larger than a yard in diameter) by the top. The combuſtion immediately ſwells the balloon with rarefied air, and when this has taken place, the aſſiſtant relinquiſhes his hold, and the balloon mounts, &c.

The aeroſtatic experiments, originally undertaken for mere curioſity, ſoon became the object of gain, and almoſt all the aërial voyages were undertaken for the ſake of profit. Perſons entirely unacquainted with any branch of natural philoſophy, offered to make aërial voyages, and to perform experiments in the atmoſphere, for which they were not in the leaſt qualified, and with inſtruments, of which they did not underſtand the uſe.

In conſequence of this practice, the aërial voyages, though numerous, have not however been productive of much information. Yet the variety of ſituations, of machines, and of accidental circumſtances, added to the obſervations of able perſons, have undoubtedly ſhewn a variety of facts which deſerve the attention of the philoſopher. Therefore omitting the particular account of all the uſeleſs voyages, I ſhall only mention thoſe which have been attended with any particular and remarkable occurrence that may appear capable of eſtabliſhing ſome uſeful fact, or to remove ſome preconceived objection.

The Abbé Bertholon ſeems to have been the firſt perſon who made uſe of ſmall balloons for exploring the electricity of the atmoſphere, which muſt be a very uſeful method, particularly in calm weather, when electrical kites cannot be raiſed. He raiſed ſeveral air-balloons, to which long and ſlender wires were attached; the lower extremity of the wire being faſtened to a glaſs ſtick or other inſulated ſtand, whereby he obtained from ſuch wires electricity enough to ſhew its kind, and even ſparks.

On the 13th of January 1784, an aeroſtatic machine, of about 37 feet in height, and 20 in diameter, was launched from the caſtle *de Piſançon*, near *Romans*, in Dauphinè. It roſe with ſurpriſing velocity, and as the wind was north, it went ſouthward; but when the machine had aſcended to the height of about 1300 feet, it went back towards the north, and in leſs than five minutes time it aſcended to the height of above 6000 feet. In leſs than ten minutes it fell at the diſtance of nearly four miles.

This experiment, and indeed the ſimilar ſucceſs of many others, ſhews that there frequently are in the

the atmoſphere currents of air in different, and ſometimes quite oppoſite, directions; this, however, is far from being always the caſe. If different currents could always be met with at different heights above the ſurface of the earth, the method of guideing balloons would be extremely eaſy; for the aërial traveller would have nothing more to do than to place himſelf in the favourable current, which he may do by throwing out either ſome ballaſt or ſome inflammable gas, according as he wiſhes to go higher or lower.

The largeſt aeroſtatic machine ever made, and filled with rarefied air, was launched at Lyons on the 19th of January 1784, with not leſs than ſeven perſons in its gallery, amongſt whom were Joſeph Montgolfier, and Pilatre de Rozier. The height of this machine was about 131 feet, and its horizontal diameter about 104. Its weight, when it aſcended, including paſſengers, gallery, &c. was about 1600 pounds.

This machine, having ſuffered conſiderably in conſequence of previous trials, was by no means in a perfect ſtate when it aſcended; nevertheleſs, when the action of the fire had inflated it, the ſeven perſons, who in ſpite of every remonſtrance had placed themſelves in the gallery, refuſing to relinquiſh their places, the machine was releaſed from the ropes which confined it, and aſcended majeſtically into the atmoſphere. At a certain height, the wind turned it towards the weſt; but it afterwards proceeded

ceeded eaſt-ſouth-eaſt, aſcending, at the ſame time, until it was at leaſt 1000 yards high.

The effect which was produced on the ſpectators by this ſpectacle, is deſcribed as the moſt extraordinary that was ever occaſioned by any production of human invention. It was a mixture of the ſtrangeſt nature imaginable. Vociferations of joy, ſhrieks of fear, expreſſions of applauſe, the ſound of martial inſtruments, and the diſcharge of mortars, produced an effect more eaſily imagined than deſcribed. Some of the ſpectators fell on their knees, and others elevated their ſuppliant hands to the heavens; ſome women fainted, and many wept; but the confident travellers, without ſhewing the leaſt appearance of fear, were continually waving their hats out of the gallery.

At about 15 minutes after the aſcent, the wind ſhifted again; but it was ſo feeble that the machine ſtood almoſt ſtationary for about four minutes. Unfortunately about this time a rent was made in the machine, which occaſioned its deſcent; and when it came within 600 feet of the ground, its velocity was conſiderably accelerated. It is ſaid that no leſs than 60000 perſons, beſides the Marechauſſée, ran to the ſpot, with the greateſt apprehenſion for the lives of the adventurous aërial travellers. They were immediately helped out of the gallery, and luckily no perſon had received any hurt, except Mr. Montgolfier an inſignificant ſcratch. The machine was torn in ſeveral places, beſides a vertical rent of upwards

upwards of 50 feet in length; which clearly ſhews how little danger is to be apprehended from the uſe of thoſe machines, eſpecially when they are properly conſtructed and judiciouſly managed.

On the 5th of April 1784, Meſſrs. de Morveau, and Bertrand, at Dijon, aſcended with an inflammable air-balloon, which, according to their barometrical obſervations, ſeems to have reached the extraordinary height of 13000 feet, when the cold was ſo great, that the thermometer ſtood at 25°.

On the 15th of July, the duke de Chartres, the two brothers Roberts, and another perſon, aſcended with an inflammable air-balloon, from the park of St. Cloud, at 52 minutes paſt ſeven in the morning. This balloon was of an oblong form, its dimenſions being 55 feet by 34. It aſcended with its greateſt extenſion nearly horizontal; and after remaining in the atmoſphere about 45 minutes, it deſcended at a ſmall diſtance from its place of aſcenſion. But the incidents that occurred during this aërial excurſion, deſerve particular notice, as nothing like it had happened before to any of the aërial travellers. This machine contained an interior ſmall balloon, filled with common air; by which means it was ſuppoſed that they might regulate the aſcent and the deſcent of the machine, without any loſs of the hydrogen gas, or of ballaſt. The boat was furniſhed with a helm and oars, that were intended to guide the machine, but which were in this, as well as in every other ſimilar, attempt found to be quite uſeleſs.

On the level of the ſea, the mercury in the barometer ſtood at 30,25 inches, and at the place of aſcenſion it ſtood at 30,12. Three minutes after its aſcenſion, the balloon was loſt in the clouds, and the aërial voyagers loſt ſight of the earth, being involved in a denſe vapour. Here an unuſual agitation of the air, ſomewhat like a whirlwind, in a moment turned the machine three times from the right to the left. The violent ſhocks which the adventurers ſuffered, prevented their uſing any of the means prepared for the direction of the machine; and they even tore away the ſilk ſtuff of which the helm was made. Never, ſaid they, a more dreadful ſcene preſented itſelf to any eye, than that in which they were involved. An unbounded ocean of ſhapeleſs clouds rolled beneath, and ſeemed to forbid their return to the earth, which was ſtill inviſible. The agitation of the balloon became greater every moment. They cut the cords which held the interior balloon, which conſequently fell on the bottom of the external balloon, juſt upon the aperture of the tube that went down to the boat, and ſtopped up that communication. At this time the thermometer was a little above 44°. A guſt of wind from below drove the balloon upwards, to the extremity of the vapour, where the appearance of the ſun ſhewed them the exiſtence of nature; but now both the heat of the ſun, and the diminiſhed denſity of the atmoſphere, occaſioned ſuch a dilatation of the gas, that the burſting of the balloon was apprehended; to avoid which, they introduced a ſtick through the tube, and endeavoured to remove the inner balloon, which ſtopped its aperture within the external balloon; but the dilatation of the gas preſſed the inner balloon ſo forcibly againſt that aperture, as to render every attempt ineffectual. During this time, they continually aſcended, until the mercury in the barometer ſtood not higher than 24,36 inches, which ſhewed their height above the ſurface of the earth to be about 5100 feet. In theſe dreadful circumſtances they thought it neceſſary to make a hole in the balloon, in order to give exit to the gas; and accordingly the duke himſelf, with one of the ſpears of the banners, made two holes in the balloon, which opened a rent of about ſeven or eight feet. In conſequence of this, they then deſcended rapidly, ſeeing at firſt no object either on earth or in the heavens; but a moment after, they diſcovered the fields, and that they were deſcending ſtraight into a lake, wherein they would inevitably have fallen, had they not quickly thrown over about 60 pounds weight of ballaſt, which occaſioned their coming down at about 30 feet beyond the edge of the lake. Notwithſtanding this rapid deſcent, none of the four adventurers received any hurt; and it is remarkable, that out of ſix glaſs bottles full of liquor, which were ſimply laid down in the boat, one only was found broken.

In the courſe of the ſummer 1784, two perſons, viz. one in Spain, and another near Philadelphia, in America,

America, were very nearly loſing their lives by going up with rarefied-air machines. The former, on the 5th of June, was ſcorched by the machine taking fire, and was hurt by the ſubſequent fall, ſo that his life was long deſpaired of. The latter, having aſcended a few feet, was waſted by the wind againſt the wall of a houſe, and ſome part of the machinery was entangled under the eaves, from which he could not extricate it. At laſt the great aſcenſional power of the machine broke the ropes or chains, and the man fell from the height of about 20 feet. The machine preſently took fire, and was conſumed.

I ſhall now relate one of the moſt remarkable aërial voyages that were ever made with an aeroſtatic machine. It is the croſſing of the Engliſh channel in an inflammable air-balloon of 27 feet in diameter. The enterpriſer of this dangerous voyage was Mr. Blanchard, an intrepid Frenchman, who had already made five other aërial voyages with the very ſame balloon, both in France and in England. Mr. Blanchard is remarkable for having made a greater number of aërial voyages in England, in France, and elſewhere, both before and after the croſſing of the Engliſh channel, than any other enterpriſer recorded in the hiſtory of aeroſtation. The only trial worth remarking which Mr. Blanchard appears to have made in his aërial excurſions, is the ineffectual uſe of oars, wings, &c. for directing the balloon. Profit ſeems to have been the principal if not the ſole object of his numerous excurſions.

On Friday the 7th of January 1785, being a fine clear morning, after a ſharp froſty night, and the wind being about N. N. W. though hardly perceptible, Mr. Blanchard, accompanied by Dr. Jeffries, an American gentleman, departed in the old balloon of 27 feet diameter, from Dover Caſtle, directing their courſe for the French coaſt. Previous to the departure, the balloon, with the boat, containing the two travellers, ſeveral neceſſaries, and ſome bags of ſand for ballaſt, were placed within two feet of the brink of the perpendicular cliff before the caſtle. At one o'clock the intrepid Blanchard deſired the boat, &c. to be puſhed off; but the weight being too great for the power of the balloon, they were obliged to throw out a conſiderable quantity of ballaſt, in conſequence of which they at laſt roſe gently and majeſtically, though making very little way, with only three bags of ballaſt of ten pounds weight each. At a quarter after one o'clock, the barometer, which on the cliff ſtood at 29,7, was fallen to 27,3; and the weather proved fine and warm. Dr. Jeffries deſcribes with rapture the proſpect which at this time was before their eyes. The country to the back of Dover, interſperſed with towns and villages, of which they could count 37, made a beautiful appearance. On the other ſide the breakers, on the Goodwin Sands, appeared formidable.

formidable. Upon the whole, they enjoyed a view perhaps more extended and diverſified than was ever beheld by mortal eye. The balloon was much diſtended, and at 50 minutes paſt one o'clock it was deſcending, in conſequence of which they were obliged to throw out one bag and a half of ſand. They were at this time about one third of the way from Dover, and had loſt diſtinct ſight of the caſtle. Not long after, finding that the balloon was deſcending very faſt, all the remaining ballaſt was thrown over, as alſo a parcel of books, in conſequence of which the balloon roſe again. They were now at about half way. At a quarter paſt two o'clock the riſing of the mercury in the barometer ſhewed that they were deſcending; in conſequencee of which the remaining books were thrown into the ſea. At 25 minutes after two, they were at about three-fourths of the way, and an enchanting view of the French coaſt appeared before their eyes; but the lower part of the balloon was collapſed, owing to the loſs or condenſation of the gas, and the machine was deſcending, which obliged them to throw over proviſions for eating, the oars or wings of the boat, and other articles. "We threw away," ſaid Dr. *Jeffries*, "our only bottle, which, in its deſcent, "caſt out a ſteam like ſmoke, with a ruſhing noiſe; "and when it ſtruck the water, we heard and felt "the ſhock very perceptibly on our car and bal-"loon." But the balloon ſtill approaching the ſea, they

they began to ſtrip and caſt away their clothes. They even intended to faſten themſelves to the cords and cut the boat away, as their laſt reſource; but at this critical point, they had the ſatisfaction to obſerve that they were riſing; their diſtance from the French ſhore, which they were approaching very faſt, was about four miles. Fear was now vaniſhing apace; the French land ſhewed itſelf every moment more beautiful, more diſtinct, and more extended; Calais, and above 20 other towns and villages, were clearly diſtinguiſhed. Exactly at three o'clock, they paſſed over the high grounds about midway between Cape Blanc and Calais; and it is remarkable that the balloon at this time roſe very faſt, and made a magnificent arch; probably owing to the heat of the land, which rarefied in ſome meaſure the hydrogen gas. At laſt they deſcended as low as the tops of the trees in the foreſt of Guinnes, and opening the valve for the eſcape of the gas, they ſoon after deſcended ſafe to the ground, after having accompliſhed an enterpriſe which will probably be recorded to the remoteſt poſterity.

The following is the melancholy account of an experiment which was attended with the death of two aërial adventurers, one of whom was Mr. de Rozier, the firſt perſon that ever aſcended with an aeroſtatic machine.

Mr. Pilatre de Rozier, deſirous of diverſifying and improving the new method of travelling through the

the air, formed a plan of combining the two ſpecies of aeroſtatic machines, from which he expected to render their joined buoyancy more laſting, and of courſe more uſeful. His plan was to place an inflammable air-balloon at top, and to affix to it, by means of ropes, a rarefied air-balloon, ſo that a ſpace of ſeveral feet might intervene between the two. The paſſenger or paſſengers were intended to take their places in the gallery of the lower machine, whence they could regulate the fire, and might, by a proper management of the fuel, elevate or depreſs the whole, without the neceſſity of loſing any inflammable gas from the upper balloon.

Accordingly this plan was put in execution. The upper or the inflammable air-balloon was of varniſhed ſilk, lined with a fine membrane, like goldbeaters' ſkin. The other aeroſtat was of ſtrong linen. On the 15th of June 1785, at ſeven o'clock in the morning, every thing being ready, Mr. Pilatre de Rozier and a Mr. Romain, placed themſelves in the gallery of the aeroſtat, with plenty of fuel, inſtruments, and other neceſſary articles; and roſe in the atmoſphere. The machine ſeemed to take the beſt poſſible direction, but the wind being both feeble and ſhifting, they changed their direction two or three times; but when they were at a conſiderable height, and not above $\frac{3}{4}$ of a mile from the place of aſcenſion, the machine appeared to be in flames, and preſently the whole was precipitated

down

down to the ground. The unfortunate adventurers were inſtantly killed, their bones disjointed and dreadfully mangled by the tremendous fall.

How the inflammable air took fire, is variouſly conjectured; but it is natural to ſuppoſe, that the ſparks of fire muſt have flown from the lower to the upper or inflammable air-balloon. On the ground, the bag of the upper balloon was in great meaſure burned or ſcorched; that of the lower was entire.

Omitting the various unintereſting, though not numerous, aërial voyages undertaken in various parts of the world, during the 17 years ſubſequent to the above-mentioned dreadful accident of Pilatre de Rozier and Mr. Romain, I ſhall only add the account of two aeroſtatic experiments lately performed in England by Mr. Garnerin, a French aeronaut. The firſt of thoſe is remarkable for the very great velocity of its motion; the ſecond for the exhibition of a mode of leaving the balloon, and of deſcending with ſafety to the ground.

On the 30th of June 1802, the wind being ſtrong, though not impetuous, Mr. Garnerin and another gentleman aſcended with an inflammable air-balloon from Ranelagh-gardens on the ſouth-weſt of London, between four and five o'clock in the afternoon; and exactly in three quarters of an hour they deſcended near the ſea, at the diſtance of four miles from Colcheſter. The diſtance of that place from

Ranelagh is ſixty miles; therefore they travelled at the aſtoniſhing rate of 80 miles per hour. It ſeems that the balloon had power enough to keep them up four or five hours longer, in which time they might have gone ſafe to the continent; but prudence induced them to deſcend when they ſaw the ſea not far off.

The ſingular experiment of aſcending into the atmoſphere with an inflammable air-balloon, and of deſcending with a machine called a *parachute (the breaker of a fall, or of a ſhock)* was performed by Mr. Garnerin on the 21ſt of September 1802. He aſcended from St. George's Parade, North Audley Street, and deſcended ſafe into a field near the Small-Pox Hoſpital at Pancras.

The balloon was of the uſual ſort, namely, of oiled ſilk, with a net, from which ropes proceeded, which terminated in, or were joined to, a ſingle rope at a few feet below the balloon. To this rope the parachute was faſtened in the following manner.

The reader may eaſily form to himſelf an idea of this parachute, by imagining to ſee a large umbrella of canvas of about 30 feet in diameter, but deſtitute of the ribs and handle. Several ropes of about 30 feet in length, which proceeded from the edge of the parachute, terminated in a common joining, from which ſhorter ropes proceeded, to the extremities of which a circular baſket was faſtened, and in in this baſket Mr. Garnerin placed himſelf. Now the ſingle rope, which has been ſaid above to proceed from the balloon, paſſed through a hole in the centre of the parachute, alſo through certain tin tubes, which were placed one after the other in the place of the handle or ſtick of an umbrella, and was laſtly faſtened to the baſket; ſo that when the balloon was in the air, by cutting the end of this rope next to the baſket, the parachute, with the baſket, would be ſeparated from the balloon, and, in falling downwards, would be naturally opened by the reſiſtance of the air. The uſe of the tin tubes was to let the rope ſlip off with greater certainty, and to prevent its being entangled with any of the other ropes, as alſo to keep the parachute at a diſtance from the baſket.

The balloon began to be filled at about two o'clock. There were 36 caſks filled with iron turnings, and diluted ſulphuric acid, for the production of the hydrogen gas. Theſe communicated with three other caſks or general receivers, to each of which was fixed a tube that emptied itſelf into the main tube attached to the balloon.

At ſix, the balloon being quite full of gas, and the parachute, &c. being attached to it, Mr. Garnerin placed himſelf in the baſket, and aſcended majeſtically amidſt the acclamations of innumerable ſpectators. The weather was the cleareſt and pleaſanteſt imaginable; the wind was gentle and about weſt

weſt by ſouth; in conſequence of which Mr. Garnerin went in the direction of about eaſt by north. In about eight minutes time, the balloon and parachute had aſcended to an immenſe height, and Mr. Garnerin, in the baſket, could ſcarcely be perceived. While every ſpectator was contemplating the grand ſight before them, Mr. Garnerin cut the rope, and in an inſtant he was ſeparated from the balloon, truſting his ſafety to the parachute.

At firſt, viz. before the parachute opened, he fell with great velocity; but as ſoon as the parachute was expanded, which took place a few moments after, the deſcent became very gentle and gradual. In this deſcent a remarkable circumſtance was obſerved; namely, that the parachute with the appendage of cords and baſket, ſoon began to vibrate like the pendulum of a clock, and the vibrations were ſo great, that more than once the parachute, and the baſket with Mr. Garnerin, ſeemed to be on the ſame level, or quite horizontal, which appeared extremely dangerous: however, the extent of the vibrations diminiſhed as he came pretty near to the ground. On coming to the earth, Mr. Garnerin experienced ſome pretty ſtrong ſhocks, and when he came out of the baſket, he was much diſcompoſed; but he ſoon recovered his ſpirits, and remained without any material hurt.

As ſoon as the parachute, &c. was ſeparated from the balloon, the latter aſcended with great rapidity, and,

and, being of an oval form, turned itſelf with its longer axis horizontal.

If it be aſked, what uſe can be made of the parachute, we can only anſwer, that it may be uſed as a precaution; viz. it may be attached to a balloon; and, in caſe the balloon ſhould take fire or burſt, the aeronaut might deſcend by the aſſiſtance of the parachute.

For farther particulars relative to the diſcovery of aeroſtatic machines, and of the various aërial voyages made ſoon after that diſcovery, as alſo for the practical part of the ſubject, ſee my Hiſtory and Practice of Aeroſtation.

CHAP. III.

FACTS ESTABLISHED BY THE VARIOUS AEROSTATIC EXPERIMENTS.

TWENTY years are now fully elapſed ſince the aeroſtatic machines were firſt invented. The experiments in this new branch of natural philoſophy have been frequently repeated, and often diverſified. Few accidents have happened; but a vaſt number of aërial voyages have perfectly ſucceeded; and if it be conſidered that moſt of the adventurers have been perſons little, if at all, ſkilled in philoſophy or mechanics, we may with more propriety wonder that a greater number of diſagreeable accidents has not happened. The ſimilarity with which a vaſt number of ſuch experiments has been performed, might enable the hiſtorian to deſcribe a great many aërial voyages with the very ſame words, ſaving the change of date, and of a few other unintereſting particulars; we have, therefore, ſelected for the preceding chapter, ſuch experiments as were attended with more remarkable reſults, whence the reader may derive a competent idea of the whole ſubject; and, in order to aſſiſt as much as poſſible the formation of an idea ſufficiently comprehenſive of aeroſtation in general, we ſhall ſubjoin a ſtatement of the moſt remarkable particulars that have been deduced from the reſults of experiments.

Two ſorts of aeroſtatic machines have been diſcovered, viz. one to be filled with rarefied common air; the other to be filled with hydrogen gas (inflammable air). The effect of thoſe machines is to lift up a certain weight into the atmoſphere, wherein they riſe to a greater or leſs height, according as they are more or leſs light than an equal bulk of common air. The firſt ſort may be filled either by applying a fire cloſe to its aperture, only before it goes up, which introduces a quantity of heated and rarefied air into the machine; or by adapting a fire-place to the neck of the machine, wherein the fire may be continued. In the firſt caſe, the aeroſtat remains only a ſhort time in the atmoſphere, viz. until the encloſed air cools, and becomes nearly of the ſame temperature as the circumambient air. In the ſecond caſe the machines remain in the air as long as the fire is continued in the fire-place. The inflammable air-balloons remain in the air as long as a ſufficient quantity of gas remains within them, which amounts in general to ſeveral hours, according to the quality of the ſtuff which forms the envelope.

The air rarefied as much as is practicable in ſuch machines, is by no means ſo light as an equal bulk of hydrogen gas; hence, in order to ſupport a given weight,

weight, an aeroſtatic machine, with rarefied air, muſt be larger than one with the gas. In order to ſupport a ſingle man of a mean ſize, a machine of the firſt ſort ought to be about 30 feet in diameter; of the latter ſort it will juſt do if the diameter be 20 feet.

In the atmoſphere, the machine is at reſt with reſpect to the ſurrounding air; hence it moves with that air; and hence the aeronauts feel no wind, nor any diſturbance whatever, excepting in the above-mentioned caſe of the duke of Chartres; ſo much ſo, that they hear their leaſt whiſpers with great diſtinction, and it is remarkable that they feel no ſickneſs or giddineſs.

Several attempts have been made to direct the aeroſtatic machines out of the direction of the wind; but the contrivances have not met with any uſeful effect. The oars or wings, or ſuch other mechaniſms, intended to let the balloon move in a direction either contrary or oblique to that of the wind, have a very trifling effect; for inſtance, in a perfect calm, by the management of the above-mentioned wings, the machine might perhaps be moved at the rate of about half a mile per hour; then if the balloon, with a moderate breeze, move in a certain direction at the rate of about 30 miles per hour, it is evident that the action of the wings, when managed by one or two ſtrong men, can hardly cauſe the deflection of the balloon from the direction of the wind in any ſenſible or uſeful degree.

What

What is the uſe, and what is the advantage, which the human ſpecies has derived, or is likely to derive, from the uſe of ſuch machines, is an important queſtion, to which as much attention ſhould be paid as the ſtate of the ſubject will admit of. During the firſt five or ſix years after the diſcovery, aeroſtatic machines excited an unparallelled enthuſiaſm throughout the civilized part of the world; perſons of every rank eagerly ſought to learn, to ſee, and to promote, the new diſcovery. Liberal ſubſcriptions have aſſiſted the enterpriſers in almoſt every part of Europe and elſewhere; and perhaps an indifferent eye was never turned away from the exhibition of aeroſtatic experiments; yet independent of the pleaſure which ariſes from a view or from the performance of ſuch experiments, the human ſpecies has not derived any real advantage from the ſubject of aeroſtation. The expence, the time, and the trouble, which attend the conſtruction, and the uſe of aeroſtatic machines, will perhaps ever prevent their being uſed as vehicles for travellers, eſpecially conſidering that they can only move in the direction of the wind, which is frequently unfavourable, and always uncertain. Nevertheleſs in certain caſes the uſe of balloons might be not only advantageous, but the only one practicable. During the late wars on the continent, it is ſaid that the French made great uſe of balloons for reconnoitring the poſition of the adjacent country, or of the armies of their enemies. For this purpoſe, an inflammable air-balloon, juſt ſufficient to hold a ſingle perſon, was faſtened by a ſlender cord, and was permitted to riſe not higher than three or four hundred feet, from which elevation the obſerver could eaſily form a plan of the country, or army, &c.

With reſpect to philoſophical experiments in the atmoſphere, little has been done by means of balloons; nor can much be expected to be done, unleſs perſons of real knowledge and ability be employed and aſſiſted in the enterpriſe.

It has been generally obſerved by aeronauts, that during the abſence of the ſun, the cold in the upper regions is conſiderable; but the direct rays of the ſun produce much heat, which is rendered more likely by conſidering that the air about the aeronaut and balloon, is reſpectively at reſt, and cannot diſſipate the heat, as the wind does with reſpect to a perſon who ſtands on a mountain. The cold of the atmoſphere increaſes, *cæteris paribus*, with the increaſe of diſtance from the earth; but the greateſt height, to which aeronauts have aſcended, though not preciſely known, ſeems to be about 16000 feet. They ſeldom ſpeak of having felt any uneaſineſs with reſpect to reſpiration, or other animal function.

I was told of a magnetic experiment ſaid to have been made by three gentlemen, who aſcended with an inflammable air-balloon from the vicinity of London, on the 3d of June 1785. They obſerved that a magnet, when in the atmoſphere, would not hold nearly as much weight as it did when it ſtood as uſual on the ſurface of the earth.

Relative to the conſtruction of aeroſtatic machines, the following particulars may be of uſe to thoſe who are deſirous of performing ſuch experiments.

The two ſorts of aeroſtatic machines have their peculiar advantages and diſadvantages. Thoſe with rarefied air are leſs expenſive, though they muſt, *cæteris paribus*, be larger than thoſe of the other ſort. The former, if ſmall, are made of paper; and when they are required to lift up conſiderable weights, ſuch as men and other things, they are made of ſtrong coarſe linen, which has ſometimes been lined with paper. When made, it would be not improper to dip them once in a ſolution of alum, and then to dry them; in that ſtate being leſs liable to take fire. But the greateſt objection to the uſe of ſuch aeroſtats, is, that they require a conſiderable quantity of fuel, which, beyond a certain meaſure, cannot be admitted into the gallery; in fact, the aërial voyages that have been made with this ſort of machines, have all been of ſhort duration. Beſides, the neceſſity of keeping up the fire is a continual ſource of trouble and of danger. However, as the materials and the fuel for the conſtruction and uſe of ſuch machines, may be found almoſt every where and at a moderate rate, their uſe may juſtly be recommended for experiments, eſpecially where the materials neceſſary for the other ſort of balloons cannot be procured.

The

The inflammable air-balloons are conſiderably more expenſive. Nothing has been found more advantageous for their envelope, than oiled, or rather varniſhed ſilk; which is by no means a cheap article, eſpecially in England. Reſpecting the production of the gas, the only method practicable for this purpoſe, is to uſe the iron turnings, which may be had at various iron manufactories, and diluted ſulphuric acid. I do not proceed to ſtate in this place the utmoſt quantity of hydrogen gas that a chemiſt can extract in his laboratory, from a given quantity of iron and acid; ſince that preciſion of operation cannot be expected with large proceſſes, ſuch as are neceſſary to fill a balloon in the open air, and with a coarſe apparatus; but I ſhall ſtate one of the moſt economical operations for filling a balloon, which came to my notice when Mr. Blanchard made an aërial excurſion with a balloon of only 20 French feet (about 21 Engliſh) in diameter, from which the reader may judge of ſimilar operations. That balloon was completely filled by the uſe of 1000 pounds weight of iron turnings, and 1250 pounds weight of ſulphuric acid. The iron, however, was too much, and 900 pounds weight of it might have ſufficed. The capacity of that balloon was 4849 cubic feet, Engliſh meaſure. The apparatus for the operation of filling it conſiſted of only four caſks, each having a tube which communicated with a common receiver inverted in water, whence the gas was conveyed into the balloon, which was ſuſpended over it. The capacity of each caſk was 120 gallons. The operation laſted between 10 and 11 hours.

Notwithſtanding the much greater expence and trouble which attend the conſtruction and the filling of this ſort of balloons, it muſt be acknowledged that they are by far the moſt uſeful and moſt pleaſant aërial vehicles. Once full, they require very little attendance; and, by a proper management of the ballaſt, the aeronauts may keep them up for a conſiderable time. A balloon of this ſort, not above 36 feet in diameter, if properly conſtructed, properly filled, and dexterouſly managed, might keep up in the atmoſphere two perſons of moderate weight, perhaps longer than 30 hours—time ſufficient, with a pretty good wind, to croſs the whole continent of Europe.

SECTION II.

OF METEORS; AND OF THE STONY SUBSTANCES, WHICH, AT VARIOUS TIMES, ARE SAID TO HAVE FALLEN FROM THE SKY.

GENERAL and frequent obſervation ſhews that fogs, miſts, dews, rain, ſnow, and hail, fall more or leſs copiouſly from the atmoſphere upon the ſurface of the earth; and that all thoſe bodies conſiſt of the ſame ſubſtance, namely, water, either in the ſtate of ſteam, or of fluid water, or, laſtly, under a congealed form.

Though we cannot rightly underſtand the mechanical operation by which water is converted into vapour, and *vice verſa*, yet it is in general known, that water reduced into vapour, aſcends in the atmoſphere, and forms the clouds; alſo that afterwards the clouds are reſolved into water, which, according to its quantity, and according to the various temperatures or other ſtates of the atmoſphere, deſcends, under various forms, on the ſurface of the earth.

The electricity, which experiments ſhew (as has been mentioned in the preceding volume) to be produced at the time of the converſion of water into vapour,

vapour, and likewiſe at the converſion of vapour into water, ſeems ſufficient to account for the thunder and lightning, which pretty often accompany the clouds. But independent of thoſe effects, there have been obſerved in the atmoſphere two other ſorts of phenomena, which the preſent ſtate of philoſophical knowledge is not ſufficient to explain; nor can even offer an hypotheſis ſufficiently plauſible for their explanation. I mean, firſt, thoſe luminous apparitions generally known under the name of *meteors*; and, 2dly, the ſtony ſubſtances which at various times are ſaid to have fallen on the ſurface of the earth.

The concurrence of ſeveral obſervations ſeems to ſhew, that there is a conſiderable connection between thoſe phenomena, and it is on this account that a compendious examination of both has been placed in this ſame ſection.

CHAPTER I.

OF METEORS.

THE ſudden apparition and ſhort duration of luminous bodies in the ſky, of different ſize, and generally of quick motion, ſeems to have been obſerved from time immemorial; for we find accounts of ſuch apparitions in a variety of ancient authors, who, according to the different ſhapes of thoſe phenomena, gave them the names of *faces*, or *globi*, or *flammæ*, &c. and in latter times they are denoted by the different names of *ſhooting-ſtars*, *balls of fire*, or *meteors*.

Not much information can be derived relative to thoſe phenomena from ancient accounts, which are moſtly too ſhort and incorrect; or they are involved in myſtery, and diſtorted by exaggerated expreſſions; but the obſervations of latter times, eſpecially thoſe which come within our remembrance, afford much more ſatisfactory information. The moſt magnificent meteor of latter times, was ſeen on the 18th of Auguſt 1783; and as I had the good fortune to obſerve it from a moſt eligible ſituation,

viz.

viz. from the terrace of Windſor caſtle; I ſhall tranſcribe the account which I ſent to the Royal Society; from which the reader may form a competent idea of meteors in general. I ſhall then ſubjoin the obſervations made on other meteors, whence the ſimilarity or the diſſimilarity of particular circumſtances may be eaſily ſeen.

The following account was formed from the concurring obſervations of a few intelligent friends with whom I then happened to be in company, every one of whom made ſome particular remark.

On the evening of the 18th of Auguſt 1783, we were ſtanding upon the north-eaſt corner of the above-mentioned terrace. The weather was calm, and agreeably warm; the ſky was ſerene, excepting very near the horizon, where a hazineſs juſt prevented the appearance of the ſtars. A narrow, ragged, and oblong cloud ſtood on the north-weſt ſide of the heavens, reaching from the extremity of the hazineſs, which roſe as high as 18 or 20 degrees, and ſtretching itſelf for ſeveral degrees towards the eaſt, in a direction nearly parallel to the horizon. It was a little below this cloud, and conſequently in the hazy part of the atmoſphere, about the N. by W. ½ W. point of the compaſs that this luminous meteor was firſt perceived. Some flaſhes of lambent light, much like the *aurora borealis*, were firſt obſerved on the northern part of the heavens, which were ſoon perceived to proceed from a roundiſh luminous body, nearly as big in diameter as the ſemidiameter

diameter of the moon, and almoſt ſtationary in the above-mentioned point of the heavens. It was then about 25 minutes after nine o'clock in the evening. This ball at firſt appeared of a faint bluiſh light, perhaps from being juſt kindled, or from its appearing through the hazineſs; but it gradually increaſed its light, and ſoon began to move, at firſt aſcending above the horizon in an oblique direction towards the eaſt. Its courſe in this direction was very ſhort, perhaps of five or ſix degrees; after which it directed its courſe towards the eaſt, and, moving in a direction nearly parallel to the horizon, reached as far as the S. E. by E. point, where it finally diſappeared. The whole duration of the meteor was half a minute, or rather leſs; and the altitude of its track ſeemed to be about 25° above the horizon. A ſhort time after the beginning of its motion, the luminous body paſſed behind the above-mentioned ſmall cloud, ſo that during this paſſage we obſerved only the light which was caſt in the heavens from behind the cloud, without actually ſeeing the body from which it proceeded for about the ſixth or at moſt the fifth part of its track; but as ſoon as the meteor emerged from behind the cloud, its light was prodigious. Every object appeared very diſtinct; the whole face of the country in that beautiful proſpect before the terrace, being inſtantly illumined. At this moment the body of the meteor appeared of an oblong form; but it preſently acquired a tail, and ſoon after it parted into ſeveral

ſeveral ſmall bodies, each having a tail, or elongation; and all moving in the ſame direction, at a ſmall diſtance from each other, and very little behind the principal body, the ſize of which was gradually reduced after this diviſion. In this form the whole meteor moved as far as the S. E. by E. point, where, the light decreaſing rather abruptly, the whole diſappeared.

During the phænomenon, no noiſe was heard by any of our company, excepting one perſon, who imagined to have heard a crackling noiſe, ſomething like that which is produced by ſmall wood when burning. But about 10 minutes after the diſappearance of the meteor, and when we were juſt going to retire from the terrace, we heard a rumbling noiſe, as if it were of thunder at a great diſtance, which, in all probability, was the report of the meteor's exploſion; and it may be naturally imagined that this exploſion happened when the meteor parted into ſmall bodies, viz. at about the middle of its track.

Now if that noiſe was really the report of the exploſion, which happened at the above-mentioned place; the diſtance, altitude, courſe, and other particulars relating to this meteor, muſt be very nearly ſuch as are expreſſed in the following liſt; they being calculated with mathematical accuracy upon the preceding particulars, and upon the ſuppoſition that ſound travels at the rate of 1150 feet per ſecond. But if the noiſe we heard was not that of the meteor's meteor's exploſion, then the following reſults muſt be conſidered as quite uſeleſs and erroneous.

Diſtance of the meteor from Windſor caſtle - - - - - -	130 miles.
Length of the path it deſcribed in the heavens - - - - -	550 miles.
Diameter of the luminous body when it came out of the clouds - -	1070 yards.
Its height above the ſurface of the earth	56½ miles.

The exploſion muſt have happened perpendicularly over Lincolnſhire *.

Such is the account which I wrote the day after the appearance of the meteor; and it is remarkable that the above-mentioned particulars were almoſt entirely confirmed by various other accounts of the ſame meteor, which were afterwards either ſent to the Royal Society, or inſerted in different publications.

Thoſe accounts, which were ſent from various parts of this iſland, as alſo from the continent, confirmed, as nearly as can be expected, the above-mentioned reſults reſpecting its ſize, velocity, elevation, and exploſion, over Lincolnſhire; but this meteor muſt have certainly had its origin much farther north than we imagined; and indeed, on

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* Philoſophical Tranſactions for the year 1784. Article IX.

account of the intervening cloud, it was impoſſible for us to perceive it at an earlier part of its courſe. It is alſo probable that it muſt have gone or terminated at a much greater diſtance than it appeared to us; for as its light diminiſhed until it vaniſhed, we muſt naturally have loſt ſight of it ſooner than thoſe who ſtood farther ſouth on the continent. The various accounts ſeem to eſtabliſh, that its courſe commenced beyond the northern extremity of this iſland, probably ſomewhere over the northern ocean. It paſſed a little weſtward of Perth, and perhaps a little eaſtward of Edinburgh: it proceeded over the ſouth of Scotland, Northumberland, the biſhopric of Durham, Yorkſhire, Lincolnſhire, over which it ſeemed to have deviated gradually to the weſtward, and in the courſe of that deviation, to have ſuffered the burſting or partition. It then paſſed over Cambridgeſhire, Eſſex, and the Straits of Dover, entering the continent probably not far from Dunkirk, where, as well as at Calais and Oſtend, it was thought to be vertical. It was ſeen at Bruſſels, Paris, Nuits in Burgundy, and, it is ſaid, even at Rome. Upon the whole it muſt have deſcribed a track upwards of 1000 miles in about half a minute; an aſtoniſhing rate of going, vaſtly ſwifter than the motion of ſound.

Such are the particulars of this magnificent meteor, which undoubtedly was one of the largeſt, and with which ſeveral other accounts may be compared for the ſake of forming ſome general idea of the ſubject.

I am unwilling to aſſert, though I have no particular reaſon to deny, that the large meteors, ſuch as we have deſcribed, and thoſe which are commonly called ſhooting-ſtars, have a common origin, or are of the ſame nature, and differ only in ſize. Our utter ignorance of their nature, and the want of accurate obſervations, do not enable us to form any other diſtinction. It appears then, that the number of meteors is immenſe; for the ſhooting-ſtars, or the meteors of the ſmalleſt ſize, are to be ſeen in plenty every clear night. Some of them are ſo ſmall as to be accidentally ſeen only through teleſcopes, others are viſible to the naked eye that happens to be directed to that part of the ſky; whilſt others, by caſting more or leſs light, excite attention, and are remarked.

The apparent ſize of thoſe meteors is various; but their apparent motions, when they happen to direct their courſe nearly at right-angles to the ſpectator, ſeem not to differ much: whence we may conclude that they are nearly at equal diſtances from the earth; and of courſe they muſt actually differ in ſize. This point, however, is much in want of confirmation, and it might be wiſhed that three or four obſervers, in a pleaſant autumnal evening, were ſituated at certain diſtances (for inſtance 10 or 20 miles) from each other, and would endeavour to remark the altitudes of all the ſhooting-ſtars they ſaw,

ſaw, together with the time of their appearance. The altitude may be eaſily aſcertained by obſerving the ſtars over or near which the meteor paſſes, and by referring it to a common celeſtial globe, rectified for the latitude of the place and time of the apparition, &c. By this means the altitudes above the ſurface of the earth, of thoſe diminutive meteors, might in great meaſure be aſcertained. With reſpect to large meteors, whoſe altitudes have been pretty well eſtimated, it is remarkable that they have been found to be nearly at the ſame height. A meteor mentioned in the 51ſt volume of the Philoſophical Tranſactions, ſeems to have attained the height of nearly 50 miles. In the acts of the Academy of Sciences at Paris, for 1771, a meteor is deſcribed which was ſeen on the 17th of July 1771; and it was reckoned to have been 54 miles high when it began, and 27 when it exploded. The greateſt altitude of the meteor of the 18th of Auguſt 1783, was about 56 miles with reſpect to ſize; a region where the air is at leaſt 30000 times rarer than near the earth.

This ſame meteor of the 18th of Auguſt, was certainly one of the largeſt; ſome accounts, however, make mention of a few larger meteors having been ſeen; but it muſt be obſerved that the dazzling light of ſuch bodies always tends to impreſs the mind of the obſerver with an enlarged idea of their ſizes.

The ſhapes of ſuch bodies have been differently deſcribed. They have been compared to torches, pillars, barrels, paper kites, &c. &c. which ſhews that they muſt really be of different forms; yet it is evident that moſt of thoſe varieties muſt ariſe from the different poſitions of thoſe bodies with reſpect to the obſervers. Their moſt uſual form is nearly globular, generally having a ſort of tail or elongation, which is of various lengths in different meteors, and changeable in the very ſame meteor. Some meteors ſeem to preſerve their ſhapes during their appearance, others change it, and frequently they are divided, or burſt, into ſmaller bodies. The ſame meteor has been ſometimes obſerved to burſt more times than once during its appearance.

At the time of the apparent burſting, a hollow ſound, like that of diſtant thunder, or a much ſharper ſound, has often been heard; and ſome of the meteors that have come nearer to the earth, have been attended with a hiſſing, or a ſort of rattling noiſe, during the greateſt part of their courſe.

The colour and ſplendour of meteors vary conſiderably in different meteors, as alſo in the ſame meteor throughout its courſe. In general it is white, with a ſhade of blue. Their luſtre has ſometimes exceeded that of the moon, and it is related that meteors have been ſeen even in the broad day-light, and full ſun-ſhine.

The duration of the appearance of meteors has hardly ever exceeded half a minute; and it is often ſo inſtantaneous as to be barely perceptible.

That meteors have, laſtly, ended their courſe upon the

the ſurface of the earth, or that ſomething hard has fallen from them, has been aſſerted in various accounts; amongſt which I ſhall tranſcribe the following, which is very circumſtantially related by John Lloyd Williams, Eſq. in the Philoſophical Tranſactions for 1802. This gentleman being in India, and having heard of an extraordinary phenomenon which had juſt happened, made particular inquiries concerning it. "The information," he ſays, "I obtained was, that on the 19th of December 1798, about 8 o'clock in the evening, a very luminous meteor was obſerved in the heavens, by the inhabitants of Benares, and the parts adjacent, in the form of a large ball of fire; that it was accompanied by a loud noiſe, reſembling thunder; and that a number of ſtones were ſaid to have fallen from it, near Krakhut, a village on the north ſide of the river Goomty, about 14 miles from the city of Benares.

"The meteor appeared in the weſtern part of the hemiſphere, and was but a ſhort time viſible: it was obſerved by ſeveral Europeans, as well as natives, in different parts of the country.

"In the neighbourhood of Juanpoor, about 12 miles from the ſpot where the ſtones are ſaid to have fallen, it was very diſtinctly obſerved by ſeveral European gentlemen and ladies; who deſcribed it as a large ball of fire, accompanied with a loud rumbling noiſe, not unlike an ill diſcharged platoon of muſquetry. It was alſo ſeen, and the noiſe heard, by various perſons at Benares. Mr. Davis obſerved the light come into the room where he was, through a glaſs window, ſo ſtrongly as to project ſhadows from the bars between the panes, on a dark-coloured carpet, very diſtinctly; and it appeared to him as luminous as the brighteſt moon-light.

" When an account of the fall of the ſtones reached Benares, Mr. Davis, the judge and magiſtrate of the diſtrict, ſent an intelligent perſon to make inquiry on the ſpot. When the perſon arrived at the village near which the ſtones were ſaid to have fallen, the natives, in anſwer to his inquiries, told him, that they had either broken to pieces, or given away, to the Teſſeldar (native collector) and others, all that they had picked up; but that he might eaſily find ſome in the adjacent fields, where they would be readily diſcovered (the crops being then not above two or three inches above the ground), by obſerving where the earth appeared to be recently turned up. Following theſe directions, he found four, which he brought to Mr. Davis: moſt of theſe, the force of the fall had buried, according to a meaſure he produced, about ſix inches deep, in fields which ſeemed to have been recently watered; and it appeared from the man's deſcription, that they muſt have lain at the diſtance of about 100 yards from each other.

" What he further learnt from the inhabitants of the village, concerning the phenomenon, was, that about 8 o'clock in the evening, when retired to their

their habitations, they obſerved a very bright light, proceeding as from the ſky, accompanied with a loud clap of thunder, which was immediately followed by the noiſe of heavy bodies falling in the vicinity. The firſt circumſtance which attracted their attention, was the appearance of the earth being turned up in different parts of their fields, as before-mentioned, where, on examining, they found the ſtones.

" At the time the meteor appeared, the ſky was perfectly ſerene; not the ſmalleſt veſtige of a cloud had been ſeen ſince the 11th of the month, nor were any obſerved for many days after.

" Of theſe ſtones, I have ſeen eight, nearly perfect, beſides parts of ſeveral others, which had been broken by the poſſeſſors to diſtribute among their friends. The form of the more perfect ones, appeared to be that of an irregular cube, rounded off at the edges; but the angles were to be obſerved on moſt of them. They were of various ſizes, from about three to upwards of four inches in their largeſt diameter; one of them meaſuring 4 ¼ inches, weighed two pounds and 12 ounces. In appearance they were exactly ſimilar: externally, they were covered with a hard black coat or incruſtation, which in ſome parts had the appearance of varniſh, or bitumen; and on moſt of them were fractures, which, from their being covered with a matter ſimilar to that of the coat, ſeemed to have been made in the fall, by the ſtones ſtriking againſt each other,

other, and to have paſſed through ſome medium, probably an intenſe heat, previous to their reaching the earth. Internally, they conſiſted of a number of ſmall ſpherical bodies, of a ſlate colour, embedded in a whitiſh gritty ſubſtance, interſperſed with bright ſhining ſpiculæ, of a metallic or pyritical nature. The ſpherical bodies were much harder than the reſt of the ſtone: the white gritty part readily crumbled, on being rubbed with a hard body; and, on being broken, a quantity of it attached itſelf to the magnet, but more particularly the outſide coat or cruſt, which appeared almoſt wholly attractable by it."

It ſeems from this account, that the meteor conſiſted of a large body, which burſt at the time when the report was heard, and that its fragments fell to the earth.—The principal remarks, which have been made concerning thoſe and other ſtony ſubſtances, ſaid to have fallen from the ſky, will be found in the following chapter.

CHAP. II.

OF THE STONY BODIES WHICH ARE SAID TO HAVE FALLEN FROM THE SKY.

THE writings even of the remoteſt antiquity, the verbal traditions of moſt nations, and various circumſtantial accounts of modern times, aſſert that ſtones, or ſtony and metallic concretions of various ſizes, have, at different times, fallen from heaven upon the ſurface of the earth.

Ignorance and ſuperſtition have frequently attributed a ſacred character to thoſe extraordinary ſtones; but ſince ſuperſtition and impoſture are nearly allied, and as the formation of ſuch ſolid bodies in the ſky is utterly unaccountable in the preſent ſtate of philoſophical knowledge, the fall of thoſe celeſtial ſtones, though generally believed by the vulgar, has been as generally diſbelieved by the learned, part of the human ſpecies.

Every ſingle account of this ſort might perhaps be rejected without impropriety; but the repeated aſſertions of a great many authors in almoſt every age; the accounts of recent caſes of this ſort that have happened in the preſence of witneſſes, living at this very time, who have been examined and interrogated with all the formality and circumſtantial minuteneſs that ſcepticiſm could demand; and, above all, the ſtrong evidence which ariſes from the chemical analyſis of various ſtones of this ſort, which have been collected at different times, and in moſt diſtant countries, are more than ſufficient to eſtabliſh the general fact in the minds of impartial perſons; and only leave for poſterity the duty of examining with the greateſt attention, and of recording with minuteneſs, all the circumſtances that may attend future caſes of this ſort; whence the origin and the nature of ſuch wonderful phenomena may be ſatisfactorily inveſtigated.

We are much indebted to Edward King, Eſq.* and to Dr. Chlodni †, for having collected a great number of accounts relative to this ſubject, and for having ably compared them with each other; and we are principally indebted to Edward Howard, Eſq. for a careful analyſis of various ſtones ſaid to have fallen from heaven.

The fall of aſhes, and even of red-hot ſtones in the vicinity of volcanos, at the time of an eruption, are ſo evidently owing to the eruption, that no doubt

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* See his *Remarks concerning Stones ſaid to have fallen from the Clouds, both in theſe Days, and in ancient Times.*—London, 1796.

† See his Tract concerning the ſuppoſed Origin of the Maſs of Iron found by Dr. Pallas in Siberia.—Riga, 1794.

can be entertained concerning the fact. The ignited matter, accompanied with very denſe ſmoke, is ſeen to riſe from the crater of the volcano, and is projected into the air, even to the perpendicular height of ſeveral miles *; the thick, dark ſmoke forms a cloud of vapour and aſhes, which is extended by the wind in its direction, over a great extent of country, ſometimes amounting to ſeveral hundred miles; upon which it drops aſhes †, and in the neareſt parts even ſtones of different ſizes, according to the various diſtances. But independent of thoſe evident volcanic productions, the ſtones of conſiderable ſize, which are ſaid to have fallen at different times, ſeem to have a different origin; firſt, becauſe they have frequently fallen at immenſe diſtances from any volcano; and, ſecondly, becauſe thoſe falls have moſtly happened at times when no volcanic eruption was known to have taken place. It is not improbable, however, as Mr. King ſeems to conjecture, that ſometimes, when an extenſive cloud of aſhes, or earthy and pyritous particles, has been projected from a volcano, and has been driven by the wind

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* See Sir William Hamilton's Account of an Eruption of Mount Veſuvius, in the Philoſophical Tranſactions for 1795, page 91 and 92.

† At an eruption of Veſuvius, anno 471, the aſhes went almoſt all over Europe, and in plenty even to the city of Conſtantinople. Carolus Sigonius, and Marcellinus Comes, make expreſs mention of that great eruption.

to a great diſtance, thoſe particles may have undergone an efferveſcence, a combuſtion, and a ſubſequent agglutination, which formed the ſtone. The facts, however, do not always ſeem to admit of ſuch a ſuppoſition. But before we attempt to aſſert or to refute any hypotheſis, it will be proper briefly to mention ſome of the lateſt and beſt atteſted facts of this nature; which I ſhall moſtly tranſcribe from the above quoted work of Mr. King.

" The well known and celebrated Cardan, in his book *De Varietate Rerum*, lib. 14, cap. 72, tells us, that he himſelf, in the year 1510, had ſeen 120 ſtones fall from heaven; among which one weighed 120 and another 60 pounds; that they were moſtly of an iron colour, and very hard, and ſmelt of brimſtone. He remarks, moreover, that about three o'clock, a great fire was to be ſeen in the heavens; and that about five o'clock the ſtones fell down with a ruſhing noiſe."

" It is related by Dr. Halley (Philoſophical Tranſactions, N° 341), that on the 21ſt of May 1676, a fire ball was ſeen to come from Dalmatia, proceeding over the Adriatic ſea; it paſſed obliquely over Italy, where a hiſſing noiſe was heard; it burſt S.S.W. from Leghorn, with a terrible report, and the pieces are ſaid to have fallen into the ſea, with the ſame ſort of noiſe as when red-hot iron is quenched or extinguiſhed in water. Its height was computed to be not leſs than 38 Italian miles; and it is ſaid to have moved with immenſe velocity. Its form was oblong, at leaſt as the luminous appearance ſeemed in its paſſage."

The Abbé Stutz, aſſiſtant in the imperial cabinet of curioſities at Vienna, in a book printed at Leipſic in 1790, deſcribes two ſtones ſaid to have fallen from the clouds; one in the *Eichſtedt* country in Germany, and another in the *Bechin* circle in Bohemia, in July 1753. He alſo deſcribes two more which were ſeen to fall not far from Agram, the capital of Croatia in Hungary; concerning which, he relates that the biſhop of Agram cauſed ſeven eye-witneſſes to be examined upon oath, and the ſubſtance of their evidence is, "that about ſix o'clock in the afternoon of the 26th of May 1751, there was ſeen towards the eaſt, a kind of fiery ball, which, after it had burſt into two parts, with a great report, exceeding that of a cannon, fell from the ſky, in the form and appearance of two chains entangled in one another; which was attended with a loud noiſe, as if a great many carriages rolled along. After this a black ſmoke was ſeen, and a part of the ball ſeemed to fall in an arable field; on the fall of which to the ground a ſtill greater noiſe was heard, and a ſhock was perceived ſomewhat like an earthquake.

"This piece was afterwards ſoon dug out of the ground, which had been particularly noted to be plain and level, and ploughed juſt before; but where it was now found to have made a grert fiſſure, or cleft, an ell wide, whilſt it ſinged the earth on the ſides.

"The

"The other piece, which fell in a meadow, was alſo dug up, and weighed 16 pounds."

The ſtone which fell in the Eichſtedt country, as mentioned in the preceding page, is ſaid to conſiſt of aſh-grey ſand, agglutinated together, and intermixed with fine particles of native iron, and with particles of yellowiſh brown iron ochre. In ſhort, it ſeems to conſiſt of ſiliceous ſand and iron. Its hardneſs is not very great. Its ſurface is covered all over with a ſolid malleable coat of native iron, like a blackiſh glazing, about two lines thick, which was ſuppoſed to be quite free from ſulphur. The whole exhibited evident marks of having been expoſed to fire.

The teſtimony of the fall of this ſtone is as follows: A labourer at a brick-kiln, in winter, when the earth was covered with ſnow, ſaw it fall down out of the atmoſphere immediately after a violent clap of thunder. He inſtantly ran to the ſpot to take it out of the ſnow; but, finding he could not effect it on account of its heat, he was obliged to wait until it cooled. The diameter of this ſtone was about half a foot. It was covered all over with a black coat like iron.

"It is related in the Hiſtory of the Academy of Sciences 1769, p. 20, that three maſſes fell down with thunder, in provinces very diſtant from one another; and which were ſent to the Academy in 1769. They were ſent from *Maine*, *Artois*, and *Cotentin*; and it is affirmed, that, when they fell, a hiſſing

hiſſing was heard; and that they were found hot. All three were like one another; all three were of the ſame colour, and nearly of the ſame grain; and ſmall metallic and pyritical particles could be diſtinguiſhed in them; and, externally, all three were covered with a hard ferruginous coat; and, on chemical inveſtigation, they were found to contain iron and ſulphur."

"On the 13th of September 1768, about half an hour after four in the afternoon, there was ſeen near the caſtle of Lucè in Maine, a tempeſtuous cloud; from which was heard an exploſion of thunder, like the firing of a cannon, but without the appearance of lightning: there was then heard a remarkable whizzing noiſe in the air; and ſome perſons travelling, on looking up, ſaw an opaque body deſcending in a curved line, which fell in a green patch of ground near the high road to *Mons*. They all ran inſtantly to the ſpot, and found a kind of ſtone, one half of which was buried in the ſoil, and which was ſo burning hot, that they could not poſſibly touch it.

"This ſtone weighed ſeven pounds and a half; was of a triangular, or rather of a *pyramidal*, form. The part which was buried in the earth was of a grey-aſh colour, and that which was expoſed to the air was extremely black, covered with a very thin black cruſt, ſomewhat puffed up in places, and which appeared to have been melted. The interior part of the ſtone, when examined with a magnifying glaſs,

glaſs, appeared of a grey pale aſh colour, ſpotted with a prodigious number of minute brilliant metallic ſpots, and of a pale yellow. The interior part, when ſtricken with ſteel, would not yield any ſparks; but the exterior coating did.

" The ſpecific gravity of the ſtone was 3,535. And the chemical analyſis of it, ſhewed it to contain, in 100 parts, 8 ½ of ſulphur, 36 of iron, and 55 ½ of vitrifiable earth."

" On the 16th of June 1794, a tremendous cloud was ſeen in Tuſcany, near Siena, and Radacoſani; coming from the north, about 7 o'clock P.M. ſending forth ſparks like rockets, throwing out ſmoke like a furnace, rendering violent exploſions, and blaſts, more like thoſe of cannon, and of numerous muſkets, than like thunder; and caſting down to the ground hot ſtones; whilſt the lightning that iſſued from the cloud was remarkably red, and moved with leſs velocity than uſual.

The cloud appeared of different ſhapes, to perſons in different ſituations, and remained ſuſpended a long time; but every where was plainly ſeen to be burning, and ſmoking like a furnace; and its original height, from a variety of circumſtances put together, ſeems to have been much above the common region of the clouds.

" The teſtimony, concerning the falling of the ſtones from it, appears to be almoſt unqueſtionable; and is evidently from different perſons, who had no communication with each other.

" For,

" For, firſt, the fall of four ſtones is preciſely aſcertained; one of which was of an irregular figure, with a point like that of a diamond, weighing 5½ pounds, and had a vitriolic ſmell. And another weighed 3½ pounds, was black on the outſide, as if from ſmoke; and, internally, ſeemed compoſed of matter of the colour of aſhes, in which were perceived ſmall ſpots of metals, of gold and ſilver.

" And beſides theſe, Profeſſor Soldani of Siena was ſhewn about 15 others, the ſurfaces of which were glazed black, like a ſort of varniſh; reſiſted acids, and were too hard to be ſcratched with the point of a penknife.

" Signior A. Montauli, who ſaw the cloud as he was travelling, deſcribed it as appearing much above the common region of the clouds, and as being clearly diſcerned to be on fire; and becoming white, by degrees, not only where it had a communication, by a ſort of ſtream of ſmoke and lightning, with a neighbouring ſimilar cloud, but alſo, at laſt, in two-third parts of its whole maſs, which was originally black. And yet he took notice, that it was not affected by the rays of the ſun, though they ſhone full on its lower parts. And he could diſcern as it were the baſon of a fiery furnace in the cloud, having a whirling motion.

" This curious obſerver gives an account alſo of a ſtone, which he was aſſured fell from the cloud, at the feet of a farmer, and was dug out of the ground into which it had penetrated; and he ſays, that it was about five inches long, and four broad, nearly ſquare, and poliſhed; black on the ſurface, as if ſmoked, but within like a ſort of ſand ſtone, with various ſmall particles of iron, and bright metallic ſtars."

Other ſtones are deſcribed by him, which were ſaid to have fallen at the ſame time, were triangular, and terminated in a ſort of pyramidal or conical figure; and others were ſo ſmall as to weigh not more than one ounce.

In the year 1795, a ſtone of remarkable large ſize was ſaid to have fallen from heaven, near the *Wold Cottage*, Yorkſhire, which ſtone was afterwards exhibited in London. The account of its fall is as follows:

"In the afternoon of the 13th of December 1795, near the Wold Cottage, noiſes were heard in the air by various perſons, like the report of a piſtol, or of guns at a diſtance at ſea, though there was neither any thunder or lightning at the time; two diſtinct concuſſions of the earth were ſaid to be perceived, and a hiſſing noiſe was alſo affirmed to be heard by other perſons, as of ſomething paſſing through the air; and a labouring man plainly ſaw (as we are told) that ſomething was ſo paſſing, and beheld a ſtone, as it ſeemed, at laſt, (about 10 yards diſtant from the ground) deſcending, and ſtriking into the ground, which flew up all about him; and, in falling, ſparks of fire ſeemed to fly from it.

"Afterwards

" Afterwards he went to the place, in company with others, who had witneſſed part of the phænomena, and dug the ſtone up from the place, where it was buried about 21 inches deep.

" It ſmelt (as it is ſaid) very ſtrongly of ſulphur, when it was dug up; and was even warm, and ſmoked. It was found to be 30 inches in length, and 28 ½ inches in breadth; and it weighed 56 pounds."

This ſtone, as it was exhibited, appeared to have a dark, black cruſt, with ſeveral concave impreſſions on the outſide, which muſt have been made before it was quite hardened; juſt like what is related concerning the cruſts of thoſe ſtones that fell in Italy. Its ſubſtance was not properly a granite (as deſcribed in the printed account that was diſtributed); but a ſort of *grit-ſtone*, compoſed (ſomewhat like the ſtones ſaid to have fallen in Italy) of ſand and aſhes. There were in it a great many pyritous particles, and ſome ſmall ruſty ſpecks, perhaps decompoſed pyrites. It did not effervеſce with acids. It ſeems that, this excepted, ſuch kind of ſtones have never been found in any part of England.

" Mr. Southey relates an account, juridically authenticated, of a ſtone weighing 10 pounds, which was heard to fall in Portugal, February 19, 1796, and was taken, ſtill warm, from the ground*."

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* Letters written during a ſhort reſidence in Spain and Portugal, page 239.

From the above and other ſimilar accounts, which might hereto be annexed *, the general fact of ſtones having actually fallen from the ſky, ſeems to be eſtabliſhed beyond the poſſibility of a doubt. On account of the exploſion, which generally attends their fall, thoſe ſtones have often been called *thunder-ſtones*, or *thunder-bolts*; and it is vulgarly and pretty generally believed, that every clap of thunder is attended with the fall of a ſtone. But a wide diſtinction muſt be made between the above-mentioned phenomena and the common thunder and lightning, which are the effects of electricity diſcharged from the clouds; and which have nothing to do with the fall of ſtones. Yet it muſt be obſerved, that ſometimes the two ſpecies of phenomena are combined, and take place both at the ſame time, as may be gathered from the preceding accounts; and the preſent ſtate of knowledge does not enable us to make a due diſtinction between them. The laſt account of the preceding chapter, deſcribing the fall of ſtones near Benares, and the circumſtances which have attended ſimilar phenomena, ſeem to indicate that every meteor,

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* Beſides the above quoted works of Mr. King and Dr. Chladni, the reader will find ſimilar accounts in Falconet's papers upon Boetilia, inſerted in the *Hiſt. des Inſcriptions et Belles Lettres*; *Zahn's Specula Phyſico-Mathematica Hiſtoriana*; *La Fiſica Satterranea di Giacinto Gemma*; and Mr. Howard's elaborate and ſatisfactory Paper in the Philoſophical Tranſactions for the year 1802.

ſuch as have been deſcribed in that chapter, is owing to the formation, or ignition, of ſomething ſolid, which moves with wonderful rapidity, moſtly through the regions of the atmoſphere vaſtly above the uſual clouds, and which, beſides the hiſſing noiſe that moſtly accompanies its courſe, generally burſts with one or more exploſions, and laſtly falls down upon the ſurface of the earth in a few or in a great many pieces. It ſeems, however, that the fall of the ſtone, which fell in Yorkſhire, was not attended with any luminous appearance.

Whence do thoſe meteors or ſolid bodies derive their origin and their motion? is the great deſideratum; the important queſtion, which the preſent ſtate of knowledge does not enable us to anſwer, any more than by the ſuggeſtion of hypotheſes. A brief ſtatement of thoſe hypotheſes will conclude this chapter; but previous to this, it will be neceſſary to adduce what may be called the ſtrongeſt evidence of ſuch ſtones having really fallen from the ſky, viz. that evidence which ariſes from their chemical analyſis, and their general external characters.

The mineralogical deſcription of the ſtones from Benares, the ſtones from Yorkſhire, one of the ſtones from Italy, and a ſtone from Bohemia; all ſaid to have fallen from the ſky, as given by Count de Bournon, is inſerted in Mr. Howard's paper in the Philoſophical Tranſactions for 1802, from which, in addition to what has been already mentioned in the preceding accounts, it appears, that all thoſe ſtones,

ſtones, whatever their ſize may be, are entirely covered with a thin cruſt of a deep black colour, unleſs they have been broken in their fall or otherwiſe; for, in this caſe, the ſurface of the broken ſide has no cruſt. Their ſurface is quite deſtitute of metallic gloſs, and is ſprinkled with aſperities. When broken, their internal texture is granulated, reſembling, more or leſs, a coarſe grit-ſtone. By the uſe of a lens, their component particles ſeem to be of four ſpecies, the proportion of which ſeems to vary a little in the different ſpecimens. Thoſe ingredients are, 1ſt, A great abundance of grey or browniſh globules of different ſizes, which may be eaſily broken in all directions; their fracture is conchoid, with a ſmooth, fine, compact, and ſomewhat gloſſy ſurface; their hardneſs is ſuch as to afford a few faint ſparks when ſtruck with ſteel; 2dly, A granulated martial pyrites, of a reddiſh yellow colour, but black when powdered. This ſubſtance, which is irregularly diſtributed through the maſs of the ſtone, is not attractable by the magnet; 3dly, Small particles of iron in a perfect metallic ſtate, which render the whole ſtone attractable by the magnet; 4thly, A ſubſtance of an earthy conſiſtence, and whitiſh grey colour, which ſeems to cement and unite the other three ingredients, and from which all the others may be eaſily ſeparated with the point of a knife, or even with the nail.

" The black cruſt with which the ſurface of the ſtone is coated, although it is of no great thickneſs, emits bright ſparks, when ſtruck with ſteel: it may be broken by a ſtroke with a hammer; and ſeems to poſſeſs the ſame properties as the very attractable black oxide of iron. This cruſt is, however, like the ſubſtance of the ſtone, here and there mixed with ſmall particles of iron in the metallic ſtate: they may eaſily be rendered viſible, by paſſing a file over the cruſt, as they then become evident on account of their metallic luſtre."

The ſpecific gravities of thoſe ſtones are:

From Benares - - -	3,352.
From Yorkſhire - - -	3,508.
From Italy - - - -	3,418.
From Bohemia - - -	4,281.

Thoſe which have a greater ſpecific gravity, evidently contain a greater quantity of iron.

The firſt ſtone of this ſort, that was chemically analyzed by the French Academicians, was found on the 13th of September 1768, yet hot, by perſons who ſaw it fall, as has been ſaid in the preceding pages.

Another ſtone of the ſame nature, but little differing in appearance, was analyzed by Mr. Barthold, who found that 100 parts of the ſtone contained 2 parts of ſulphur, 20 of iron, 14 of magneſia, 17 of alumine, 2 of lime, and 42 of ſiliceous earth.

Mr. Howard inſtituted a very particular analyſis of of the four diſtinct bodies which form the ſtones from Benares, and aſcertained the following particulars: The external coat contains a good deal of iron attractable by the magnet, and ſome nickel, which form its principal components. The ſhining or pyritous particles, irregularly diſſeminated through the ſtone, being carefully ſeparated and analyzed, were found to contain 2 parts of ſulphur, 10 ½ of iron, nearly 1 of nickel, and 2 of extraneous earthy matter. The globular bodies contained 50 parts of ſilica, 15 of magneſia, 34 of oxide of iron, and 2 ½ of oxide of nickel. Laſtly, the earthy matter, which formed the cement or matrix for the other ſubſtances, was found to contain 48 parts of ſilica, 18 of magneſia, 34 of oxide of iron, and 2 of oxide of nickel.

The ſtone from Siena, on being analyzed, was found to contain 70 parts of ſilica, 34 of magneſia, 52 of oxide of iron, and 3 of oxide of nickel.

The ſtone from Yorkſhire was found to contain 75 parts of ſilica, 37 of magneſia, 48 of oxide of iron, and 2 of oxide of nickel.

The ſtone from Bohemia was found to contain 25 parts of ſilica, 9 ½ of magneſia, 23 ½ of oxide of iron, and 1 ½ of oxide of nickel.

The great ſimilarity which the chemical analyſis, and a careful examination of the mineralogical or apparent formation of thoſe ſtones, ſhew to exiſt among ſpecimens collected at different times, and brought from various parts of the world ſo very remote from each other, undoubtedly is the ſtrongeſt proof of their being different from common minerals; and of their owing their origin to the ſame general cauſe. The mineralogiſts, who have examined them, find them different from any other ſort of mineralogical ſubſtance ever deſcribed by the writers on that ſubject. Thoſe facts alone ſeem to convey perfect conviction concerning the accidental deſcent of thoſe ſtones upon our globe; but a careful examination of all the circumſtances, the ſimilarity of the accounts, as given by various perſons of different nations, and unknown to each other, who could not poſſibly accord in a falſe account; the nature of thoſe ſtones, and the ancient accounts related by a variety of credible authors, or handed down by tradition; all thoſe circumſtances, I ſay, when duly conſidered, ſeem to eſtabliſh the general fact of the fall, &c. beyond the poſſibility of doubt. We ſhall therefore conclude this ſubject with a conciſe ſtatement of the moſt rational hypotheſes that have been offered in explanation of thoſe phenomena.

Unwilling to force upon the reader any particular hypotheſis concerning meteors and the fall of ſtones, I have confined the preceding chapter to the former of thoſe ſubjects, and the preſent to the latter only; yet, by the laſt account in the preceding chapter, and by various accounts in the preſent, the reader muſt naturally remark the great connection which appears to exiſt between the two phenomena.

Without attempting to decide definitively upon the ſubject, we may nevertheleſs place the hypothetical part of both phenomena under one point of view. The vague opinions entertained by the ancients, of the ſtones coming from the ſun or the moon, need not be formally refuted.

It was Doctor Halley's opinion, that a ſtratum or train of inflammable vapour, gradually raiſed from the earth and accumulated in an elevated region, ſuddenly took fire at one end, and the ſucceſſive inflammation of the ſtratum, like the inflammation of a train of gun-powder, produced the apparent motion as it were of a ball of fire which conſtituted the meteor*. But the leaſt examination of the different parts of this hypotheſis, will readily manifeſt its imperfections.

In a diſſertation on this ſubject by Profeſſor Clap, of Yale College, in New England, we find a ſuppoſition, that the bodies which form the meteors, may be ſolid bodies revolving round the earth, as the comets revolve round the ſun, and now and then ſome of them coming ſo near as to fall upon it. This hypotheſis ſeems, at firſt ſight, to be attended with apparent improbability; yet a little conſideration may perhaps render it more intelligible to the ſpeculative philoſopher, and more applicable to the explanation of the phenomena.

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* Philoſophical Tranſactions, N° 360.

With reſpect to thoſe phenomena I am inclined to propoſe the following explanation. Imagine that a revolving body moves round the earth with a velocity ſomewhat like that of the moon, or of the earth in its orbit; alſo ſuppoſe that the attractive force in proportion to the centrifugal, is rather ſtronger than that which is required to keep the revolving body in the ſame immutable orbit; and that conſequently the ſaid body muſt move in a ſort of ſpiral, coming continually nearer and nearer to the earth. Now when this body comes within a certain part, however rare, of the atmoſphere, with its immenſe velocity, the friction it ſuffers may poſſibly heat it to the degree of incandeſcence, checking at the ſame time its centrifugal force, which conſequently increaſes the gravitating or attractive power. The great heat, which the body acquires in conſequence of the friction, produces two natural effects. In the firſt place, it partly melts or vitrifies the external ſurface, which forms the common black cruſt of the body (viz. the black cruſt of the ſtones ſaid to have fallen from the ſky); and, ſecondly, by expanding unequally the parts of the body, cauſes it to break with exploſion, in the ſame manner as ſtones often do in a common fire.

The greateſt objection to this hypotheſis ſeems to be, that the revolution of ſo many bodies round the earth as are neceſſary to form all the meteors, compriſing the numerous ſhooting-ſtars, ſeems rather unlikely.

The ſuppoſition that meteors are the effect of, or nothing more than, a ſeparate quantity of electric matter, though, at firſt ſight, may appear to be warranted by certain electrical phenomena, is, on mature conſideration, liable to very great objections.

I ſhall laſtly ſubjoin Mr. King's hypotheſis concerning the fall of ſtones at Siena in Italy.

This very learned gentleman eſtabliſhes his ſuppoſition upon a careful examination of all the circumſtances that ſeemed to be at all concerned with that wonderful phenomenon. He remarks that the ſpace of ground within which the ſtones fell, was from three to four miles; that the phenomenon took place the very day after the great eruption of Veſuvius, which is not leſs diſtant from Siena than 200 miles, and that Veſuvius is ſituated to the ſouth of the ſpot; whereas the cloud came from the north, about 13 or at moſt 18 hours after the eruption. Mr. King then briefly mentions his former obſervations on the formation of ſtones and rocks, either by the means of fire or of water; after which he ſays, "It is alſo well known, that a mixture of "pyrites of almoſt any kind, beaten ſmall, and "mixed with iron filings and water, when buried "in the ground, will take fire, and produce a ſort "of artificial volcano; and ſurely then, wherever a "vaſt quantity of ſuch kind of matter ſhould at

" any time become mixed together, as flying duſt " or aſhes, and be by any means condenſed together, or compreſſed, the ſame effect might be " produced, even in the atmoſphere and air.

" Inſtead, therefore, of having recourſe to the " ſuppoſition of the cloud in Tuſcany having been " produced by any other kind of exhalations from " the earth, we may venture to believe, that an immenſe cloud of aſhes, mixed with pyritical duſt, " and with numerous particles of iron, having been " projected from Veſuvius to a moſt prodigious " height, became afterwards condenſed in its deſcent, took fire, both of itſelf as well as by means " of the electric fluid it contained, produced many " exploſions, melted the pyritical, metallic, and argillaceous particles, of which the aſhes were compoſed; and by this means had a ſudden cryſtallization and conſolidation of thoſe particles taken " place which formed the ſtones of various ſizes " that fell to the ground; *but did not harden the " clayey aſhes ſo rapidly as the metallic particles cryſtallized*; and therefore gave an opportunity for *impreſſions to be made* on the ſurfaces of ſome of the " ſtones as they fell, by means of the impinging of " the others*."

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* Remarks concerning Stones ſaid to have fallen, &c. page 11.

SECTION III.

OF MEASURES AND WEIGHTS.

CHAPTER I.

OF THE STANDARD MEASURE.

THE fluctuating nature of the bulks of all ſorts of bodies, ſuch as are within our graſp, the general expanſion and contraction which ariſe from heat and cold, the ſhrinking and warping which are the effects of the evaporation and abſorption of fluids, and the loſs of matter from the ſurfaces of moſt bodies, ariſing from friction, or abraſion, render it extremely difficult to form a certain invariable length or ſtandard meaſure, of any ſort whatever, with which other extenſions may, in future, be compared.

It is true that ſeveral ſtandard meaſures of glaſs, of braſs, of iron, or of other metal, that are now preſerved in diverſe public and private repoſitories for the regulation of meaſures and weights in civil economy, when duly examined, are found to agree ſo well with each other, as that the error or difference ſeldom amounts to the thouſandth part of the whole; and ſuch difference would indeed be too trifling to deſerve notice, were it not for the accumulation of the error which takes place when that meaſure comes to be repeated a great number of times. Thus, if I meaſure a certain extenſion with a foot ruler, which ruler is one thouſandth part of a foot deficient, or leſs than the real ſtandard, it is evident that when I have meaſured 1000 feet with ſuch ruler, my meaſurement is one foot leſs than the truth. Now ſuch error would be of very great conſequence in a variety of caſes *.

On the above-mentioned accounts, and becauſe it is not eaſy to ſend an accurate ſtandard meaſure from place to place, wherever it may be wanted, or to prevent its being loſt or broken by accidents in proceſs of time, various plans have been propoſed for forming a ſtandard meaſure at any time; or, in other words, plans have been propoſed for inſtructing a perſon how to form, or to determine, the meaſure of a foot, or of a yard, or of any other given denomination by means of words only, viz. without actually ſhewing him that meaſure.

Of the different plans which have been propoſed for this purpoſe, two are undoubtedly the beſt, and thoſe I ſhall endeavour briefly to explain.

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* See General Roy's Paper on the Meaſurement of a Baſe Line on Hounſlow Heath, Philoſophical Tranſactions, Vol. LXXV.

1ſt, The length of the pendulum which vibrates ſeconds, has long been uſed for a ſtandard of meaſure; for if you faſten a leaden ball, or any other weight to a flexible thread, and, having ſuſpended the upper part of the thread to a nail, you cauſe it to vibrate; and, by obſerving with a clock or watch, you count the vibrations, and lengthen or ſhorten the thread, until that pendulum performs 60 vibrations in one minute, or 3600 vibrations in one hour; then the length of that pendulum, in the latitude of London, will be little more than 39,1 Engliſh inches. In any other latitude the length of the pendulum that vibrates ſeconds, muſt be longer or ſhorter than 39,1 inches, according as the place is nearer to one of the poles, or nearer to the equator of the earth; but the quantity by which the pendulum muſt be ſhortened or lengthened, in order that it may vibrate ſeconds in any given latitude, may be eaſily calculated *; hence that pendulum or a pendulum that vibrates any other aſcertained number of times in a minute, may be uſed as a ſtandard of meaſure in any known latitude. But the inaccuracy to which this method is liable, ariſes principally from the difficulty of meaſuring the preciſe diſtance between the real point of ſuſpenſion, and the centre of oſcillation of the pendulum.

In order to obviate in great meaſure the errors to which the above-mentioned method is liable, the

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* See a table of thoſe lengths on the other ſide of this leaf.

late ingenious Mr. Whitehurſt contrived a machine, or piece of clock-work, having a pendulum with a moveable centre of ſuſpenſion, whence it might be lengthened or ſhortened at pleaſure, and which of courſe might be adjuſted ſo as to vibrate any number of times in a given interval of time. He then propoſed to uſe as a ſtandard of meaſure, not the length of the whole pendulum, but the difference of the lengths of the ſame pendulum, when it performed

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[*] A Table, ſhewing how much a pendulum which vibrates ſeconds at the equator, would gain every 24 hours in different latitudes, and how much the pendulum need to be lengthened in thoſe latitudes in order to vibrate ſeconds.

Degrees of Latitude.	Time gained in one day, in ſeconds.	Lengthening in decimals of an inch, neceſſary to vibrate ſeconds.
5°	1,7	0,0016
10	6,9	0,0062
15	15,3	0,0138
20	26,7	0,0246
25	40,8	0,0369
30	57,1	0,0516
35	75,1	0,0679
40	94,3	0,0853
45	114,1	0,1033
50	134.	0,1212
55	153,2	0,1386
60	171,2	0,1549
65	187,5	0,1696
70	201,6	0,1824
75	213.	0,1927
80	221,4	0,2033
85	226,5	0,2050
90	228,3	0,2065

performed a certain number of vibrations in one hour, and when it performed another certain number of vibrations likewiſe in one hour; by which means the above-mentioned ſources of error would in great meaſure be obviated[*].

After the death of Mr. Whitehurſt, Sir George Shuckburgh Evelyn reſumed the ſubject, and, being poſſeſſed of the very ſame machine which Mr. Whitehurſt had conſtructed, he made all the experiments which that machine was capable of performing; and at laſt he came to the following concluſion, which we have already tranſcribed in the ſecond volume of this work. "It appears," *he ſays*, "that the difference of the length of two "pendulums, ſuch as Mr. Whitehurſt uſed, vibrating 42 and 84 times in a minute of mean "time in the latitude of London, at 113 feet above "the level of the ſea, in the temperature of 60°, "and the barometer at 30 inches, is equal to "59,89358 inches of the parliamentary ſtandard; "from whence all the meaſures of ſuperficies and "capacity are deducible[†]."

2dly. The other method, which was lately practiſed by the French Academicians, for determining an invariable ſtandard meaſure, is to uſe a certain

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[*] See Mr. Whitehurſt's *Attempt to obtain Meaſures of Length, &c. from the Menſuration of Time, or the true Length of Pendulums.* London, 1787.

[†] Philoſophical Tranſactions for 1798, page 174.

portion of the whole circumference of the earth. For this purpoſe the extent of ſeveral degrees of the meridian, are actually meaſured with any given ruler, from which meaſurement it is eaſy to calculate the extent of the whole meridian; that is, of the whole circumference of the earth; then a certain portion of that circumference is to be uſed as a ſtandard meaſure; for inſtance, if that circumference ſhould be found equal to one million times the above-mentioned ruler, then the millionth part of that circumference, or that identical ruler, may be the ſtandard meaſure. Should a nation, or a perſon in any other country, and at any diſtance of time, wiſh to form a ſtandard meaſure equal to the above, they muſt actually meaſure ſome degrees of the meridian with any ruler at pleaſure; whence they may calculate the number of ſuch rulers that are equal to the whole circumference of the earth; laſtly, taking the thouſandth part of that extent, they will have the ſtandard meaſure as above.

Now, the French Academicians have taken the forty millionth part of the whole circumference of the earth for their ſtandard meaſure, they have formed rulers, or ſcales, exactly equal to that part which they call *metre*, and which, by a careful compariſon, with accurate ſcales of Engliſh inches, feet, &c. at the temperature of 62°, has been found equal to 39,371 Engliſh inches*.

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* Journals of the Royal Inſtitution of Great Britain, N° 8. Or, *La Bibliotheque Britannique*, N° 148.

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In ſhort, the inch of ſtandard Engliſh meaſure, 12 of which form a foot, &c. and with which all other meaſures are compared, is an extenſion which, if it be multiplied by 59,89358, the product is equal to the difference of the lengths of two pendulums, one of which vibrates 42, and the other 84 times in a minute of mean time, at the temperature of 60°, and, in the latitude of London, 113 feet above the level of the ſea*. Or the above-mentioned Engliſh inch is an extenſion, which, if multiplied by 39,371, the product is equal to a French metre, 40 millions of which (at the temperature of 62° Fahrenheit's thermometer) are equal to the whole meridian or circumference of the earth.

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* "Such are the inches that are marked on Mr. Bird's Scale of Length, now preſerved in the Houſe of Commons; which is the ſame, or agrees within an inſenſible quantity, with the ancient ſtandards of the realm." Philoſophical Tranſactions for 1798, page 175.

CHAP. II.

OF BRITISH MEASURES AND WEIGHTS.

Lineal Engliſh Meaſures, or Meaſures of Length.

HAVING ſhewn in the preceding chapter how to determine the length of an Engliſh inch, or number of inches, we ſhall now proceed to ſtate the meaſures of other denominations that are uſed in this iſland, by ſhewing the number of inches to which they are equal; thus, from the following table, it appears that 12 inches make a foot; that 36 inches, or 3 feet, make a yard; that 198 inches are equal to 16½ feet, or to 5½ yards, or to one rod; that 7920 inches are equal to 660 feet, or to 220, or to 40 poles (otherwiſe called rods) or to one furlong, &c.

Inches.	Feet.	Yards.	Pole, or Rod.	Furlong.	Mile.
12	1				
36	3	1			
198	16,5	5.5	1		
7920	660	220	40	1	
63360	5280	1760	320	8	1

One

One degree of a great circle of the earth is commonly reckoned equal to 69¼ miles, or to 365640 feet.

A fathom is equal to ſix feet, and is generally uſed in meaſuring depths.

For meaſuring of cloth the following meaſures are uſed.

Inches.	Nails.	Quarters.	Yards.	Ell.
2¼	1			
9	4	1		
36	16	4	1	
45	20	5	1¼	1

The following are uſed for meaſuring long extenſions of land.

Inches.	Links of a Chain.	Feet.	Yards.	Poles, or Rods.	Chains.	Mile.
7,92	1					
792	100	66	22	4	1	
63360	8000	5280	1760	320	80	1

The heights of horſes are generally meaſured by *hands*. A *hand* is equal to 4 inches.

Square Engliſh Meaſures.

Sqre. Inches.	Sq. Feet.	Sq. Yrds.	Sq. Pol.	Sqre. Roods.	Sq. Acre.	Sq. Mile
144	1					
1296	9	1				
39204	272,25	30,25	1			
1568160	10890	1210	40	1		
6272640	43560	4840	160	4	1	
4014489600	27878400	3097600	102400	2560	640	1

Lineal Scotch Meaſures.

Inches.	Feet.	Ells.	Falls.	Furlongs.	Miles.
12	1				
37,2	3,1	1			
223,2	18,6	6	1		
8928	744	240	40	1	
71424	5952	1920	320	8	1

Inches.	Links of a Chain.	Feet.	Ells.	Falls, or Short Roods.	Chains.	L. Rood.	M.
8,928	1						
892,8	100	74,4	24	4	1		
		111	36	6	1,5	1	
					80	53⅓	1

Square Scotch Meaſures.

Sq. Inches.	Sq. Feet.	Sq. Ells.	Sq. Falls, or Sq. Roods.	Sq. R.	Sq. A.	Sq. M.
144	1					
	9,61	1				
	345,96	36	1			
	13838,4	1440	40			
	55353,6	5760	160	4	1	
					640	1

Correſpondence between Engliſh and Scotch Meaſures.

24,8 Engliſh yards are equal to one Scotch chain.

One Engliſh mile is equal to 71 Scotch chains.

6150 Square Engliſh yards are equal to a Scotch acre.

One Engliſh acre is equal to 0,787 (or to little more than ¾) of a Scotch acre.

One Scotch acre is equal to 1,27 (or to little more than 1 ¼) Engliſh acre.

Of Engliſh Weights.

The ſtandard of lineal meaſures being once aſcertained, a ſtandard weight is thereby eaſily determined; for if you take a body of a uniform ſubſtance, and of any given dimenſions, the weight of that body will ſerve for the ſtandard weight. Thus it has been determined, that a cubic inch of pure diſtilled water, when the barometer is at 29,74 inches, and the thermometer at 66°, weighs 252,422 parliamentary grains, 5760 of which make one pound troy*.

There are three ſorts of weights principally uſed in Great Britain; namely, *Troy weights*; *Avoirdupois*, or *Avoirdupoize, weight*; and *Apothecaries weight*; but the Troy pound, conſiſting of 5760 grains, as mentioned above, is conſidered as the beſt integer to adopt as the ſtandard of weight.

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* Viz. According to the ſtandard weights made by Mr. Harris, Aſſay Maſter of the Mint, under the orders of the Houſe of Commons in the year 1758, which are kept in the ſame cuſtody with Mr. Bird's Scale of Length, and appear to have been made with great care, as a mean reſult from a great number of compariſons of the old weights in the Exchequer. Philoſophical Tranſactions for 1798, page 173.

Troy Weights.

24 grains make *one penny weight.*
20 penny weight make *one ounce.*
12 ounces make *one pound.*

Avoirdupois Weights.

16 drams make *one ounce.*
16 ounces make *one pound.*
14 pounds make *one ſtone.*
28 pounds make *a quarter of a hundred weight.*
4 quarters of a hundred (or 112 pounds) make *one hundred weight.*
20 hundreds weight (or 2240 pounds) make *one ton.*

Apothecaries Weights.

20 grains make *one ſcruple.*
3 ſcruples make *one dram.*
8 drams make *one ounce.*
12 ounces make *one pound.*

Correſpondence between Troy and Avoirdupois Weights.

41 ounces Troy are equal to 45 ounces Avoirdupois, or
1 ounce Troy is equal to 1,09707 ounce Avoirdupois, or
1 ounce Avoirdupois is equal to 0,91152 ounce Troy.

1 pound

1 pound Troy is equal to 0,82274 of a pound Avoirdupois.

1 pound Avoirdupois is equal to 1,21545 pound Troy, or to 1 pound 11 penny weights and 20 grains Troy*.

The Troy weights are uſed for weighing gold, ſilver, coſtly liquors, and a few other articles.

The Avoirdupois weights are uſed in commerce for weighing all kinds of grocery, fruit, tobacco, butter, cheeſe, iron, braſs, lead, tin, ſoap, tallow, pitch, roſin, ſalt, wax, &c.

The apothecaries and chemiſts compound and ſell their medicines by the above-mentioned *apothecaries weights*; but they buy their articles by the Avoirdupois weights.

There are a few weights of other denominations uſed in commerce, or in particular parts of England, for weighing wool and a few other articles; but for thoſe we muſt refer the reader to the works on commerce.

Trone or old Scotch Weight.

20 ounces make *one pound.*
16 pounds make *one ſtone.*

Hay, wool, Scotch lint, hemp, butter, cheeſe,

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* This correſpondence is taken from the experiments made in the year 1744, by Martin Folkes, Eſquire, Preſident, and ſeveral other gentlemen, members of the Royal Society.

tallow, &c. are always ſold in Scotland by Trone weight.

Engliſh Dry Meaſures of Capacity.

Pints.	Quarts.	Pottles.	Gallons.	Pecks.	Buſhels.	Quarts.	Way, or Load.	Laſt.
2	1							
4	2	1						
8	4	2	1					
16	8	4	2	1				
64	32	16	8	4	1			
512	256	128	64	32	8	1		
2560	1280	640	320	160	40	5	1	
5120	2560	1280	640	320	80	10	2	1

The capacity of a Wincheſter buſhel is equal to 2150,42 cubic inches.

A ſtriked buſhel is to a heaped buſhel as 3 to 4, viz. a heaped buſhel is one-third more than a ſtriked buſhel.

The capacity of a peck is equal to 537,6 cubic inches.

The avoirdupois weight of a buſhel of wheat, at a mean, is 60 pounds: ditto of barley is 50 pounds; ditto of oats is 38 pounds.

The weight of a pint (or $\frac{1}{16}$ part of a peck) dry meaſure, in avoirdupois ounces, at a mean of wheat, is 15 ounces; of barley is $12\frac{1}{2}$ ounces; of oats is $9\frac{1}{2}$ ounces.

Sixty ſolid, or cubic, feet of Newcaſtle coal make one London *chaldron.* A cubic foot of ditto generally

nerally weighs 50 pounds avoirdupois. An heaped buſhel thereof generally weighs 83 pounds avoirdupois, and 36 buſhels (or one chaldron) weigh 26,67 hundred weight; that is, 2988 pounds avoirdupois.

In Scotland, a lippie, or a feed for a horſe, is equal to 200,345 cubic inches.

Engliſh Liquid Meaſures.

The following table ſhews what number of meaſures of one denomination make up one of another denomination, as alſo the number of cubic inches to which each meaſure is equal. Thus, for inſtance, it ſhews that the capacity of one barrel is equal to 34 gallons, or to 136 quarts, or to 272 pints, or to 9588 cubic inches, according to the country meaſure; alſo it ſhews that 35 ¼ cubic inches are equal to a pint, 2 pints are equal to a quart, 4 quarts are equal to a gallon, &c. The like explanation muſt be applied likewiſe to the table of wine meaſures, as alſo to that of the Scotch liquid meaſures. Beer meaſure for London is 36 gallons to the barrel. Ale meaſure for ditto is 32 gallons to the barrel. Beer and Ale meaſure for the country is 34 gallons (viz. a mean between the two former) to the barrel.

Beer and Ale Meaſures.

	Cubic Inches.	Pints.	Qrts.	Gallons.	Barrls	Hſhds
Beer - - - -	15228	432	216	54	1 $\frac{1}{2}$	1
Ale - - - -	13536	384	192	48		
Country Meaſure	14382	408	204	51		
Beer - - - -	10152	288	144	36	1	
Ale - - - -	9024	256	128	32		
Country Meaſure	9588	272	136	34		
Beer - - - -	282	8	4	1		
Ale - - - -						
Country Meaſure						
Beer - - - -	70 $\frac{1}{2}$	2	1			
Ale - - - -						
Country Meaſure						
Beer - - - -	35 $\frac{1}{4}$	1				
Ale - - - -						
Country Meaſure						

Wine Meaſures.

Cubic Inches.	Pints.	Quarts.	Gallons.	Barrels.	Hogſhead.
14553	504	252	63	2	1
7276,5	252	126	31 $\frac{1}{2}$	1	
231	8	4	1		
57,75	2	1			
28,875	1				

231 cubic inches make one gallon wine meaſure by act of parliament 5th of Q. Anne; but the ſtandard gallon, at Guildhall, contains only 224 cubic inches.

Scotch Liquid Meaſures.

Cubic Inches.	Gills.	Mutchkins	Chopins.	Pints.	Qrts.	Gallons	Hogſhd.
13235,7	2048	512	256	128	64	16	1
827,23	128	32	16	8	4	1	
206,8	32	8	4	2	1		
103,404	16	4	2	1			
51,7	8	2	1				
25,85	4	1					
6,462	1						

The *ſtirling Jug*, containing one Scotch pint, is the original ſtandard of all liquid and dry meaſures, and of all weights in Scotland. It contains 103,404 cubic inches. When accurately filled with the water of Leith, the water weighs 3 pounds and 7 ounces of Scots Troy (equal to 55 ounces, or to 26180 Engliſh Troy grains); ſo that one ounce weighs 476 Engliſh Troy grains.

By the act of Union, the barrel for Engliſh country meaſure of 34 gallons, the capacity of which is 9588 cubic inches, is reckoned equal to 12 Scots gallons, making 9926,7 cubic inches.

CHAP. III.

OF FRENCH MEASURES AND WEIGHTS.

PREVIOUS to the late French revolution, the principal lineal meaſures of that nation were *lines*, *inches*, *feet*, and *toiſes*; 12 lines are equal to one inch; 12 inches make one foot; and 6 feet make one toiſe.

One Engliſh foot is equal to 0,9383 of a French foot.

One French foot is equal to 1,06575 Engliſh foot.

One French toiſe is equal to 6,3945 Engliſh feet.

The Paris *arpent* conſiſts of 100 ſquare *perches*; each is 18 Paris feet lineal meaſure, viz. 324 ſquare feet, which, multiplied by 100, gives 32400 ſquare Paris feet (or 36720 ſquare Engliſh feet) for the *arpent*; that is, in round numbers, about $\frac{5}{6}$ of the Engliſh acre. But according to the *meſure royale*, a *perche* has 22 feet of lineal meaſure, and conſequently is 484 ſquare feet, which, multiplied by 100, gives 48400 ſquare Paris feet (or 54853,36 Engliſh feet) to the *arpent*. This arpent is above 1 $\frac{1}{4}$ Engliſh acre. But the former arpent of 32400 feet was the meaſure uſed about Paris.

The cubic Paris foot or inch is to the cubic Engliſh foot or inch, nearly as 1,21 to 1; ſo that one cubic Paris foot, or inch, is about $1\frac{1}{5}$ Engliſh cubic foot or inch: hence 5 Paris cubic feet make 6 Engliſh cubic feet. 16 *litrons* make a *boiſſeau*; 3 *boiſſeaux* make one *minot*; 2 *minots* make one *mine*; 2 *mines* make one *ſeptier*; and 12 *ſeptiers* make one *muid.*

The Paris *ſeptier* for wheat contains 6912 Paris cubic inches, which are equal to 8363 Engliſh cubic inches, or 4 Engliſh buſhels nearly. The Paris *ſeptier* for oats is double the one for wheat.

The French Poids de Marc.

72 *grains* make one *groſs*, 8 *groſſes* make one *ounce*, and 16 *ounces* make one *pound*. One French grain is very nearly equal to 0,8203 of an Engliſh troy grain. One ounce *poids de marc*, which contains 576 French grains, is equal to 472,49 Engliſh troy grains.

Since the French revolution, all the meaſures and weights of that nation are deduced from the *metre*, which we have already ſaid to be equal to the 40 millionth part of the whole circumference of the earth, and to be equal to 39,371 Engliſh inches; the Engliſh ſcale being at 62° of temperature, and the French metre at 32°.

Meaſures

Meaſures of Length, or Lineal Meaſures.

Theſe new French meaſures, as well as the weights, proceed in a decimal order; for inſtance, the millimetre is the 10th part of the centimetre; the latter is the 10th part of the decimetre, the decimetre is the 10th part of the metre, and ſo on. The numbers which are annexed to the following names of the French meaſures, expreſs the number of Engliſh inches or Troy grains to which they are equivalent.

Millimetre - - - -	0,039371 Eng. in.
Centimetre - - - -	0,39371
Decimetre - - - -	3,9371
Metre - - - -	39,371
Decametre - - -	393,71
Hecatometre - -	3937,1
Chiliometre - -	39371,
Myriometre -	393710.

	Engliſh Miles.	Furl.	Yds.	Feet.	Inches.
A decametre is equal to	0	0	10	2	9,7
A hecatometre - - -	0	0	109	1	1
A chiliometre - - -	0	4	213	1	10,2
A myriometre - - -	6	1	156	0	6

Eight chiliometres are nearly equal to five miles.

Meaſures of Capacity.

Millilitre - - -	0,06103 Engliſh cubic inches.
Centilitre - - -	0,61028
Decilitre - - -	6,1028
Litre - - - -	61,028
Decalitre - -	610,28
Hecatolitre -	6102,8
Chiliolitre -	6102,8
Myriolitre -	610280

A litre is nearly equal to 2 $\frac{1}{8}$ Engliſh wine pints.

14 decilitres are nearly equal to three Engliſh wine pints.

A chiliolitre is equal to one tun, and 12,75 Engliſh wine gallons.

Weights.

Milligramme - - -	0,0154 Engliſh troy grains.
Centigramme - -	0,1544
Decigramme - - -	1,5444
Gramme* - - -	15,4440
Decagramme - -	154,4402
Hecatogramme	1544,4023
Chiliogramme	15444,0234
Myriogramme	154440,2344

A decametre is equal to 6 penny weights and 10,44 grains Engliſh troy weights, or to 5,65 avoirdupois drams.

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* A gramme is the weight of a cubic centimetre of pure water at its maximum of denſity.

An hecatogramme is equal to 3 ounces and 8,5 drams avoirdupois.

A chiliogramme is equal to 2 pounds, 3 ounces, and 5 drams avoirdupois.

A myriogramme is equal to 22 pounds 1,15 ounces avoirdupois.

100 myriogrammes are equal to 1 ton, wanting 32,8 pounds.

Agrarian Meaſures.

A ſquare *decametre* is equal to 3,95 perches.

An *hecatare*, equal to 2 acres, 1 rood, and 35,4 perches.

For Fire-wood.

A *deciſtere*, equal to $\frac{1}{10}$ ſtere, equal to 3,5317 Engliſh cubic feet.

A *ſtere*, equal to one cubic metre, equal to 35,317 Engliſh cubic feet.

CHAP. IV.

OF THE MEASURES AND WEIGHTS OF VARIOUS NATIONS.

I HAVE endeavoured in the preceding chapters to give an accurate ſtatement of the meaſures and weights of Great Britain, and of the French nation, becauſe theſe have been determined with all the accuracy which the preſent ſtate of knowledge relative to philoſophy and mechanics could ſuggeſt. It is much to be deſired, that other nations would follow their example, aad either eſtabliſh or make known their invariable ſtandard, or adopt the meaſures of one of the above-mentioned nations. The weights and meaſures lately eſtabliſhed by the French, are undoubtedly the moſt rational in theory, the leaſt perplexing in practice, and the moſt eaſily remembered; yet it muſt be acknowledged that great innovations of this ſort, though evidently for the better, are not reliſhed by moſt nations. In this caſe they might at leaſt determine with accuracy the ſtandard of their ancient meaſures and weights, and make it known to the world for the advantage of philoſophy and commerce.

In collecting the ſtandards of meaſures and weights of the principal nations of Europe, I have met with a much greater difficulty than I at firſt expected. The unſettled ſtate of thoſe meaſures in certain countries, the variety of meaſures uſed in the ſame country, the difficulty of obtaining direct and authentic information, and the diſagreement between authors who deſcribe the meaſures and the weights of the very ſame nation, have prevented the making of as complete a ſtatement of the general meaſures and weights of different nations as might have been wiſhed. I have therefore ſtated thoſe particulars only which, from the concurrence of the moſt creditable authors, ſeem to be beſt aſcertained. In this ſtatement the reader will find the value of the different meaſures, &c. expreſſed in Engliſh meaſures and weights.

Sir George Shuckburgh Evelin, having examined various ancient rules, and having meaſured ſeveral ancient buildings, ſays, " The mean reſult of theſe " experiments, gave me for the length of the an-
" cient Roman foot - - 11,617 Engliſh inches
" Ditto, as before from the
" rules - - - - 11,606 ditto.
" The mean of the two
" modes of determination 11,612 ditto.

" I may add, that in the Capitol is a ſtone, of no very ancient date however, let into the wall, on

which

" which is engraven the length of ſeveral meaſures,
" from whence I took the following:

" The ancient Roman foot = 11,635 Engliſh inches
" The modern Roman palm = 8,82 ditto
" The ancient Greek foot = 12,09 ditto*

	Eng. feet.
The ancient Roman *mile* (by Plinius)	= 4840,5
The ancient Roman *mile* (by Strabo)	- 4903
The *ſtadium* of the ancient Romans	- 606
The *ſtadium* of the Egyptians - -	- 730,8
The *li* of the Chineſe - - - - -	- 606

		Eng. inches.
The *archine* of Ruſſia	- - - -	= 28,35
The *Rynland foot* of Denmark	- - -	- 12,36
The Swediſh *foot*	- - - - - -	- 11,692
The Vienna *foot* in Auſtria	- - -	- 12,44
The Amſterdam *foot*	- - - - -	- 11,17
The Amſterdam *ell*	- - - - - -	- 26,8
The Spaniſh *vara*	of Madrid - - -	- 39,16
	of Seville - - -	- 33,12
	of Caſtille - - -	- 32,952
The Turin *foot*	- - - - - - -	- 20,17
The Turin *trabucco*	- - - - - -	- 121,02
The Turin *ras*	- - - - - - - -	- 23,5

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* Philoſophical Tranſactions for 1798, page 169.

		Eng. inches.
The Genoa *palm*		= 9,6
		9,8
The Genoa *canna*		87,6
The Venice *foot*		14
The Venice *braccio*	for meaſuring ſilk	25,3
	for meaſuring cloth	27
The Florence *braccio*		22,8
		22,91
The *braccio* of Rome	for architects	30,73
	for merchants	34,27
The Roman *canna*		78
The Naples *palm*		10,31
The Naples *canna*		82,9
The *braccio* of Milan		20,7
The Bologna *foot*		15
The *braccio* of Parma and Piacenza		26,9
The *braccio* of Lucca		23,5
The *braccio* of Breſcia and Mantua		25,1
The *royal foot* of China		12,6

The Swediſh foot is divided into 12 inches. The Swediſh kanne (which contains 8 *quadrantes*, each of which contains 12½ Swediſh cubic inches) is equal to 107,892 Engliſh cubic inches. But an Engliſh gallon, wine meaſure, is equal to 231 cubic inches; therefore the Swediſh kanne is to the Engliſh gallon as 107,892 to 231; viz. equal to little leſs than half a gallon.

The

The Amſterdam Weights.

$29\frac{11}{18}$ grains	make	1 drop
16 drops		1 ounce
16 ounces		1 pound
16 pounds		1 ſtone

One Engliſh pound troy, is equal to 0,757 of a pound of Amſterdam weight.

SECTION IV.

ADDITIONAL ARTICLES.

Vol. I. page 159. After line the 9th of the note, by way of illuſtration add.

viz. $b^2 = annd$; and (ſubſtituting for a its value $\frac{d}{2-nn}$) $b^2 = \frac{d}{2-nn}\,nnd = \frac{dd\,nn}{2-nn}$. Then by extracting the ſquare root, we have the ſemi-conjugate $b = \frac{nd}{\overline{2-nn}|^{\frac{1}{2}}}$.

Vol. III. After the ſecond line of the note in page 54, add. Though the freezing point of quickſilver be −39°; yet that metal requires a temperature of −45°, in order to aſſume its perfectly ſolid ſtate. Philoſophical Tranſactions for 1801, page 133.

Vol. III. Note to the paragraph in the middle of page 95.

Mr. Bouguer, after many trials, concluded, that the light of the ſun is about 300000 times greater than that of the moon.

Dr. Smith (Optics, Vol. I. Art. 95.) thought that he had proved, from two different conſiderations, that the light of the full-moon is to our day-light, as one to about 90900, if none of the rays incident from the ſun upon the ſurface of the moon were loſt by the irregularities of the latter.

Vol. III. page 115. The experiment, which is deſcribed in that page, may be performed with a ſingle reflector; for if the thermometer be placed in one of the conjugate foci, and the burning charcoal, or the ice, be placed in the other of thoſe foci, the ſame effect will take place, but not ſo effectually, nor at ſo great a diſtance as when two reflectors are uſed.

A remarkable difference is to be obſerved between the radiant heat from the ſun, and that from a common fire; viz. the former will paſs through water, glaſs, &c. and will hardly heat them; but the radiant heat of a fire, heats thoſe ſubſtances, and is almoſt entirely ſtopped by them.

Vol. III. page 328. To be added after the fourth line.

Dr. Hulme, in a ſecond paper on the ſpontaneous light of fiſh, &c. (Philoſophical Tranſactions for 1801. Art. XXI.) relates ſeveral new experiments and obſervations, the principal reſults of which are contained in the following paragraphs.

" Theſe experiments prove, that objects which abound with ſpontaneous light in a latent ſtate, ſuch as herring, mackerel, and the like, do not emit it when deprived of life, except from ſuch parts as have been ſome time in contact with the air.

" They likewiſe ſhew, that the blaſt of a pair of bellows does not increaſe this ſpecies of light, as it does that which proceeds from combuſtion.

" It appears that oxygen gas does not act upon this kind of light, ſo as to render it much more vivid than it is in atmoſpherical air, which is quite contrary to what ſome authors have alledged.

" It is a remarkable circumſtance, that azotic gas, which is incapable of ſupporting light from combuſtion, ſhould be ſo favourable to the ſpontaneous light which is emitted from fiſhes, as to preſerve its exiſtence and brilliancy for ſome time *when applied upon a cork*; yet that it ſhould prevent the *fleſh* of the herring and the mackerel from becoming luminous, and alſo extinguiſh the light proceeding from rotten wood.

" It appears that hydrogen gas, in general, prevents the emiſſion of ſpontaneous light, and alſo extinguiſhes it when emitted; but at the ſame time it does not hinder its quick revival when the ſubject of the experiment is again expoſed to the action of the atmoſpherical air, although the light may have been a conſiderable time in an extinguiſhed ſtate.

"Carbonic acid gas, or fixed air, has alſo an extinguiſhing property with reſpect to ſpontaneous light; but, in general, the light returns, if the object of experiment be taken out and expoſed to the open air.

"It appears that ſulphurated hydrogen gas extinguiſhes ſpontaneous light much ſooner than carbonic acid gas, and that, in general, the light returns much more ſlowly when the ſubject is expoſed to atmoſpheric air.

"Nitrous gas, we obſerved to have totally prevented the emiſſion of light, and to have quickly extinguiſhed that which had been emitted: likewiſe that the luminous objects which had been under its influence (except the glow-worm) did not experience a revival of their light, when taken out and kept for ſome time in common air.

"A piece of ſhining wood was put under the receiver of an air-pump; the light diminiſhed in proportion as the air was exhauſted; but revived on the re-admittance of the air.

"The ſame thing took place with the luminous matter of a herring.

"It appears that ſolar light, when imbibed by Canton's phoſphorus, is ſubject to the ſame laws, with reſpect to heat and cold, as the ſpontaneous light of fiſhes, rotten wood, and glow-worms, viz. heat diſpoſes the phoſphorus to yield the light quickly, but ſoon exhauſts it; whereas cold prevents, in great meaſure, both its emiſſion and its diſſipation."

See the ſame paper (Philoſophical Tranſactions for 1801, page 426) for an improvement in the conſtruction of Canton's phoſphorus.

Vol. III. To be added after the 7th line of page 193.

An ingenious application of the principle mentioned in the above, and a few preceding pages, was lately made by Dr. Wollaſton; viz. he has rendered it capable of meaſuring the refractive and diſperſive powers of various ſubſtances. The paper, with the account of thoſe improvements, was lately publiſhed in the Philoſophical Ttanſactions for the year 1802. Art. XII. from which I ſhall tranſcribe the following paragraphs.

" Since the range of inclination, within which total reflection takes place, depends not only on the denſity of the reflecting priſm, but alſo on the rarity of the medium adjacent to it, the extent of that range varies with the difference of the denſities of the two media. When, therefore, the refractive power of one medium is known, that of any rarer medium may be learned by examining at what angle a ray of light will be reflected from it.

" In examining the refractive powers of fluids, or of fuſible ſubſtances, the requiſite contact is eaſily obtained; but, with ſolids, which can in few inſtances

ſtances be made to touch to any great extent, this cannot be effected without the interpoſition of ſome fluid, or cement, of higher refractive power than the medium under examination. Since the ſurfaces of a ſtratum ſo interpoſed are parallel, it will not effect the total deviation ſo a ray paſſing through it, and may therefore be employed without riſk of any error in conſequence.

" Thus, reſins, or oil of ſaſſafras, interpoſed between plate-glaſs and any other priſm, will not alter the reſult.

" If, on the ſame priſm, a piece of ſelenite, and another of plate-glaſs, be cemented near each other, their powers may be compared with the ſame accuracy as if they were both in abſolute contact with it.

" For ſuch a mere compariſon of any two bodies, a common triangular priſm is beſt adapted; but, for the purpoſe of actual meaſurement of refractive powers, I have preferred the uſe of a ſquare priſm, becauſe, with a very ſimple apparatus, it ſhews the ſine of refractive power ſought, without the need of any calculation.

" Let A, fig. 14, Plate XXVIII. be a ſquare or rectangular priſm, to which any ſubſtance is applied at *b*, and let any ray of light, parallel to *cb*, be refracted through the priſm, in the direction *bde*.

" Then, if *e f* and *e d* be taken proportional to the ſines that repreſent the refractive powers of the priſm, and

and of air, fg, which is intercepted between f, and the perpendicular eg will be the correſponding ſine to repreſent the refractive power of the medium b. For, ſince edg (oppoſite to ef) is the angle of refraction, efg (oppoſite to ed) muſt be equal to the angle of incidence bdh; and $ef : fg :: bd : dh ::$ ſine of chi : ſine of hbd.

“ All therefore that is requiſite for determining the refractive power of b, is to find means of meaſuring the line fg. On this principle the inſtrument, fig. 15, Plate XXVIII. is conſtructed. On a board ab is fixed a piece of flat deal cd, to which, by a hinge at d, is jointed a ſecond piece de, ten inches long, carrying two plane ſights at its extremities. At e is a ſecond hinge, connecting ef 15,83 inches long; and a third at the other extremity of ef, by which fg is connected with it. At i alſo is a hinge, uniting the radius ig to the middle of ef; and then, ſince g moves in a ſemicircle egf, a line joining e and g would be perpendicular to fg.

“ The piece cd has a cavity in the middle of it, ſo that when any ſubſtance is applied to the middle of the priſm P, it may continue to reſt horizontally on its extremities. When ed has been ſo elevated that the yellow rays in the fringe of colours (obſervable where perfect reflection reminates) are ſeen through the ſights, the point g, by means of a vernier which it carries, ſhews by inſpection the length of the ſine of refraction ſought.

“ The advantages which this method poſſeſſes above

above the uſual mode of examining refractive powers, are greater than they may at firſt ſight appear.

" The facility of determining refractive powers, is conſequently ſuch as to render this property of bodies a very convenient teſt in many philoſophical inquiries. For diſcovering the purity of eſſential oils, ſuch an examination may be of conſiderable utility, on account of the ſmallneſs of the quantity requiſite for trial."

For ſuch purpoſes, the refractive power of opaque ſubſtances, which could not be learned by any means at preſent in uſe, may often be deſerving of inquiry. For, in the uſual mode, a certain degree of tranſparency is abſolutely neceſſary; but, for trial by contact, the moſt perfect opacity does not occaſion the leaſt impediment.

With reſpect to the experiments which Dr. Wollaſton made with the above-mentioned machine, I muſt refer the reader to the paper itſelf.

FINIS.

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For ſuch purpoſes, the refractive powers of opaque ſubſtances, which could not be learned by any means previouſly in uſe, may very often be determined. For, in the uſual mode, a certain degree of tranſparency is abſolutely neceſſary; but, for that by contact, the moſt perfect opacity does not occaſion the leaſt impediment.

With reſpect to the experiments which Dr. Wollaſton made with the above-mentioned machine, I muſt refer the reader to the paper itſelf.

F I N I S.

THE

INDEX.

INDEX.

INDEX.

INDEX.

Luke Hanſard, Printer,
Great Turnſtile, Lincoln's-Inn Fields.

ERRATA.

VOL. I.

Page 67, line 15; inſtead of *triangular*, read *triangle.*

VOL. II.

Page 5, line 7, from the bottom; inſtead of *ſix*, read *eight.*
—— 6, line 1; after the Georgian planet, add two more planets, viz. *Ceres Ferdinandea*, and *Pallas*, which have been diſcovered ſince that ſheet was printed.
—— 6, line 3; inſtead of *ſeven*, read *nine.*
—— 9, the dimenſions of the earth as given in this page, have been corrected by ſubſequent meaſurements and calculations, for which ſee vol. iv. page 13.
—— 16, line 10; inſtead of *Mollybdenite* read *Molybdenite.*
—— 29, line 1; inſtead of *line* I S, read *line* I L.
—— 41, line 15; inſtead of *cork is*, read *cork* O *is.*
—— 70, line 15; add, *See fig.* 19, *of Plate* X.
—— 78, line 12; inſtead of *Jungſten*, read *Tungſten.*
—— 113, line 25; inſtead of *Deſoguliers*, read *Deſaguliers.*
—— 120, line 22, add, *as in fig.* 18, *Plate* XI.
—— 142, line 7; inſtead of *cohere*, read *adhere.*
—— 187, line 3 from the bottom; inſtead of *fig.* 22, read *fig.* 26.
—— 238, at the end of line 9, add, *fig.* 11, *Plate* XIII.

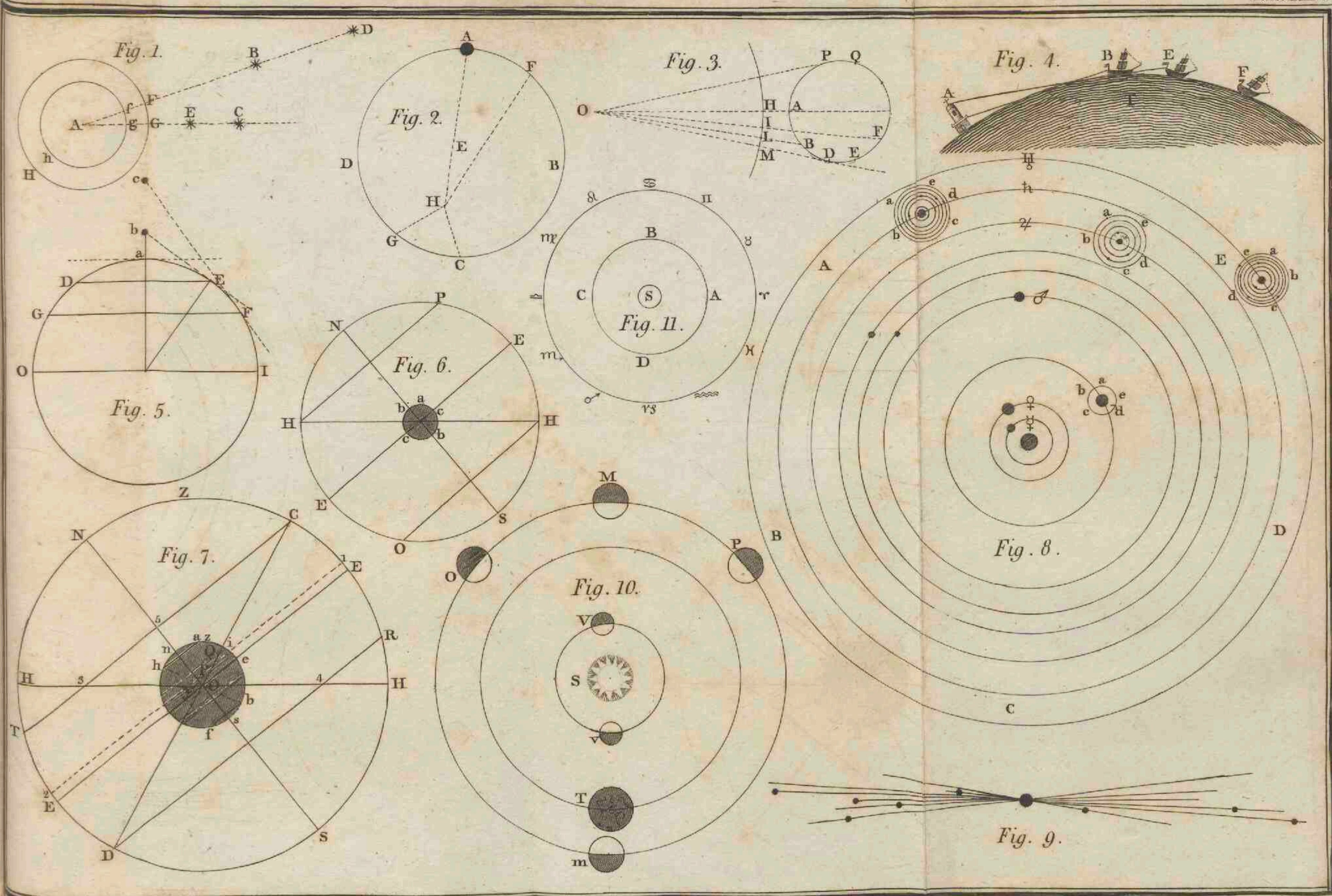
VOL. III.

Page 33, line 4; inſtead of *rarefied*, read *condenſed.*
9; inſtead of *rarefaction*, read *condenſation.*
—— 95, line 22; inſtead of *hundred*, read *thouſand.*
—— 266, line 8; inſtead of *four*, read *five.*
—— 329, line 16; inſtead of *Beecari*, read *Beccari.*

VOL. IV.

Page 398, line 25; inſtead of *and which*, read *and which at* 32° *of temperature.*
—— 399, line 13; inſtead of 62°, read 32°.

Plate XXVI.

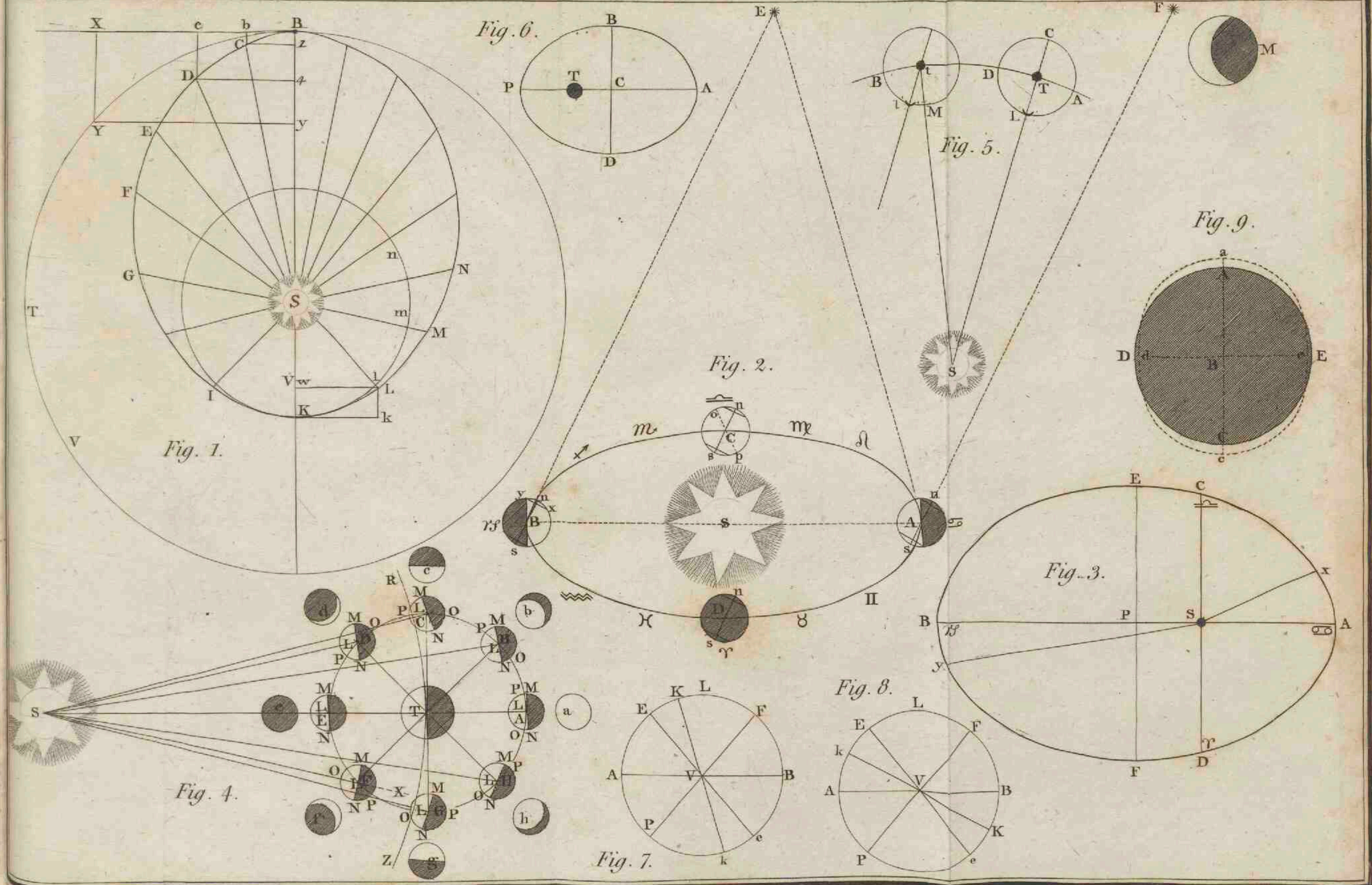


C. del^t.

J^s. Basire sculp.

Published 25^th March 1802, by Cadell & Davies, Strand.

Plate XXVII.



del. J^s Basire sc.

Published 25th March, 1802, by Cadell & Davies, Strand.

Plate XXVIII.

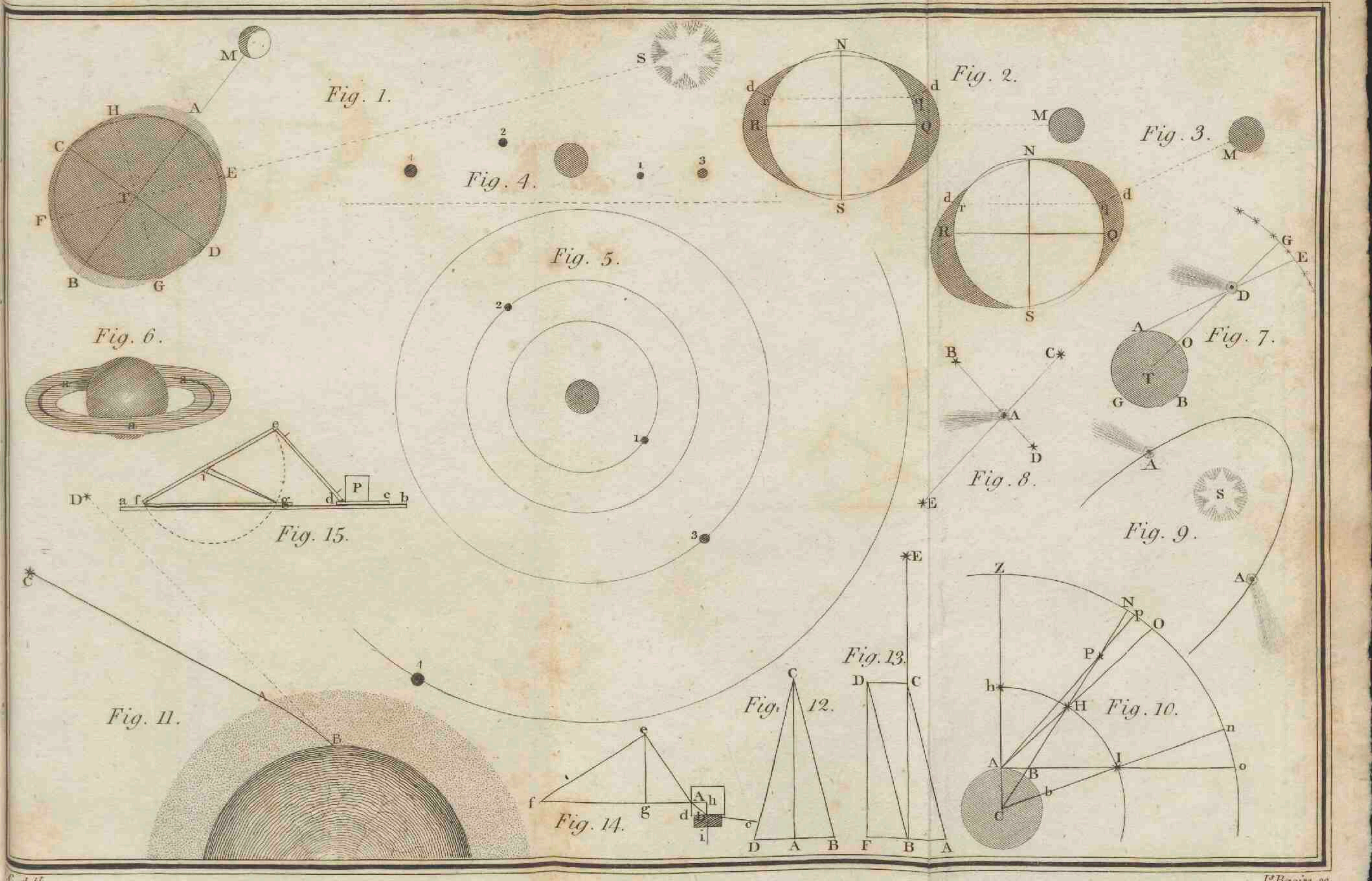


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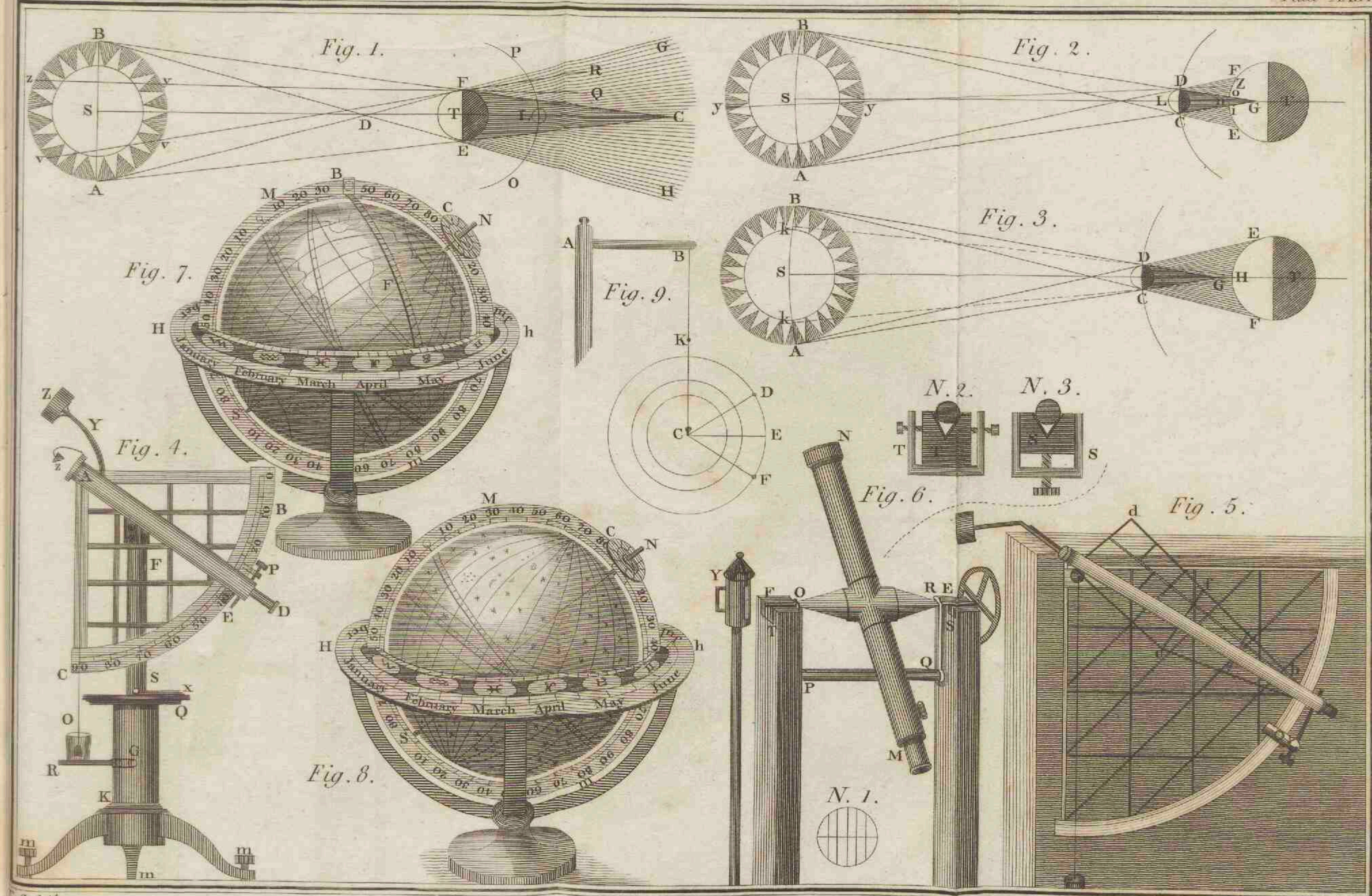
Plate XXIX.



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