Astronomical and geographical essays : containing a full and comprehensive view, on a new plan, of the general principles of astronomy; the use of the celestial and terrestrial globes ... the description and use of the most improved planetarium, tellurian, and lunarium; and also an introduction to practical astronomy / By the late George Adams.

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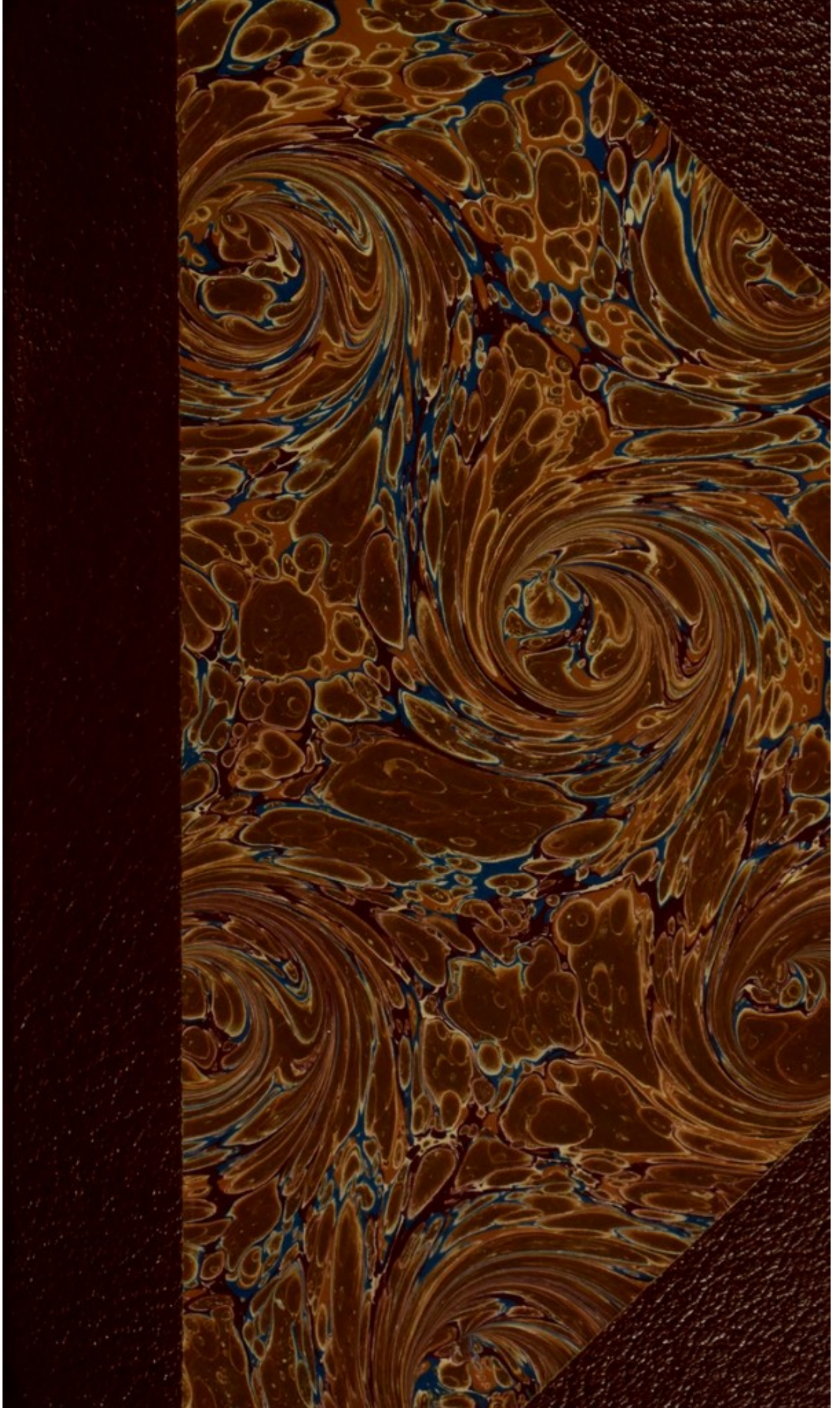London : Printed for, and sold by W. and S. Jones, 1803.

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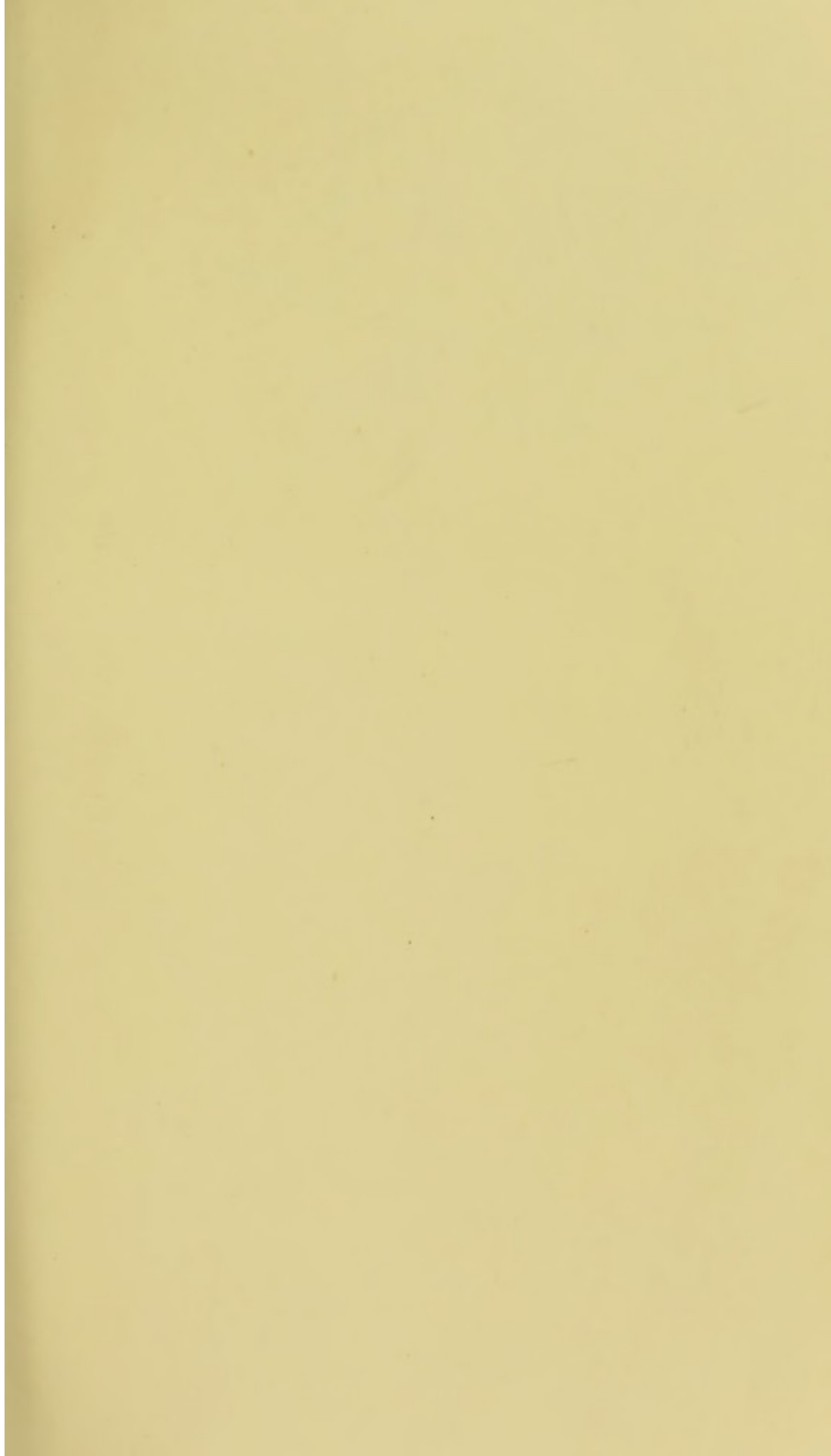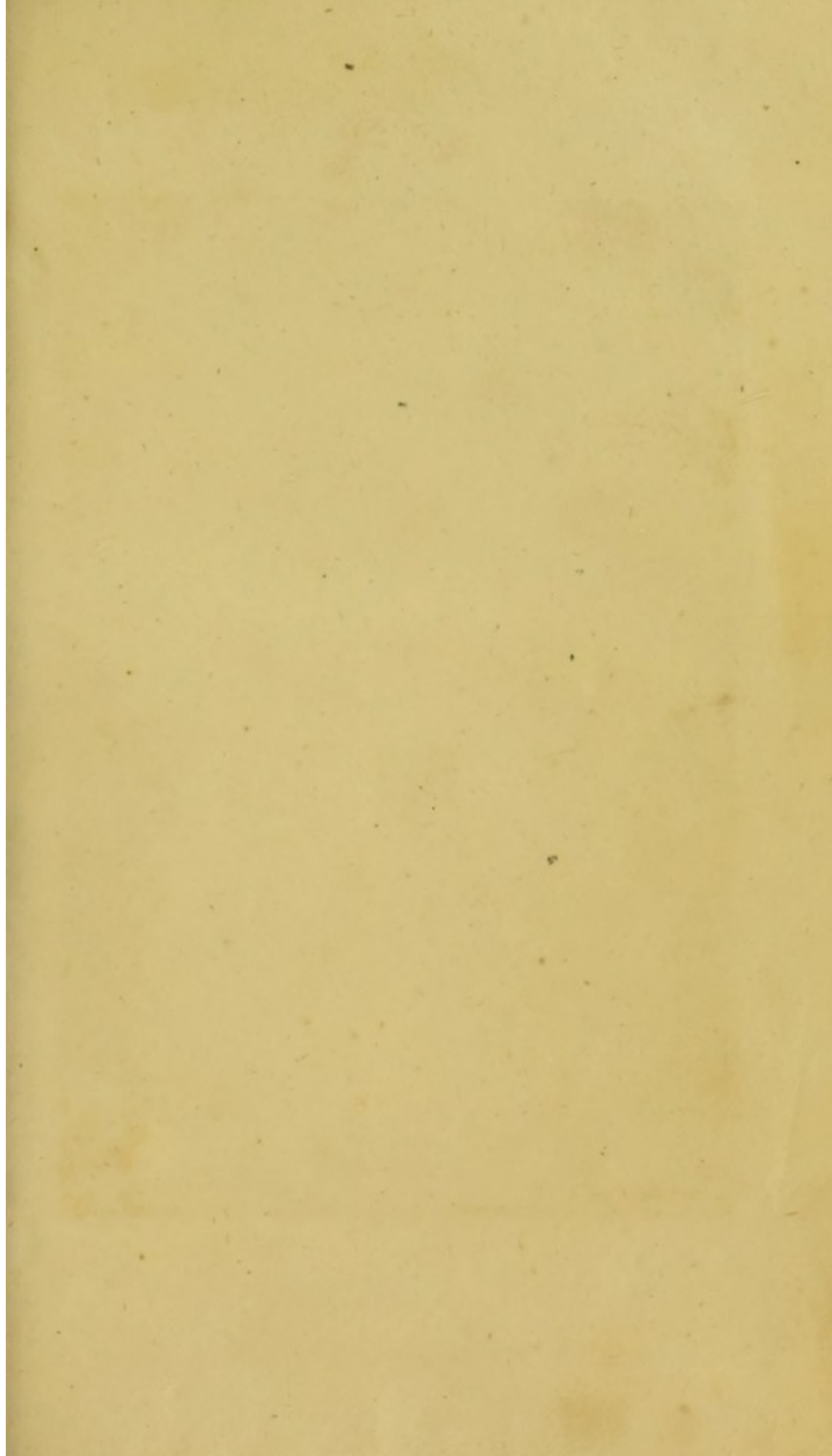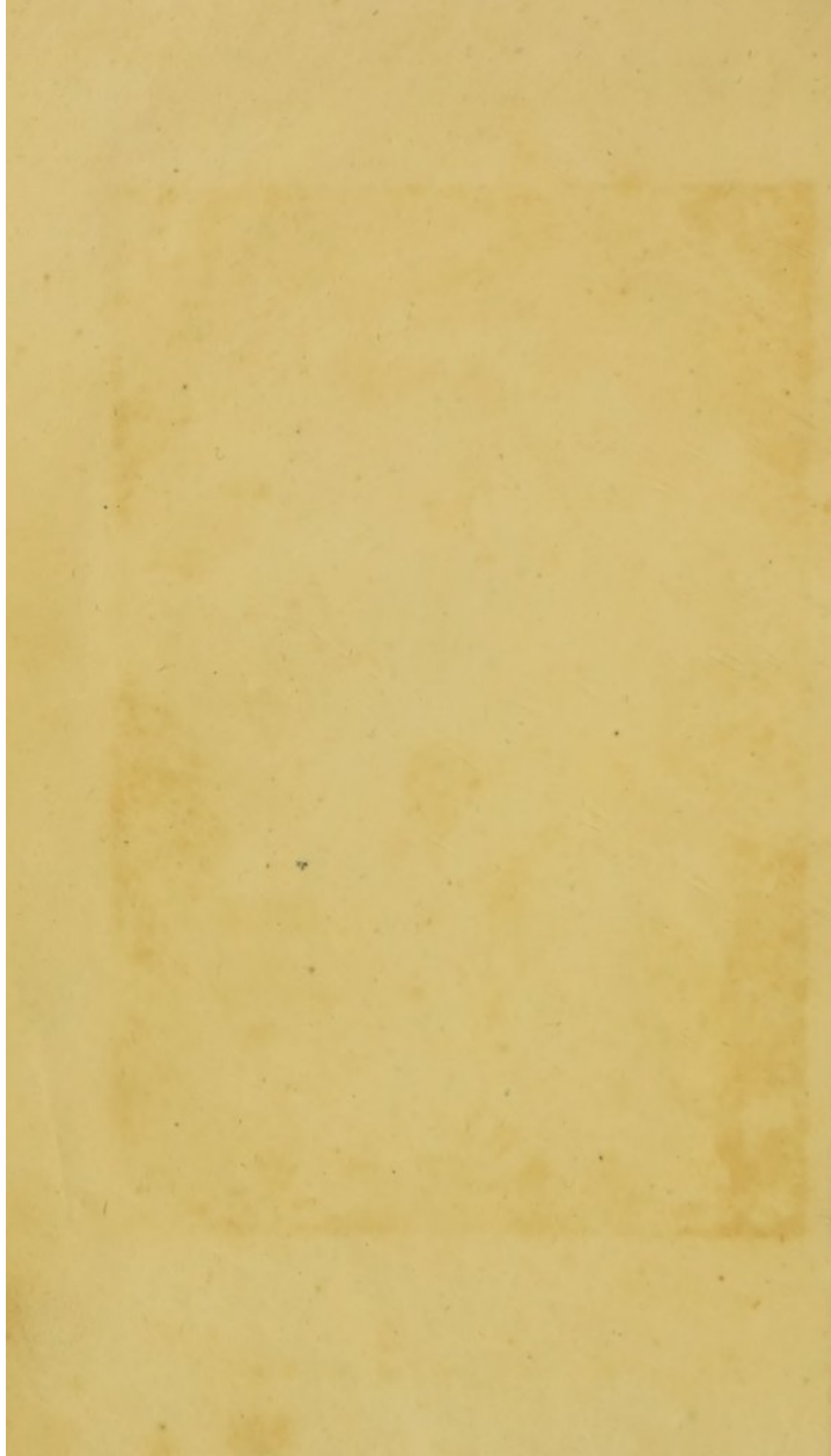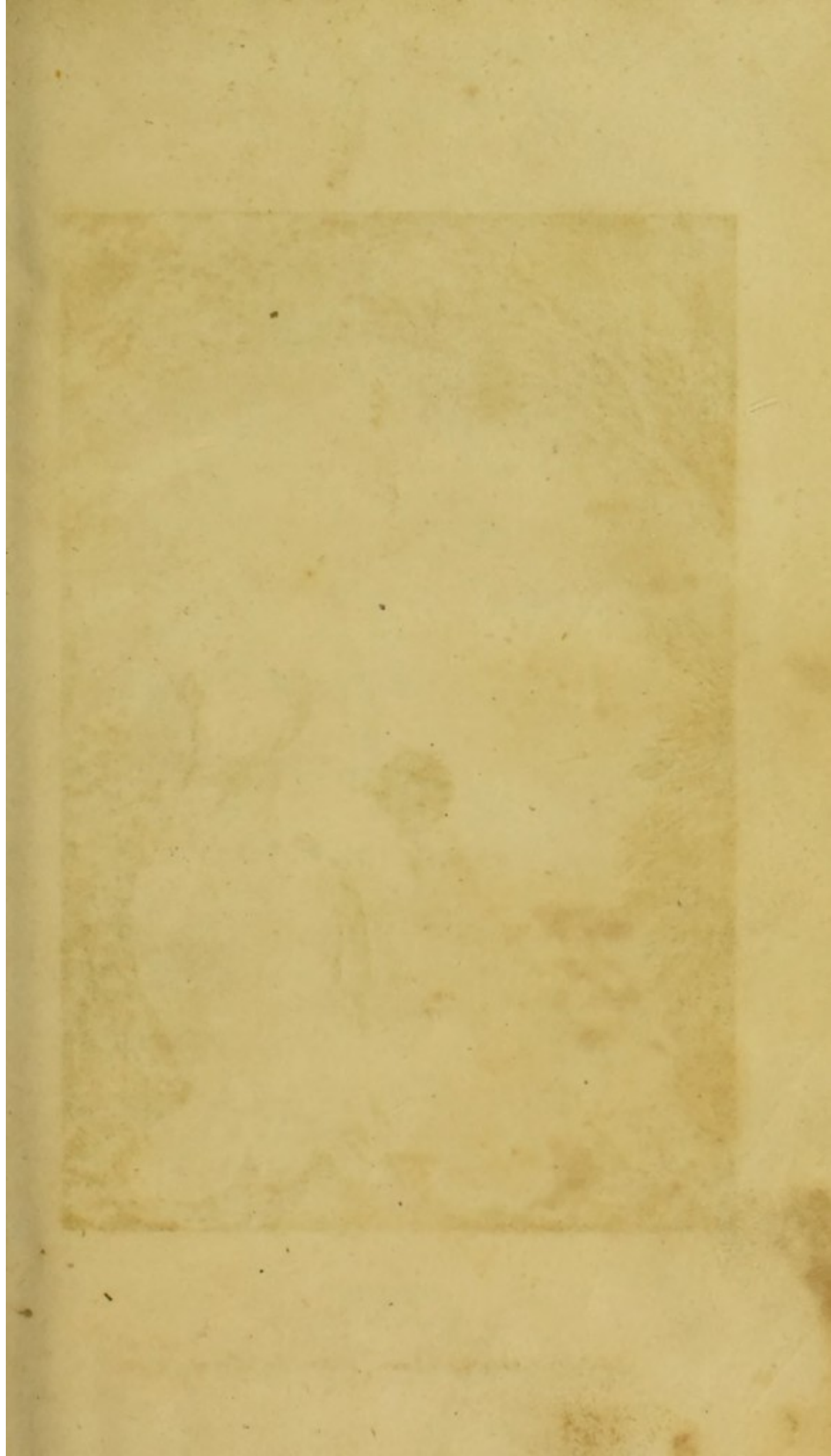
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ASTRONOMICAL AND GEOGRAPHICAL

ESSAYS:

CONTAINING

A FULL AND COMPREHENSIVE VIEW,

ON A NEW PLAN,

OF THE

GENERAL PRINCIPLES OF ASTRONOMY;

THE USE OF THE

CELESTIAL AND TERRESTRIAL

GLOBES,

EXEMPLIFIED IN A GREATER VARIETY OF PROBLEMS, THAN ARE TO BE FOUND
IN ANY OTHER WORK;

THE DESCRIPTION AND USE

OF THE MOST IMPROVED

PLANETARIUM, TELLURIAN,

AND

LUNARIUM;

AND ALSO.

An Introduction to Practical Astronomy.

BY THE LATE GEORGE ADAMS,

Mathematical Instrument Maker to his Majesty, &c.

THE FIFTH EDITION, CORRECTED AND ENLARGED,

By WILLIAM JONES, F.Am.P.S.

LONDON:

PRINTED FOR, AND SOLD BY, W. AND S. JONES, OPTICIANS,
HOLBORN.
1803.

Price 10s. 6d. *in Boards.*

PREFACE.

THE connexion of astronomy with geography is so evident, and both in conjunction so necessary to a liberal education, that no man will be thought to have deserved ill of the republic of letters, who has applied his endeavours to diffuse more universally the knowledge of these useful sciences, or to render the attainment of them easier; for as no branch of literature can be fully comprehended without them, so there is none which impresses more pleasing ideas on the mind, or affords it a more rational entertainment.

The fifth edition of my father's treatise on the globes being out of print, I was solicited to reprint it. To obviate several objections to the form in which he had disposed the problems, I was induced to undertake the present work, in which they are arranged in a more methodical manner, and a great number added to them. Such facts are also occasionally introduced, such observations interspersed, and such relative information communi-

cated, as it is presumed will excite curiosity, and fix attention.

Having proceeded so far in this work, I found that it was easy to render it subservient to my plan of publishing, from time to time, " ESSAYS DE- SCRIBING THE USE OF MATHEMATICAL AND PHI- LOSOPHICAL INSTRUMENTS ;" for the description of those which have been contrived to smooth the path to the science of astronomy, or to facilitate the prac- tice of the arts depending on it, could no where be introduced with so much propriety, as in a work which treated of its elementary principles.

To further this design, it was necessary to prefix an introduction to astronomy. This is divided into three parts : in the first, the pupil is supposed to be placed in the sun, the centre of the solar system ; from this situation he considers the motion of the heavenly host, and finds that all is regular and har- monious. In the second part, his attention is di- rected to the appearances of the planetary bodies, as observed from the earth. It were to be wished, that the tutor would, at this part, exhibit to his pupil the various phenomena in the heavens themselves : by teaching him thus to observe for himself, he would not only raise his curiosity, but so fix the im- pressions which the objects have made on his mind, that by proper cultivation they would prove a fruitful source of useful employment ; and he would thereby also gratify that eager desire after novelty, which

continually animates young minds, and furnish them with objects on which to exercise their natural activity. In the third part of this introduction, the received, or Copernican system is explained : by this system the various phenomena of the heavens are rationally accounted for ; it shews us how to reconcile the real state of things with the fallacies arising from the senses ; and teaches us that the irregularities observable in the motion of the heavenly bodies, are for the most part to be attributed to the situation from which they are observed. Astronomy, in common with other branches of mathematics, while it strengthens the powers of the mind, restrains it from rash presumption, and disposes it to a rational assent.

The principles of the Copernican system are further elucidated in the third Essay ; in which the most improved planetarium, lunarium, and tellurian, are described. These instruments, though less complicated in their construction and less expensive to the purchaser, than those large ones heretofore made for the same purpose, are equally, perhaps better, adapted to explain the general principles of astronomy. In describing them, it was necessary to reconsider many subjects which had been previously treated ; but as they are here placed in another point of view, presented to the mind under a different form, are generally described in other words, and often with the addition of new matter, it is hoped that these repetitions, so far from being an object of complaint,

will be found to contribute to the main intention of this work, by conveying further instruction, fixing it more deeply in the mind, and rendering that obvious which before might be found difficult.

One part seemed wanting to an introductory treatise on practical astronomy; something that would gently lead the pupil to a knowledge of the practical part of this science, a branch of astronomy to which we are indebted for our present knowledge of the heavens, by which geography has been improved, and by which the passage of ships over the trackless ocean is facilitated.

There is no part of mathematical science more simple and easy, than the measurement of the relative positions and distances of inaccessible objects; yet, to the uninstructed, to determine the distance of a ship on the ocean, to ascertain the height of the clouds and meteors that float in the atmosphere, to fix the latitude and longitude of places, &c. are problems that have ever appeared to be above the reach of human art; they are therefore particularly calculated to engage the attention of young minds, and may be used to encourage diligence, and reward application.

To introduce the pupil to this branch of astronomy, I have described two instruments, each of which is simple in its construction, and of small expence. By these he may find the distance of any

inaccessible object, the height of a spire, a mountain, or any other elevation; learn to plot a field; ascertain the altitude of a cloud, a fire ball, or any other meteor; determine with accuracy the hour of the day, the latitude or longitude of a place, with many other curious problems. In the selection of these, for the first edition, I have to acknowledge the assistance I received from an ingenious friend.

The Editor to this fifth edition, thinks it necessary to inform the Reader, that this work has been again carefully revised by him, all observed errors corrected, new astronomical discoveries inserted, and such additions made, as appeared necessary to the information of the beginner and the use of the preceptor.

NEW GLOBES.

W. and S. JONES think it proper hereby to inform the reader, that there were lately completed two entire new sets of engraved plates, for Globes of eighteen and twelve inches in diameter. The many recent geographical and astronomical discoveries have rendered the old globes inaccurate and obsolete, and new ones indispensably necessary.

On the 18-inch Terrestrial, are inserted all the latest discoveries from the voyage of Capt. *Cook, Vancouvre, Perouse,* &c. engraved from an accurate drawing by Mr. *Arrowsmith,* and all the names of the places delineated in a clear and distinct manner. On the Celestial, is depicted the exact places of more than 6000 stars, clusters, planetary, nebulæ, &c. communicated by Dr. *Herschel* and other astronomers, and calculated, in position, for the present century, or the beginning of 1800, by *W. Jones.* The size of these Globes, which is considered of the dimensions the most manageable, renders them comprehensive of many particulars not to be contained in smaller ones. The graduation of the great circles are to 20 minutes of a degree ; and by simple and improved hour circles, the time is shewn to a few minutes. The Globes are so constructed, as in the simplest manner to be capable of all solutions that it is possible for globes to give, and the names are in the English language.

The general prices, per pair, are from 7 to 16 guineas, according to the frames, mounting, &c. as may be seen in *W.* and *S. Jones's* Catalogue of Instruments annexed.

The 12-inch Globes are reduced copies of the above 18-inch, and contain rather more than half the countries, stars, &c. that are upon the 18-inches. The graduations of the great circles are to 30 minutes, or half a degree.

The price in plain frames, the pair, is 3 guineas and an half, and 5 shillings for the addition of a compass fitted to both horizons of the Globes. In mahogany claw-feet frames, 5 guineas and an half.

The Globes may be packed securely in packing cases, so as to be conveyed safely to all parts of the world.

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P A R T I.

MANKIND have in all ages been desirous of form-
ing rational conceptions of the nature and motion
of those bodies that appear in the vast concave above
their heads. Amidst the infinite variety of objects
which surround them on every side, the heavenly
bodies must have been amongst those which first at-
tracted their attention. They are of all objects the
most conspicuous, the most important, and the most
beautiful.

Astronomy instructs us in the laws, or rules, that
govern and direct the motions of the heavenly host.
It weighs and considers the powers by which they
circulate in their orbs. It enables us to discover
their size, determine their distance, explain their
various phenomena, and correct the fallacies of the
senses by the light of truth.

A

Astronomy is not merely a speculative science; its use is as extensive as its researches are sublime. Navigation owns it for its guide; by it, commerce has been extended and geography improved. It is astronomical observations that form the basis of geography. Thus, it has co-operated with other causes in the greatest of all works, the diffusion of knowledge and the civilization of man.

As, in order to attain an accurate idea of any piece of mechanism, it is best to begin our investigation by an examination of those parts which give motion to the rest, the primary causes of those effects for which the machine was made; so the young pupil will more easily gain a just idea of the motion of the heavenly bodies, by considering them as seen from the sun, the centre of our system, and the principal agent used by the LORD OF NATURE for conducting and regulating the planetary system.

It will not be difficult, after this, to inform him how those appearances are to be accounted for, that arise from his particular situation; whence he views the heavens from a point which is not in the centre of the system, and is consequently the source of many apparent irregularities. This knowledge attained, it will be easy to prove to him, that the real and apparent motions of the heavenly bodies are frequently the reverse of each other. For, being by this means put into possession of the universals of this science, the knowledge of particulars will be rendered facile and clear.

OF THE SOLAR SYSTEM AS SEEN BY A SPECTATOR SUPPOSED TO BE PLACED IN THE SUN.

As the centre of the system is the only place from which the motion of the planets can be truly seen, let us suppose an observer placed in the centre of the sun. In this situation he will see at one view all the heavens, which will appear to him perfectly spherical, the stars being so many lucid points in the concave surface of the sphere, whose centre is the sun, or, in the present instance, the eye of the observer.

Our spectator will not, however, immediately conclude from appearances, either that the heavens are really spherical, or that the sun is in the centre of that sphere, or that the stars are all at an equal distance from him; having been previously taught by experience and observation, that while he remains in the same place, he cannot judge properly of the distance of surrounding objects, at least of those which are placed beyond the ordinary reach of view. When objects are removed beyond the distances we are accustomed to, the principles by which we form our general judgment fail us; and we can only tell which is nearest, or which is furthest, either by our own motion, or that of the objects.

To illustrate this, let us suppose a number of lamps to be placed irregularly, at different distances from the eye, in a dark night. Now, if in this case we suppose the darkness to be so complete, that no intermediate objects could be seen, no difference in

colour discerned, nor any convergence towards the point of sight be perceived; our judgment could not assist us in distinguishing the distance of one from the other, and they would therefore all seem to be at an equal distance from the spectator.

For the same reason, the sun and moon, the stars and planets, appear to be all at an equal diftance from us, though it is highly probable, that some of the stars are many millions of times nearer to us than others. The sun is demonstrated to be nearer than any of the stars. The moon and some of the planets are known by ocular proof to be nearer to us than the sun, because they sometimes come between it and our eye, and hide the whole, or a great part of his disc, from our view. They all, however, appear equally distant, and as if placed in the surface of a sphere, whereof our eye is the centre. In whatever place, therefore, the spectator resides, whether it be on this earth, in the sun, or in the regions of Saturn, he will consider that place as the middle point of the universe, and the centre of the world; for it will be to him the centre of a spherical surface, in which all distant bodies seem to be placed.

These things being rendered plain, the pupil may proceed to consider the observations of the solar spectator; to whom, as we have already observed, the heavens will appear as the surface of a concave sphere, concentrical to his eye: in this surface he will discover an innumerable host of fixt stars, which will for some time engage his attention, before he discovers that they may be distinguished into two

kinds; the one, dispersed through the whole hea-
vens, differing in their degree of brightness, but re-
maining always at the same relative distance from
each other; these he will therefore call *fixed stars*,
or only *stars*. Besides these, he will find some others
moving among the foregoing with different velocities,
which he will call *wandering stars* or *planets*.

OF THE CELESTIAL SIGNS AND CONSTELLA-
TIONS.

Having proceeded thus far, our spectator will en-
deavour to find out some method of distinguishing
the stars from each other; concluding, that as they do
not change their relative positions one to the other,
he may easily make an exact description of them, and
by repeated observations determine the position and
order which subsist among them.

That he may avoid confusion in description, and
be able to point out any particular star, without be-
ing obliged to give a name to each, he will divide
them into several parcels; to each of these he will
assign a figure at pleasure; these assemblages or
groupes of stars, he will call *constellations*. Thus,
a number of stars near the north pole is called the
Bear, because the stars which compose it are at such
distances from each other, that they may fall within
the figure of a bear. Another constellation is called
the *Ship*, because that collection of stars which com-
pose it is represented upon a celestial globe as com-
prized within some part of the figure of a ship.

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As the fixed stars will appear to our observer of different degrees of magnitude and splendor, he will divide them into different classes. Those which seem the largest and brightest, he will call stars of the firſt magnitude ; the smallest that we can see with the naked eye are called stars of the sixth magnitude ; and the intermediate ones, according to their different apparent sizes, he will call of the second, third, fourth, or fifth magnitudes. Those stars which cannot be seen without the assistance of a telescope, are not reckoned in any of these classes, and are called *telescopic stars.*

By a knowledge of the fixed stars and their positions, our observer will obtain so many fixed points, by which he may observe the motions of the planets, and the relation of these motions to each other ; he will use them as so many land-marks, if the word may be allowed, by which the situations of other celestial bodies may be ascertained, and the varieties to which they are subjeƈt be observed. For, from the same place, the motions of the heavenly bodies can only be estimated by the angle formed at the spectator's eye by the space which the moving body passes over.

To measure the spaces, the stars muſt be used, and considered as so many luminous points fixed in the concavity of a sphere, whose radius is indefinite, and of which the observer's eye is the centre. We may learn from hence the necessity of forming an exact catalogue of stars, and of determining their

positions with accuracy and care. With such a catalogue the science of astronomy begins.

Although, to those who are unacquainted with the nature of celestial observation, it might at first sight appear almost impossible to number the stars; yet their relative situations have been so carefully observed by astronomers, that they have not only been numbered, but even their places in the heavens have been ascertained with greater accuracy than the relative situations of most places on the surface of the earth.

The greatest number of stars that are visible to the naked eye, are to be seen on a winter's night, when the air is clear, and no moon appears. But even then a good eye can scarce distinguish more than one thousand at a time in the visible hemisphere: for, though on such a night they appear to be almost innumerable, this appearance is a deception, that arises from our viewing them in a transient and confused manner; whereas, if we view them distinctly, and only consider a small portion of the heavens at a time, and, after some attention to the situation of the remarkable stars contained in that portion, begin to count, we shall be surprized at the smallness of their number and the ease with which they may be enumerated.

The number of the ancient constellations was 48; in these were included 1022 stars. Many conftellations have been added by modern astronomers; so that the catalogue of *Flamsteed* and *De la Caille*, when added together, are found to contain near five

thousand stars. The names of the constellations, their situation in the heavens, with other particulars, are best learned by studying the artificial representation of the heavens, a modern celestial globe.

The Galaxy or milky way must not be neglected; it is one of the most remarkable appearances in the heavens; it is a broad circle of a whitish hue, in some places it is double, but for the most part consists of a single path surrounding the whole celestial concave. The great *Galileo* discovered by the telescope, that the portion of the heavens which this circle passes through was every where filled with an infinite multitude of exceeding small stars, too small to be discovered by the naked eye, but by the combination of their light, diffusing a shining whiteness through the heavens. Mr. *Brydone* says, that when he was at the top of Mount Ætna, the milky way had the most beautiful effect, appearing like a pure flame that shot across the heavens.

The stars appear of a sensible magnitude to the naked eye, because the retina is not only affected by the rays of light which are emitted directly from them, but by many thousands more, which, falling upon our eye-lashes, and upon the visible aerial particles about us, are reflected into our eyes so strongly, as to excite vibrations, not only in those points of the retina where the real images of the stars are formed, but also in the other parts round about it. This makes us imagine the stars to be much bigger, than they would be if we saw them only by the few rays which come directly from them to our eyes,

without being intermixed with others. Any one may be made sensible of this, by looking at a star of the first magnitude through a long narrow tube; which, though it takes in as much of the sky as would hold a thousand of such stars, scarce renders that one visible.

The number of the stars almost infinitely exceeds what we have yet been speaking of. An ordinary telescope will discover, in several parts of the heavens, ten times as many stars as are visible to the naked eye. *Hooke* in his Micrographia says, that with a telescope of twelve feet he discovered seventy-eight stars among the Pleiades, and with a more perfect telescope, many more. *Galileo* reckoned eighty in the space between the belt and the sword of Orion, and above five hundred more in another part of the same constellation, within the compass of one or two degrees square. *Antonia Maria de Rheita* counted in the same constellation above ten thousand stars. Future improvements in the telescopes may enable us to discover numberless stars, that are now invisible; and many more may be which are too remote to be seen through telescopes, even when they have received their ultimate improvement. Dr. *Herschel*, to whose ingenuity and assiduity the astronomical world is so much indebted, and whose enthusiastic ardor has revived the spirit of discoveries, of which we shall speak more largely in another part of this essay, has evinced what may be effected by improvements in the instruments of observation. In speaking here of his discoveries, I shall use the words of

M. *De la Lande.** " In passing rapidly over the heavens with his new telescope, the universe increased under his eye; 44000 stars, seen in the space of a few degrees, seemed to indicate, that there were seventy-five millions in the heavens." He has also shewn that many stars, which to the eye or through ordinary glasses appear single, do in fact consist of two or more stars.† The Galaxy or milky way owes its light entirely to the multitude of small stars, placed so close as not to be discoverable even by an ordinary telescope. The nebulæ, or small whitish specks, discerned by means of telescopes, owe their origin to the same cause ; former astrologers could only reckon 103, Dr. *Herschel* has discovered upwards of 1250 of these clusters, besides a species which he calls planetary nebulæ. But what are all those, when compared to those that fill the whole expanse, the boundless fields of ether ! Indeed, the immensity of the world must contain such numbers, as would exceed the utmost stretch of the human imagination : for who can say, how far the universe extends, or where are the limits of it ? where the Creator stayed " his rapid wheels ;" or where he " fixed the golden compasses ?"

OF THE PLANETS, AS SEEN FROM THE SUN.

Our solar observer having attained a competent knowledge of the fixed stars, will now apply him-

* Memoires de l'Academie de Dijon, 1785.

† In all the larger sort of telescopes, the apparent number of stars is found to be encreased, as the aperture of the tube is augmented. EDIT.

self to consider the planets: these, as we have already observed, he will soon distinguish, by their motion, from the fixed stars; the stars always remaining in their places, but the planets will be seen passing by them with unequal velocities. Thus, on observing the earth, for instance, he will find it moving among the fixed stars, and approaching nearer and nearer to the more eastern ones; in a year's time it will complete its revolution, and return to the same place again.

He will find seven of these bodies revolving round the sun, to each of which he will assign a name, calling the swiftest *Mercury*, denominating the others in order, according to their velocities, as *Venus*, then the *Earth*, and afterwards *Mars, Jupiter, Saturn,* and the *Georgium Sidus*.

Proceeding with attention in thus exploring and examining the heavens, he will perceive that the Earth is always accompanied by a small star, Jupiter by four, Saturn by seven, and the Georgium Sidus by two :* these sometimes precede, as others follow; now pass before, and then behind the planets they respectively attend. These small bodies he will call *secondary planets, satellites,* or *moons.*

The observer, by remarking the exact time when each planet passes over some fixed star, and the time they employ from their setting out to their return to the same star again, will find the times elapsing between each successive return of the same planet to

* Four more have lately been discovered by Dr. *Herschel.* EDIT.

the same star, to be equal; and he would say, that the several planets describe circles in several periods; but that each of them always completes its own circle in the same space of time.

He will further observe, that there are certain bodies, which at their first appearance are small, obscure, ill-defined, and that move very slow, but which afterwards increase in magnitude, light, and velocity, until they arrive at a certain size, when they lose these properties, and diminish in the same manner as they before augmented, and at last disappear. To these bodies, which he will find in all the regions of the heavens, moving in different directions, he will give the name of *comets.*

OF THE PATHS OF THE PLANETS.

Our observer will take notice, that the planets run successively through those constellations which he has denominated *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces*; and that they never move out of a certain space or zone of the heavens, which we call the *zodiac.*

He will find, by proceeding in his observation, that the orbits of the planets are not all in the same plane, but that they cross each other in different parts of the heavens; so that, if he makes the orbit of any one planet a standard, and considers it as having no obliquity, he would judge the paths of all the rest to be inclined to it; each planet having

one half of its path on one side, and the other half on the opposite side of the standard path or orbit. Astronomers generally assume the earth's orbit as a standard from which to compute the inclination of the others, and call it the *ecliptic*.   The points where the orbits intersect each other, are called the *nodes*.

This inclination of the orbits to each other may be rendered more familiar to the imagination,* by taking as many hoops as there are planets, with a wire thrust through each, and thereby joined to that hoop which represents the ecliptic; the other hoops may be then set more or less obliquely to the representative of the ecliptic.

The several orbits do not cross or intersect the ecliptic in the same point, or at the same angles; but their nodes or intersections, are at different parts of the ecliptic.

It should, however, be observed here, that in speaking of the orbits of the planets, nothing more is meant by this term, than the paths they pass through in the open space in which they move, and in which they are retained by a celestial but continuous mechanism.

OF THE MOTION OF THE PLANETS ROUND THEIR AXES.

By attentively considering, with a telescope, the surface of the primary planets, our solar observer will find that some parts or spots are more obscure than others.   By continued observation he will find,

* Dr. *Watts*'s Astronomy.

that these spots change their places, and move from one side of the planet to the other; then disappear for a certain space of time ; after which they again, for a while, become visible on the side where they were first seen, always continuing the same motion nearly in an uniform manner. The distance between the spots grows wider as they advance from the edge towards the middle of the planet, and then grows narrow again as they pass from the middle to the other edge. The time they are seen on the planet's disc is somewhat less than the time of their disappearance.

From these circumstances he will conclude, first, that these spots adhere to the body of the planet; and secondly, that each planet is a globe turning on its axis, and has consequently two motions; one whereby it is moved round its axis in a short time, the other whereby it revolves round the sun. These motions may be easily conceived, by only imagining a small ball to roll round a large sphere. The first of these motions, or that of a planet round its axis,. is called the *diurnal motion*; and the second, or its revolution round the sun, is called the *annual motion.*

The tutor may in some measure realize to his pupil the foregoing heliocentric phenomena, by *plate* 1, *fig*. 1, of the solar system ; or still much better by means of a planetarium : for, by supposing himself on the brass ball which represents the sun, he will see that all the planets move round him in a beautiful and harmonious order. If on account of their distance, he refers their motions to the fixed stars,

he will see how readily the periods of their revolutions may be obtained, by observing the time that elapses between their setting out from any fixed point, or star, and their returning to the same again. He will also see, that if the paths of the planets were in one plane, as in the instrument, they would all be transferred to one circle in the heavens.

When he understands these particulars, the tutor may proceed to shew him that the motions, which are so regular when viewed from the sun, become intricate and perplexed when viewed from the earth; and infer from hence, that whenever " we examine the works of the DEITY at a proper point of distance, so as to take in the whole of his design, we see nothing but uniformity, beauty, and precision." Thus the heavens present us with a plan, which, though inexpressibly magnificent, is yet regular beyond the power of invention; and the volume of the universe will be found to be as perfect as its AUTHOR, containing mines of truth for ever opening, fountains of good for ever flowing, an endless succession of bright and still brighter exhibitions of the glorious Godhead, answering to the nature and idea of infinite fulness and perfection.

ESSAY I.

PART II.

OF THE PHENOMENA OF THE HEAVENS, AS SEEN FROM THE EARTH.

THE various appearances of the celestial bodies as seen from the earth, are the facts which lay the foundation of all astronomical knowledge. To account for, and explain them, is its principal business: a true idea of these phenomena is therefore a necessary step to a knowledge of astronomy. Let us therefore suppose ourselves in the open air, contemplating the appearances that occur in the heavens.

OF THE APPARENT MOTION OF THE SUN.

The first and most obvious phenomenon is the daily rising of the sun in the east, and his setting in the west; after which the moon and stars appear, still keeping the same westerly course, till we lose sight of them altogether. These appearances give rise to what is called the apparent diurnal motion of the heavens.

This cannot be long observed, before we must also perceive, that the sun does not always rise exactly at the same point of the heavens, his motions

deviating considerably at particular seasons from those they perform at other times. Sometimes we perceive him very high in the heavens, as if he would come directly over our heads; at other times he is almost sunk in the southern part of the heavens. If we commence our observations of the sun, for instance, in the beginning of March, we shall find him appear to rise more to the northward every day, to continue longer over the horizon, to be more vertical, or higher, at mid-day; this continues till towards the end of June, when he moves backward in the same manner, and continues this retrograde motion till near the end of December, when he begins to move forwards, and so on.

It is this change in the sun's place that occasions him to rise and set in the different parts of the horizon, at different times of the year. It is from hence that his height is so much greater in summer, than in winter. In a word, the change of the sun's place in the heavens is the cause of the different length in the days and nights, and the vicissitudes of the seasons.

As the knowledge of the sun's *apparent* motion is of great importance, and a proper conception of it absolutely necessary, in order to form a true idea of the phenomena of the heavens the reader will excuse my dwelling something longer upon it. If on an evening we take notice of some fixed star near the place where the sun sets, and observe it for several successive evenings, we shall find that it approaches the sun from day to day, till at last it will

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disappear, being effaced by his light, though but a few days before it was at a sufficient distance from him. That it is the sun which approaches the stars, and not the stars the sun, is plain, for this reason : the stars always rise and set every day at the same points of the horizon, opposite to the same terrestrial objects, and are always at the same distance from each other; whereas the sun is continually changing both the place of its rising and setting, and its distance from the stars.

The sun advances nearly one degree every day, moving from west to east ; so that in 365 days we see the same star near the setting sun, as was observed to be near him on the same day in the preceding year. In other words, the sun has returned to the place from whence he set out, or made what we call his annual revolution.

We cannot indeed observe the sun's motion among the fixed stars, because he darkens the heavens by his splendor, and effaces the feeble light of those stars that are in his neighbourhood ; but we can observe the instant of his coming to the meridian altitude; we can also compute what part of the starry heaven comes to the same meridian, at the same time, and with the same altitude. The sun must be at that point of the starry heavens thus discovered. Or we can observe that point in the heavens, which comes to the meridian at midnight, with a declination as far from the equator on one side, as the sun's is on the other side ; and it is evident, the sun must be in that part of the heavens, which is diametrically

opposite to this point. By either of these methods we can ascertain a series of points in the heavens, through which the sun passes, forming a circle called the *ecliptic*.*

OF THE APPARENT PHENOMENA OF THE MOON.

The motion of the moon through the heavens, and her appearance therein, are still more remarkable than those of the sun; she engages the attention " by the nightly changes in her circling orb." At the *new moon*, or when she first becomes visible, she is seen in the western part of the heavens, at no great distance from the sun. She increases every night in size, and removes to a greater distance from the sun, till at last she appears in the eastern part of the horizon, when the sun is disappearing in the western; she then appears with a full round face, and we say it is *full moon*. After this, she gradually removes further and further eastward, till at last she seems to approach the sun as nearly in the east as she did before in the west, and rises a little before him in the morning; whereas in the first part of her course she set in the west, long after him. All these different appearances happen in the space of a month, after which they re-commence in the same manner; " sometimes half-restoring day with her waxing brightness; sometimes waning into dimness, and scarcely scattering the nocturnal gloom."

* The conformity of this definition of the ecliptic, with that given in page 13, will be seen hereafter.

There is sometimes an irregularity in these appearances, particulary in harvest-time, when the moon appears for several days to be stationary in the heavens, and to preserve nearly the same distance from the sun ; in consequence of which, she rises at that season of the year nearly at the same hour for several nights.

OF THE APPARENT MOTION OF THE STARS.

In contemplating the Stars, it is observed that some among them have the singular property of neither rising in the east, nor setting in the west ; but seem to turn round one immoveable point, near which is placed a single star, called the *pole*, or *polar star*.

This point is more or less elevated, according to the part of the earth from which it is viewed. Thus to the inhabitants of Lapland it is much more vertical, or elevated above the horizon, than with us : we see it more elevated than the inhabitants of Spain : and these again see it more elevated than those of Barbary. By continually travelling southward, we should at last see the pole star depressed to the horizon, and the other pole would appear in the south part of the horizon, round which the stars in that part would revolve. There is, however, no star in the southern hemisphere so near the pole as that in the northern hemisphere. Supposing us still to travel southward, the north pole would entirely disappear, and the whole hemisphere would seem to

turn round a single point in the south, as the northern hemisphere appears to turn round the polar star.

The general appearance, therefore, of the starry heaven is that of a vast concave sphere turning round two fixed points (diametrically opposite to each other, the one in the north, the other in the south) once in twenty-four hours.

Hence it is that the stars, though they keep the same relative places with respect to each other, yet change their situation very sensibly with respect to the horizon; some rising above, others descending below it; some that were invisible, now becoming visible; while, on the other hand, many are disappearing. Some never descend below the horizon; although, as they turn round, they are sometimes nearer to, at others, further from it, describing whole circles about a point above it. If the observer turns himself round, he will find some stars rise only as it were to set again; many describing small arcs, and others larger ones.

THE APPEARANCES OF THE PLANETS.

Besides the fixed stars, there are other bodies in the heavens, which are continually changing their places, both with respect to the stars, and one another; these are called *planets*. They move among the signs of the zodiac, never departing far from the ecliptic. Their apparent motion is very irregular, confused, and perplexed; sometimes they appear as

going forwards, sometimes backwards, and at others are stationary.

Mercury emits a bright white light, but keeps so near the sun, and is so small, that he is very seldom visible; and when he does make his appearance, his motion towards the sun is so swift, that he can only be discerned for a short time. He appears a little after sun-set, and again a little before sun-rise.

Venus is the most beautiful star in the heavens, known by the names of the *morning* and *evening star*. She also, like Mercury, keeps near the sun, though she recedes from him much further, and, like him, is never seen in the eastern quarter of the heavens when the sun is in the western; but always either attends him in the evening, or gives notice of his approach in the morning.

Mars is of a red fiery colour, giving a much duller light than Venus, though he sometimes appears almost equal to her in size. He is not subject to the same limitations in his motions as Venus and Mercury, but appears sometimes very near the sun, at others at a greater distance from him, rising when the sun sets, or setting when he rises.

Jupiter and *Saturn* likewise often appear at great distances from the sun. The former shines with a bright light, the latter with a pale faint one. The motion of Saturn among the fixed stars is so slow, that unless carefully observed, and that for some time, he will not be thought to move at all.

The *Georgium Sidus* is the planet discovered by Dr. *Herschel.* It is reckoned to be twice the distance

of Saturn from the sun, but cannot be readily perceived without the assistance of a telescope.

From the preceding observations, any person may easily learn to distinguish all the planets. For if after sun-set he sees a planet nearer the east than the west, he may conclude that it is neither Mercury nor Venus; and may determine whether it be Saturn, Jupiter, or Mars, by the colour and light; by which, also, he may distinguish between Venus and Mercury.

That the light of each planet has its peculiar tinge; and that there are certain fixed stars that have the same teints, was known to the Chaldæans. It is an observation best verified in those countries, where the air is the clearest.

Besides the motions which we observe in all the planets, their apparent magnitudes are very different at different times. Every one must have observed that Venus, though she constantly appears with great splendor, is not always of the same size: but this difference of magnitude is most conspicuous in Mars, it is remarkable in Jupiter, but less so in Saturn and Mercury.

The only phenomena visible to the unassisted sight, besides those already described, are those unexpected obscurations of the sun and moon, called *eclipses*, of which we shall hereafter speak more particularly.

I have now described those appearances, which are the most striking to every person who has paid the least attention to what is passing over his head. The

tutor would do well in his place, first, to bring his pupil acquainted with the appearances themselves, and then explain them to him by the globe, or some other instrument. It would not be amiss, if he were now to instruct him by practical observations, and shew him, by a small quadrant, how to measure the elevation of the stars, &c. always remembering that young minds are ever active in search of impressions from external objects; and that these are more permanent than those made by words; in the former, the mind energizes, and is brought into action; in the latter, it is in a great degree passive.

ESSAY I.

PART III.

OF THE COPERNICAN OR SOLAR SYSTEM.

AFTER having stated what would be the appearances of the heavenly bodies, if we were placed at the centre of the system, and then given a general view of their phenomena as seen from the earth; it will now be proper to shew how the irregularities that are discovered in one situation are to be reconciled with the harmony and order that would be visible if they were to be seen from the other; or, in other words, to shew why the motions of the planets appear to us so different from what they really are.

One of the ends for which man was formed, is to correct appearances and errors, by the investigation of truth: whoever considers him attentively, from infancy to manhood, and from manhood to old age, will find him ever busy in endeavouring to find some reality, to supply the place of the false appearances, by which he has hitherto been deceived.

It is the business of the present part of this Essay to correct the errors arising from appearances, and to point out truth by a brief detail of the principal parts of the Copernican system, which is now uni-

versally received, because it rationally accounts for and accords with the phenomena of the heavens.

" At the appointed time, when it pleased the Supreme Dispenser of every good gift to restore light to a bewildered world, and more particularly to manifest his wisdom in the simplicity, as well as in the grandeur of his works, he opened the glorious scene with a revival of sound astronomy ;"* and raised up *Copernicus* to dispel the darkness in which it was then involved.

The Copernican system consists of the sun, seven primary, fourteen secondary planets, and the comets.

The seven planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and the Georgium Sidus, move round the sun,† in orbits included one within the other, and in the order here used in mentioning their names, Mercury being that which is nearest the sun.

The seven which revolve round the sun as their centre, are called *primary planets*.

The fourteen planets, which revolve round the primary ones as a centre, and are at the same time carried round the sun with them, are called *secondary planets, moons*, or *satellites*.

The Georgium Sidus is attended by two moons, Saturn by seven, Jupiter by four, and the Earth by one ; all of these, excepting the last, are invisible to

* *Pringle*'s Six Discourses to the Royal Society.
† The sun is not absolutely at rest, being subject to a small degree of motion, which is considered in larger works on Astronomy.

the naked eye, on account of the smallness of their size, and the greatness of their distance from us.

Mercury and Venus, being within the Earth's orbit, are called *inferior planets*; but Mars, Jupiter, Saturn, and the Georgium Sidus, being without it, are called *superior planets*.

The orbits of all the planets are elliptical; but as the principal phenomena of the Copernican system may be satisfactorily illustrated, by considering them as circular, the latter supposition is usually adopted in giving a general idea of the disposition and motion of the heavenly bodies.

Before we enter into a description of the solar system, it may be necessary to define what is meant by the *axis* of a planet; lest the pupil should conceive them to turn on such material axis, as are used in the machines which are contrived to represent the planetary system.

The *axis of a planet* is a line conceived to be drawn through its centre, and about which it is conceived to turn in the course of its revolution round the sun; the extremities of this line terminate in opposite points of the surface of the planet, and are called its *poles*; that which points towards the northern part of the heavens, is called the *north pole*; that which points towards the southern, the *south pole*. A ball whirled from the hand into the open air, turns round upon a line within itself, while it is moving forward; such a line as this is meant, when we speak of the axis of a planet.

Fig. 1, *plate* 1, represents the solar system, wherein ☉ denotes the sun ; A B, the circle which the nearest planet, Mercury, describes in moving round it ; C D, that in which Venus moves ; F G, the orbit of the earth ; H K, that of Mars ; I N, that of Jupiter ; O P, that of Saturn ; and Q R, that of the Georgium Sidus.　Beyond this are the starry heavens.

The sun and the planets are sometimes expressed by marks or characters, instead of writing their names at length. The characters are as follow : ☉ the Sun, ☿ Mercury, ♀ Venus, ⊕ the Earth, ♂ Mars, ♃ Jupiter, ♄ Saturn, ♅ Georgium Sidus.

OF THE SUN.

The Sun is the centre of the system, round which the rest of the planets revolve.　It is the first and greatest object of astronomical knowledge, and is alone enough to stamp a value on the science to which it belongs.　The Sun is the parent of the seasons ; day and night, summer and winter, are among its surprizing effects.　All the vegetable creation are the offspring of his beams ; our own lives are supported by its influence.　Nature revives, and puts on a new face, when it approaches nearer to us in spring ; and sinks into a temporary death at his departure from us in winter.

Hence the Sun was with propriety called by the ancients *cor cœli*, the *heart of heaven* ; for, as the heart is the heart of the animal system, so is the Sun the centre of our universe.　As the heart is the

fountain of the blood, and the centre of heat and motion; so is the Sun the life and heat of the world, and the first mover of the mundane system. When the heart ceases to beat, the circuit of life is at an end; and if the Sun should cease to act, a total stagnation would take place throughout the whole frame of nature.

The Sun is placed near the centre of the orbits of all the planets, and turns round his axis in $25\frac{1}{4}$ days. His apparent diameter, at a mean distance from the earth, is about 32 minutes 12 seconds.

Those who are not accustomed to astronomical calculation, will be surprized at the real magnitude of this luminary; which on account of its distance from us, appears to the eye not much larger than the moon, which is only an attendant on our earth. When looking at the Sun, they are viewing a globe, whose diameter is 890,000 English miles; whereas the earth is not more in diameter than 7970 miles: so that the Sun is about 1,392,500 times bigger than the earth. Thus, as it is the fountain of light and heat to all the planets, so it also far surpasses them in its bulk.

If the Sun were every where equally bright, his rotation on his axis would not be perceptible; but by means of the spots which are visible on his pure and lucid surface, we are enabled to discover this motion.

When a spherical body is near enough to appear of its true figure, this appearance is owing to the shading upon the different parts of its surface: for

as a flat circular piece of board, when it is properly shaded by painting, will look like a spherical body ; so a spherical body appears of its true shape, for the same reason that the plane board, in the present instance, appears spherical. But if the sphere be at a great distance, this difference of shading cannot be discerned by the eye, and consequently the sphere will no longer appear of its true shape ; the shading is then lost; and it seems like a flat circle.

It is thus with the Sun; it appears to us like a bright flat circle, which flat circle is termed the *sun's disc*. By the assistance of telescopes, dark spots have been observed on this disc, and found to have a motion from east to west ; their velocity is greater when they are at the centre, than when they are near the limb. They are seen first on the eastern extremity, by degrees they come forwards towards the middle, and so pass on till they reach the western edge; they then disappear; and after they have lain hid about the same time that they continued visible, they appear again as at first. By this motion we discover not only the time the sun employs in turning round his axis, but also the inclination of his axis to the plane of the ecliptic.*

* The young observer may view the spots of the sun with a refracting telescope of two or three feet, or a reflecting one of 12 inches, 18 inches, or two feet, taking care to guard the eye with a dark glass, to take off the glaring light : or the image or pic- of the sun, with his spots, may be thrown into a dark room, through a telescope, and received upon a piece of paper placed nearer or further from the glass at pleasure.

The page of history informs us, that there have been periods, when the sun has wanted of its accustomed brightness, shone with a dim and obscure light for the space of a whole year. This obscurity has been supposed to arise from his surface being at those times covered with spots. Spots have been seen that were much larger than the earth.

The sun is supposed to have an atmosphere, which occasions that appearance which is termed the *zodiacal light*. This light is seen at some seasons of the year, either a little after sun-set, or a little before sun-rise. It is faintly bright, and of a whitish colour, resembling the milky way. In the morning it becomes brighter and larger, as it rises above the horizon, till the approach of day, which diminishes its splendor, and renders it at last invisible. Its figure is that of a flat or lenticular spheriod, seen in profile. The direction of its longer axis coincides with the plane of the sun's equator. But its length is subject to great variation, so that the distance of its summit from the sun, varies from 45 to 120 degrees. It is seen to the best advantage about the solstices. It was first described and named by *Cassini*, in 1683; it was noticed by Mr. *Childrey*, about the year 1650.

OF THE INFERIOR PLANETS, MERCURY AND VENUS.

OF MERCURY. ☿

Of all the planets, *Mercury* is the least; at the same time, it is that which is nearest the sun. It is from his proximity to this globe of light, that he is so seldom within the sphere of our observation, being lost in the splendor of the solar brightness; yet it emits a very bright white light. It is oftener seen in those parts of the world, which are more southward than that which we inhabit; and oftener to us than to those who live nearer the north pole; for the more oblique the sphere is, the less is the planet's elevation above the horizon.

Mercury never removes but a few degrees from the sun. The measure of a planet's separation, or distance, from the sun, and is called its *elongation*. His greatest elongation is never more than 28 degrees, or about as far as the moon appears to be from the sun, the second day after new moon. In some of its revolutions, the elongation is not more than 18 degrees.

Mercury is computed to be 37 millions of miles from the sun, and to revolve round him in 87 days, 23 hours, and nearly 16 minutes, which is the measure of its year, about one fourth of our's. As from the nearness of this planet to the sun, we neither know the time it revolves round its axis, nor the inclination of that axis to the plane of its orbit, we

are necessarily ignorant of the length of its day and night, or the variety of seasons it may be liable to. Mercury is 3000 miles in diameter. Large as Mercury, when thus considered, appears to be, it is but an atom, when compared with Jupiter, whose diameter is 90,000 miles. Its apparent diameter, at a mean distance from the earth, is 20 seconds.

Mercury is supposed to move at the rate of 110,680 miles per hour. The sun is above 26,000,000 times as big as Mercury; so that it would appear to the inhabitants of Mercury nearly three times larger than it does to us; and its disc, or face, about seven times the size we see it. As the other five planets are above Mercury, their phenomena will be nearly the same to it as to us. Venus and the earth, when in opposition to the sun, will shine with full orbs, and afford a brilliant appearance to the Mercurian spectator.

Mercury, like the moon, changes its phases, according to its several positions with respect to the sun and earth. He never appears quite round or full to us, because his enlightened side is never turned directly towards us, except when he is so near the sun as to become invisible. The times for making the most favourable observations on this planet are, when it passes before the sun, and is seen traversing his disc in the form of a black spot: this passage of a planet over the face of the sun is called a *transit*. It happens in its lower conjunction, at a particular situation of the nodes; which leads us to mention their place in the ecliptic.

C

The angle formed by the inclination of the orbit of Mercury with the plane of the ecliptic, is 16° 59'; the node from which Mercury ascends northward, above the plane of the ecliptic, is 16° 1' 30"; in Taurus, the opposite one, 14° 1' 24"; in Sagitarius, its nodes move forward about 50" per year.

If Mercury, at his inferior conjunction, comes to either of his nodes about these times, he will appear to *transit* over the disc of the sun. But in all other parts of his orbit his conjunctions are invisible, because he either goes above or below the sun.

OF VENUS. ♀

Venus is the brightest and largest, to appearance, of all the planets, distinguished from them all by a superiority of lustre; her light is of a white colour, and so considerable, that in a dusky place she projects a sensible shade.

The diameter of Venus is 7,699 miles; her distance from the sun is 69,500,000 miles; she goes round the sun in 224 days, 16 hours, 49 minutes, moving at the rate of 80,995 miles per hour. Her motion round her axis has been fixed by some at 23 hours, 22 minutes; by others, at above 24 days. She, like Mercury, constantly attends the sun, never departing from him above 47 or 48 degrees. Like Mercury, she is never seen at midnight, or in opposition to the sun, being visible only for three or four hours in the morning or evening, according as she is before or after the sun.

One would not imagine that this planet, which appears so much superior to Saturn in the heavens, is so inconsiderable when compared to it; for the diameter of Saturn is nearly 78,000 miles; while, on the other hand, one would scarce imagine that Venus, which appears but as a lucid spangle in the heavens, was so large a globe as she truly is, her diameter being 7,699 miles. It is the distance which produces these effects; which gives and takes away the magnitude of things. Her apparent size varies with her distance; at some seasons she appears near 32 times larger than at others.

When this planet is in that part of its orbit which is west of the sun, that is, from her inferior to her superior conjunction, she rises before him in the morning, and is called *phosphorus* or *lucipher*, or the *morning star*. When she appears east of the sun, that is, from her superior to her inferior conjunction, she sets in the evening after him ; or, in other words, shines in the evening after he sets, and is called *hesperus* or *vesper*, or the *evening star*.

The inhabitants of Venus see the planet Mercury always accompanying the sun; and he is to them, by turns, an evening or a morning star, as Venus is to us. To the same inhabitants, the sun will appear almost twice as large as he does to us.

Venus, when viewed through a telescope, is seldom seen to shine with a full face; but has phases, just like the moon, from the fine thin crescent to the enlightened hemisphere. Her illuminated part is constantly turned towards the sun; hence its

horns are turned towards the east when it is a morning star, and towards the west when it is an evening star. Some astronomers have thought they perceived a satellite moving round Venus; but, as succeeding observers have not been able to verify their observations, they are supposed to have originated in error. In observing the transit of Venus, Mr. *Dunn*, and other gentlemen, saw a penumbra which took place about five seconds before the contact, preceding the egress of the planet; and from thence they concluded that it had an atmosphere of about 50 geographical miles in height.

We are told, that when *Copernicus* first published his account of the solar system, it was objected to him that it could not be true, because, if it was, the inferior planets must have different phases, according to their different situation with respect to the sun and earth; whereas they always appear round to us. The answer said to be made by him is, that they appear round to the eye by reason of their distance; but, if we could have a nearer, or more distinct view of them, we should see in them the same phases as we do in the moon. The invention of telescopes is said to have verified this prediction of *Copernicus*. But it is neither probable, that a defender of the Ptolemaic system should make such an objection, or *Copernicus* such an answer; since, in the Ptolemaic, as well as in the Copernican system, the shape of these planets ought to change just as the moon does; consequently, the mere change of shape in the inferior planets is an argument which

in the common way of urging it, proves nothing at all as to the truth or falshood of the Copernican system. If, besides the changes of shape made in the inferior planets, we consider the situation of the planets with respect to the sun, when these changes happen; this, indeed, will shew us that the Ptolemaic system is false,* as will be seen in a subsequent part of these essays.

Venus is sometimes seen passing over the disc of the sun, as a round dark spot. These appearances, which are called *transits*, happen very seldom; though there have been two within these few years, the one in June 1761, the other in June 1769; the next will be in the year 1874.

OF THE EARTH. ⊕

The next planet that comes before us is the Earth that we inhabit: small as it really is, when compared to some of the other planets, it is to us of the highest importance; we wish only to attain knowledge of others, that we may find out their relation to this, and from thence learn our connexion with the universe at large. But, when viewed with an eye to eternity, its value to us is heightened in a manner that exceeds expression, and surpasses all the powers of the human mind. He alone can form some idea of it, who in the regions of celestial bliss

* *Rutherford's* System of Natural Philosophy, vol. ii. p. 781.

is become a partaker of the length and breadth, the depth and height of divine love.

The orbit of the Earth is placed between those of Venus and Mars. The diameter of the Earth is 7970 miles; its distance from the sun is 96 millions of miles, and goes round him in a year, or 365 days, 6 hours, 9 minutes, moving at the rate of 68,856 miles per hour. Its apparent diameter, as seen from the sun, is about 21 seconds.

It turns round its axis from west to east in 24 hours, which occasions the apparent diurnal motion of the sun, and all the heavenly bodies round it, from east to west in the same time; it is of course the cause of their rising and setting, of day and night.

The axis of the earth is inclined $23\frac{1}{2}$ degrees to the plane of its orbit, and keeps in a direction parallel to itself throughout its annual course, which causes the returns of spring and summer, autumn and winter. Thus his diurnal motion gives us the grateful vicissitude of night and day, and his annual motion the regular succession of seasons.

OF THE MOON. ☾

Next to the sun, the *Moon* is the most splendid and shining globe in the heavens, the satellite, or inseparable companion of the earth. By dissipating, in some measure, the darkness and horrors of the night, subdividing the year into months, and regulating the flux and reflux of the sea, she not only

becomes a pleasing, but a welcome object; an object affording much for speculation to the contemplative mind, of real use to the navigator, the traveller, and the husbandman. The Hebrews, the Greeks, the Romans, and, in general, all the ancients, used to assemble at the time of new moon, to discharge the duties of piety and gratitude for its manifold uses.

That the moon appears so much larger than the other planets, is owing to her vicinity to us; for, to a spectator in the sun she would be scarcely visible, without the assistance of a telescope. Her distance is but small from us, when compared with that of the other heavenly bodies: for among these, the least absolute distance, when put down in numbers, will appear great, and the smallest magnitude immense.

The Moon is 2161 miles in diameter; her bulk is about $\frac{1}{41}$ of the earth's; her distance from the centre of the earth 240,000 miles; she goes round her orbit in 27 days, 7 hours, 43 minutes, moving at the rate of 2299 miles per hour. The time in going round the earth, reckoning from change to change, is 29 days, 12 hours, 44 minutes. Her apparent diameter, at a mean distance from the earth, is 31′ 16½″; but, as viewed from the sun, at a mean distance about 6″.

Her orbit is inclined to the ecliptic, in an angle of five degrees, 18 minutes, cutting it in two points, which are diametrically opposite to each other; these points are called her *nodes*. Her nodes have a motion westward, or contrary to the order of the signs, making a complete revolution in about 19 years; in which

time each node returns to that point of the ecliptic whence it before receded.

If the moon were a body possessing native light, we should not perceive any diversity of appearance; but, as she shines entirely by light received from the sun, and reflected by her surface, it follows, that, according to the situation of the beholder with respect to the illuminated part, he will see more or less of her reflected beams; for only one-half of a globe can be enlightened at once.

Hence, while she is making her revolution round the heavens, she undergoes great changes in her appearance. She is sometimes on our meridian at midnight, and, therefore, in that part of the heavens which is opposite to the sun: in this situation she appears as a complete circle, and it is said to be *full moon*. As she moves eastward, she becomes deficient on the west side, and in about $7\frac{1}{3}$ days comes to the meridian at about six in the morning, having the appearance of a semicircle, with the convex side turned towards the sun; in this state, her appearance is called the *half moon*. Moving on still eastward, she becomes more deficient on the west, and has the form of a crescent with the convex side turned towards the sun; this crescent becomes continually more slender, till about fourteen days after the full moon she is so near the sun that she cannot be seen, on account of his great splendor. About four days after this disappearance, she is seen in the evening a little to the eastward of the sun, in the form of a fine crescent with the convex side turned from the sun;

moving still to the eastward, the crescent becomes more full; and, when the Moon comes to the meridian, about six in the evening, she has again the appearance of a bright semicircle: advancing still to the eastward, she becomes fuller on the east side; at last, in about 29½ days, she is again opposite to the sun, and again full. It frequently happens, that the Moon is eclipsed when at the full; and that the sun is eclipsed sometime between the disappearance of the Moon in the morning on the west side of the sun and her appearance in the evening on the east side of the sun. The nature of these phenomena will be more fully considered, when we come to treat particularly of eclipses.

In every revolution of the Moon about the earth, she turns once round upon her axis, and therefore always presents to us the same face; and as, during her course round the earth, the sun enlightens successively every part of her globe only once, consequently she has but one day in all that time, and her day and night together are as long as our lunar month. As we see only one side of the Moon, we are therefore invisible to the inhabitants on the opposite side, without they take a journey to that side which is next to us, for which purpose some of them must travel more than 1500 miles.

As the moon illuminates the earth by a light reflected from the sun, she is reciprocally enlightened, but in a much greater degree by the earth, for the surface is above thirteen times greater than that of the Moon; and, therefore, supposing their power of

reflecting light to be equal, the earth will reflect thirteen times more light on the Moon than she receives from it. When it is what we call New Moon, we shall appear as a full moon to the Lunarians; as it increases in light to us, ours will decrease to them: in a word, our earth will exhibit to them the same phases as she does to us.

We have already observed, that from one half of the Moon the earth is never seen; from the middle of of the other half, it is always seen over head, turning round almost thirty times as quick as the moon does. To her inhabitants, the earth seems to be the largest body in the universe, about thirteen times as large to them, as she does to us. As the earth turns round its axis, the several continents and islands appear to the Lunarians as so many spots of different forms; by these spots they may determine the time of the earth's diurnal motion; by these spots, they may perhaps measure their time; they cannot have a better dial.

OF THE SUPERIOR PLANETS.

Mars, *Jupiter*, *Saturn*, and the *Georgium Sidus*, are called *superior planets*, because they are higher in the system, or farther from the centre of it than the earth is.

They exhibit several phenomena, which are very different from those of Mercury and Venus; among other things, they come to our meridian both at noon and midnight, and are never seen crossing the sun's disc.

OF MARS. ♂

Mars is the least bright and elegant of all the planets; its orbit lies between that of the Earth and Jupiter; but very distant from both. He appears of a dusky reddish hue; from the dullness of his appearance, many have conjectured that he is encompassed with a thick cloudy atmosphere; his light is not near so bright as that of Venus, though he is sometimes nearly equal to her in size.

Mars, which appears so inconsiderable in the heavens, is 5,309 miles in diameter. Its distance from the sun is 146,000,000 miles. It goes round the sun in one year, 321 days, 23 hours, moving at the rate of 55,287 miles per hour. It revolves round its axis in about 24 hours, 40 minutes. To an inhabitant in Mars, the sun would appear one third less in diameter than it does to us. Its apparent diameter, as viewed at a mean distance from the earth, is 30 seconds.

Mars, when in opposition to the sun, is five times nearer to us than when in conjunction. This has a very visible effect on the appearance of the planet, causing him to appear much larger at some periods than at others.

The analogy between Mars and the earth is by far the greatest in the whole solar system; their diurnal motion is nearly the same; the obliquities of their respective ecliptics not very different. Of all the superior planets, that of Mars is by far the nearest like the earth: nor will the Martial year appear so

dissimilar to our's, when we compare it with the long duration of the years of Jupiter, Saturn, and the Georgium Sidus. It probably has a considerable atmosphere; for besides the permanent spots on its surface, Dr. *Herschel* has often perceived occasional changes of partial bright belts, and also once a darkish one in a pretty high latitude; alterations which we can attribute to no other cause than the variable disposition of clouds and vapours floating in the atmosphere of the planet.

A spectator in Mars will rarely, if ever, see Mercury, except when he sees it passing over the sun's disc. Venus will appear to him at about the same distance from the sun, as Mercury appears to us. The earth will appear about the size of Venus, and never above 48 degrees from the sun; and will be, by turns, a morning and evening star to the inhabitants of Mars. It appears, from the most accurate observations, that Mars is a spheriod, or flatted sphere, the equatorial diameter to the polar being in the proportion of about 131 to 127; and there is reason to suppose that all the planets are of this figure.

OF JUPITER. ♃

Jupiter is situated still further in the system, revolving round the sun, between Mars and Saturn. It is the largest of all the planets, and easily distinguished from them by his peculiar magnitude and light. To the naked eye it appears almost as large as Venus, but not altogether so bright.

Jupiter revolves round its axis in nine hours, 56 minutes; its revolution in its orbit to the same point of the ecliptic is 11 years, 314 days, 10 hours. The disproportion of Jupiter to the earth, in size, is very great; viewing him in the heavens, we consider him as small in magnitude; whereas he is in reality 90,228 miles in diameter; his distance from the sun is 494,750,000 miles; he moves at the rate of rather more than 29,083 miles; per hour. Its apparent diameter, as seen at a mean distance from the earth, is 39".

To an eye placed in Jupiter, the sun would not be a fifth part of the size he appears to us, and his disc be 25 times less. Though Jupiter be the largest of all the planets, yet its revolution round its axis is the swiftest. The polar axis is shorter than the equatorial one, and his axis perpendicular to the plane of his orbit.

Jupiter, when in opposition to the sun, is much nearer the earth, than when he is in conjunction with him; at those times he appears also larger, and more luminous than at other times.

In Jupiter, the days and nights are of an equal length, each being about five hours long. We have already observed, that the axis of his diurnal rotation is nearly at right angles to the plane of his annual one, and consequently there can be scarce any difference in seasons; and here as far as we may reason from analogy, we may discover the footsteps of wisdom: for, if the axis of this planet were inclined by any considerable number of degrees, just

so many degrees round each pole would, in their turn, be almost six years in darkness; and as Jupiter is of such an amazing size, in this case immense regions of land would be uninhabitable.

Jupiter is attended by four satellites, or moons; these are invisible to the naked eye; but through a telescope they make a beautiful appearance. As our moon turns round the earth, enlightening the nights, by reflecting the light she receives from the sun; so these also enlighten the nights of Jupiter, and move round him in different periods of times, proportioned to their several distances: and as the moon keeps company with the earth in its annual revolution round the sun, so these accompany Jupiter in its course round that luminary.

In speaking of the satellites, we distinguish them according to their places; into the first, second, and so on; by the first, we mean that which is nearest to the planet.

The outermost of Jupiter's satellites will appear almost as big as the moon does to us; five times the diameter, and twenty-five times the disc of the sun. The four satellites must afford a pleasing spectacle to the inhabitants of Jupiter; for sometimes they will rise all together, sometimes be all together on the meridian, ranged one under another, besides frequent eclipses. Notwithstanding the distance of Jupiter and his satellites from us, the eclipses thereof are of considerable use for ascertaining with accuracy the longitude of places. From the four satellites the inhabitants of Jupiter will have four different

kinds of months, and the number of them in their year not less than 4,500.

An astronomer in Jupiter will never see Mercury, Venus, the Earth, or Mars; because, from the immense distance at which he is placed, they must appear to accompany the sun, and rise and set with him; but then he will have for the objects of observation, his own four moons, Saturn, his ring and satellites, and probably the Georgium Sidus.

OF SATURN. ♄

Before the discovery of the Georgium Sidus, *Saturn* was reckoned the most remote planet in our system; he shines but with a pale feeble light, less bright than Jupiter, though less rudy than Mars. The uninformed eye imagines not, when it is directed to this little speck of light, that it is viewing a large and glorious globe, one of the most stupendous of the planets, whose diameter is nearly 78,000 miles. We need not, however, be surprized at the vast bulk of Saturn, and its disproportion to its appearance in the heavens; for we are to consider that all objects decrease in their apparent magnitude, in proportion to their distance; but the distance of Saturn is immense; that of the earth from the sun is 96,000,000 miles; of Saturn, 916,500,000 miles.

The length of a planet's year, or the time of its revolution round its orbit, is proportioned to its distance from the sun. Saturn goes round the sun in 29 years, 167 days, six hours, moving at the rate of

rather more than 22,298 miles per hour. His apparent diameter at a mean distance from the earth is 16′.

It has not yet been ascertained with certainty by astronomical observation, whether Saturn revolves or not upon his axis. The sun's disc will appear ninety times less to an inhabitant of Saturn, than it does to us; but notwithstanding the sun appears so small to the inhabitants of the regions of Jupiter and Saturn, the light that he will afford them is much more than would be at first supposed; and calculations have been made, from which it is inferred, that the sun will afford 500 times as much light to Saturn, as the full moon to us; and 1600 times as much to Jupiter. To eyes like our's, unassisted by instruments, Jupiter and the Georgium Sidus would be the only planets seen from Saturn, to whom Jupiter would sometimes be a morning, sometimes an evening star.

One of the first discoveries by the telescope, when brought to a tolerable degree of perfection, was, that Saturn did not appear like other planets. *Galileo*, in 1610, supposed it composed of three stars or globes, a larger in the middle, and a smaller on each side; and he continued his observations till the two lesser stars disappeared, and this planet looked like the others. Further observation shewed that what *Galileo* took for two stars, were parts of a ring. This singular and curious appendage to the planet Saturn, is a thin, broad, opake ring, encompassing the body of the planet, without touching it, like the horizon of an artificial globe, appearing double when

viewed through a good telescope. The space between the ring and the globe of Saturn is supposed to be rather more than the breadth of the ring, and the greatest diameter of the ring to be in proportion to that of the globe, as seven to three; the plane of the ring is inclined to the plane of the ecliptic, in an angle of 30°, and is about 21,000 miles in breadth. It puts on different appearances to us, sometimes being seen quite open, at others only as a line upon the equator. It is probable, that it will at times cast a shadow over vast regions of Saturn's body. The ring of Saturn considered as a broad flat ring of solid matter, suspended round the body of the planet, and keeping its place without any connexion with the body, is quite different from all other planetary phenomena with which we are acquainted. Of the nature of this ring, various and uncertain were the conjectures of the first observers, though not more perplexed than those of the latest. Of its use to the inhabitants of Saturn, we are as ignorant as of its nature; though there are reasons for supposing that it would appear to them as little more than a white or bright-coloured cloud. Some of the phenomena of Saturn's ring will be treated of more particularly in another part of this essay.

Saturn is not only furnished with this beautiful ring, but has also seven attendant moons.

D

OF THE GEORGIUM SIDUS. ♄

From the time of *Huygens* and *Cassini*, to the discovery of the *Georgium Sidus* by Dr. *Herschel*, though the intervening space was long, though the number of astronomers was increased, though assiduity in observing was assisted by accuracy and perfection in the instruments of observation, yet no new discovery was made in the heavens, the boundaries of our system were not enlarged. The inquisitive mind naturally inquires, why, when the number of those that cultivated the science was increased, when the science itself was so much improved, in practical discoveries it was so deficient! A small knowledge of the human mind will answer the question, and obviate the difficulty. The mind of man has a natural propensity to indolence; the ardour of its pursuits, when they are unconnected with selfish views, are soon abated, small difficulties discourage, little inconveniencies fatigue it, and reason soon finds excuses to justify, and even applaud this weakness. In the present instance, the unmanageable length of the telescopes that were in use, and the continual exposure to the cold air of the night, were the difficulties that the astronomer had to encounter with ; and he soon persuaded himself, that the same effects would be produced by shorter telescopes, with equal magnifying power; herein was his miftake, and hence the reason why so few discoveries have been made since the time of *Cassini*. A similar instance of the retrogradation of science occurs in the history of

the microscope, as I have shewn in my Essays on that instrument.

The Georgium Sidus was discovered by Dr. *Herschel*, in the year 1781: for this discovery he obtained from the Royal Society the honorary recompence of Sir *Godfrey Copley*'s medal. He named the planet in honour of his Majesty King George III. the Patron of science, who has taken Dr. *Herschel* under his patronage, and granted him an annual salary. By this munificence he has given scope to a very uncommon genius, and enabled him to prosecute his favourite studies with unremitted ardour.

In so recent a discovery, of a planet so distant, many particulars cannot be expected. Its year is supposed to be more than 80 siderial years; its diameter 34,299 miles; the inclination of its orbit 43′ 35″; its diameter, compared to that of the earth, as 431,769 to 1; in bulk it is 8,049,256 times as large as the earth. Its light is of a bluish white colour, and its brilliancy between that of the moon and Venus.

Though the Georgium Sidus was not known as a planet till the time of Dr. *Herschel*, yet there are many reasons to suppose it had been seen before, but had been considered as a fixed star. Dr. *Herschel*'s attention was first engaged by the steadiness of its light; this induced him to apply higher magnifying powers to his telescope, which increased the diameter of it: in two days he observed that its place was changed; he then concluded it was a comet; but in a little time Dr. *Maskelyne* himself and others, determined that it was a planet, from its vicinity to

the ecliptic, the direction of its motion, being stationary in the time, and in such circumstances as to correspond with similar appearances in other planets.

With a telescope, which magnifies about 300 times, it appears to have a very well-defined visible disc; but with instruments of a smaller power it can hardly be distinguished from a fixed star between the sixth and seventh magnitude. When the moon is absent, it may be seen by the naked eye.

Dr. *Herschel* has since discovered that it is attended by six satellites: a discovery which gave him considerable pleasure, as the little secondary planets seemed to give a dignity to the primary one, and raise it into a more conspicuous situation among the great bodies of our solar system.

As the distances of the planets, when marked in miles, are a burden to the memory, astronomers often express their mean distances in a shorter way, by supposing the distance of the earth from the sun to be divided into ten parts. Mercury may then be estimated at four of such parts from the sun, Venus at seven, the earth at ten, Mars at fifteen, Jupiter at fifty-two such parts, Saturn at ninety-five, and the Georgium Sidus 190 parts.

By comparing the periods of the planets, or the time they take to finish their revolutions, with their distance from the sun, they are found to observe a wonderful harmony and proportion to each other; for the nearer any planet is to the sun, the sooner does he finish his revolution. And in this there is a

constant and immutable law, which all the bo-
dies of the universe inviolably observe in their cir-
culations; namely, *That the squares of their perio-*
dical times are as the cubes of their distances from the
centre of the orbit about which they regularly per-
form their motions. We are indebted to the sagacity
of *Kepler* for the discovery of this law; he was in-
deed one of the first founders of modern astronomy.

I cannot conclude this general survey of the solar
system better than in the words of that excellent
mathematician, Mr. *Maclaurin.* " The view of na-
ture, which is the immediate object of sense, is
very imperfect, and of small extent; but by the as-
sistance of art, and the aid of reason, becomes en-
larged, till it loses itself in infinity. As magnitude
of every sort, abstractedly considered, is capable of
being increased to infinity, and is also divisible with-
out end; so we find, that in nature the limits of the
greatest and least dimensions of things are actually
placed at an immense distance from each other.

" We can perceive no bounds of the vaft expanse,
in which natural causes operate, and fix no limit, or
termination, to the universe. The objects we com-
monly call great, vanish, when we contemplate the
vast body of the earth. The terraqueous globe itself
is lost in the solar system; the sun itself dwindles
into a star; Saturn's vast orbit, and all the orbits of
the comets, crowd into a point, when viewed from
numberless places between the earth and the nearest
fixed stars. Other suns kindle to illuminate other
systems, where our sun's rays are unperceived; but

they also are swallowed up in the vast expanse. When we have risen so high, as to leave all definite measures far behind us, we find ourselves no nearer to a term or limit.

" Our views of nature, however imperfect, serve to represent to us, in a most sensible manner, that mighty power which prevails throughout, acting with a force and efficacy that suffers no diminution from the greatest diſtances of space, or intervals of time; and to prove that all things are ordered by infinite wisdom and perfect goodness ; scenes which should excite and animate us to correspond with the general harmony of nature."*

ACCOUNT OF THE DISCOVERY OF TWO NEW PLANETS NAMED CERES AND PALLAS.†

Professor *Piazzi*, of the university of Palermo, in Italy, a very able astronomer, discovered on the first of January, 1801, a moveable star which had the appearance of a new planet ; he estimated its bulk to be about $1\frac{1}{3}$ that of the earth, and its position in our system to be between Mars and Jupiter. In compliment to the present sovereign, the founder of the Palermo observatory, he denominated it *Ceres Ferdinandia*, and it is now generally called *Ceres*. Subsequent observations on this planetary body made by Dr. *Maskelyne*, Dr. *Herschel*, and other

* Maclaurin.

† I have availed myself of the opportunity of inserting the above discovery in the present edition. EDIT.

astronomers of this country, France and Germany, appear at present to confirm its identity with the other planets. On the 4th of February, 1802, Dr. *Maskelyne* at the Royal Observatory, Greenwich, observed this planet passing the meridian, between 3 and 4 o'clock in the morning, having about 188° 43' right ascension, and 12° 38' north declination, in appearance like a star of the 8th magnitude; and preceding the 11th of the same month, he had sufficiently observed it, so as fully to ascertain its motion. With a power of 60, it appeared to have a visible disc, when on the meridian, and through a clear air, the disc was round and well defined, and rather smaller than that of the 34th of Virgo, an approximate star of the 6th magnitude; at the same time Dr. *Maskelyne* remarked that the smallness and rotundity of the appearance of the fixed stars is a good criterion of the clearness of the air. The light of this planet is of a reddish hue, and has been judged to resemble that of the planet Mars. From the earth's position and quicker motion in its orbit, it appeared stationary on the 6th and 7th of February last, and has had since an apparent retrograde motion. Dr. *Herschel* judges it to be not larger than a fourth part of the diameter of the Georgium Sidus, and its apparent diameter 22". This planet was in opposition to the sun on March 17, 1802. Therefore, at this time, October 6th, its proximity to the sun, and twilight, prevents any observation. In the month of January next, observations of it may be reassumed. Baron *De Zach's* computation of its place for April

6th last, was 178° 29' right ascension, and 18" 10 north declination.

On the 28th of March, 1802, a remarkable dis-covery of another new planetary body was made by Dr. *Olbers*, of Bremen, in Germany; it is of small apparent magnitude, and then formed an equilateral triangle with the stars 20 and 19 of Virgo, he found it had a perceptible change of place, and the follow-ing observations were communicated by him of it, to an astronomer Dr. *Schroeter*.

1802. March 28^d 9^h 25' 10" meantime

App. R. Ascen. 184°. 56' 49"

App. Declin. 11 33 30 N

29^d 8^h 49' 14" M. T. App. R. A. 184 46 36

App. Declin. 11 52 59 N

Dr. *Olbers* did not observe any sensible disc; in comparison to Ceres, its light was pale and white, and less bright than the Georgium Sidus; he has given it the name of *Pallas*. From calculations made by Dr. *Gaufs*, founded upon a set of obser-vations by Baron *de Zuch*, it appears, that it is a planetary body moving between the orbits of Mars and Jupiter, with a very great eccentricity and inclination, and whose orbit comes very near to the orbit of the planet Ceres. Dr. *Herschel*, from his observations upon this planetary body, judges the apparent diameter to be rather less than Ceres, about 13" or 17", and its diameter in English miles 93 or 71, and that of Ceres 163, to have a colour less ruddy than Pallas, both this and Ceres to have generally *comas* or haziness about them, he thinks

that they both differ from the general character of planets in their diminutive dimensions, in their great inclination of their orbits, in the comas surrounding them, and in their mutual proximity of their orbits; that they differ from comets in their defect of excentricity, and of a considerable nebularity.

Pallas like Ceres will not be sufficiently apparent till January next (1803). Baron *de Zuch*, has given us the positions for the 29th of June last (1802) as follows, $188°\ 32'$ right ascension, and $19°\ 6''$ N. declination, and observes that it may be difficult to find Pallas next year, for the elements of an orbit calculated upon so small an arc as $7°\frac{1}{2}$, may give an error of several degrees in January, 1803. On this account I shall forbear the insertion of the several tables of the motions of these two planets as calculated upon the elements computed by various ingenious astronomers. The places of the Georgium planet are annually published in the Nautical Ephemeris, and that of White's; and it can only be from a continued series of accurate observations for a length of time, that a proper data can be obtained, to construct true elements from.

AN EXPLANATION OF VARIOUS PHENOMENA, AGREEABLE TO THE COPERNICAN SYSTEM.

Having given a general idea of the Copernican system, and the bodies of which it is composed, it will be necessary to enlarge these ideas by a more minute description of the particular parts which

form this great whole; and to strengthen them by the force of that evidence, on which the system is founded.

OF THE FIGURE AND MAGNITUDE OF THE EARTH.

The places of the heavenly bodies could not be settled with accuracy from observations made on the surface of the earth, unless its figure and magnitude were previously known; and without this knowledge, computations from the observations of the heavenly bodies, for ascertaining the situation of places on the earth, could not be depended on.

I have already observed, that the appearance of the heavenly bodies is not the same to the inhabitants of various parts of the earth; that the sun, the moon, and the stars, rise and set in Greenland in a manner very different from what they do in the Eaſt Indies, and in both places very different to what they do in England: and, as it was natural to attribute the cause of this change in the apparent face of the heavens to the figure of the earth, (for appearances must ever answer to the form and structure of the things) the nature of this figure was, therefore, one of the first objects of inquiry among philosophers and astronomers.

Some of the sages of antiquity concluded, that the earth must necessarily be of a spherical figure, because that figure was, on many accounts, the most convenient for the earth, as an habitable world: they also argued, that this figure was the most na-

tural, because any body exposed to forces, which tend to one common centre, as is the case with the earth, would necessarily assume a round figure. The assent, however, of the modern philosopher to this truth was not determined by speculative reasoning, but on evidence derived from facts and actual observation. From these I shall select those arguments, that I think will have the greatest weight with young minds.

It is known, from the laws of optics and perspective, that if any body, in all situations and under all circumstances, project a *circular shadow*, that body must be a globe.

It is also known, that eclipses of the moon are caused by the shadow of the earth.

And we find, that whether the *shadow* be projected towards the east or west, the north or the south, under every circumstance *it is circular:* the body therefore that casts the shadow, which is the earth, must be of a *globular* figure.

We shall obtain another convincing proof of the globular shape of the earth, by inquiring in what manner a person standing upon the coast of the sea, and waiting for a vessel which he knows is to arrive, sees that vessel. We shall find, that he first of all, and at the greatest distance, sees the top of the mast rising out of the water; and the appearance is, as if the ship was swallowed up in the water. As he continues to observe the object, more and more of the mast appears; at length he begins to see the top of the deck, and by degrees the whole body of the

vessel. On the other hand, if the ship be departing from us, we first lose sight of the hull, at a greater distance the main-sails disappear, at a still greater the top-sails. But if the surface of the sea were a plane, the body of the ship, being the largest part of it, would be seen first and from the greatest distance, and the masts would not be visible till it came nearer.

To render this, if possible, still clearer, let us consider two ships meeting at sea, the top-mast of each are the parts first discovered by both, the hull, &c. being concealed by the convexity of the globe which rises between them. The ships may, in this instance, be resembled to two men, who approach each other on the opposite sides of a hill; their heads will be first seen, and gradually, as they approach, the body will become entirely in view. From hence is derived a rational method of estimating the distance of a ship, which is in use among sea-faring people, namely, of observing *how low they can bring her down*, that is to say, the man at the mast-head fixes his eyes on the vessel in sight, and slowly descends by the shrouds, till she becomes no longer visible. The less the distance, the lower he may descend before she disappears. If observations of this kind be made with a telescope, the effect is still more remarkable; as the distance increases or diminishes, the ship in sight will appear more and more immersed, or to rise gradually out of the water.

This truth is fully evinced by the following consideration; that ships have sailed round the earth,

have gone out from the westward, and have come home from the eastward; or in other words, the ships have kept the same course, and yet returned from the opposite side into the harbour whence they first sailed. Now we are certain that this could not be the case, if the earth were a plane; for then a person, who should set out for any one point, and go on straight forward without stopping, would be continually going further from the point from which he set out. This argument may be much elucidated, by referring the pupil to a modern terrestial globe, on which he may follow the tracks of an *Anson* and a *Cook* round the world.

Plate 2, *fig.* 1 and 2, are illustrations of the foregoing principles. *Fig.* 1, shews that if the earth was a plane, the whole of a ship would be seen at once, however distant from the spectator, and that whether he was placed at the top or bottom of a hill. From *fig.* 2, it appears, that the rotundity of the earth, represented by the circle A B C, conceals the lower part of the ship d, while the top-mast is still visible; and that it is not till the ship comes to e, that the whole of it is visible.

The following remarks evince the same truth. Observe any star nearer the northern part of the horizon, and if you travel to the south, it will seem to dip farther and farther downwards, till by proceeding, it will descend entirely out of sight. In the mean time, the stars to the southward of our traveller will seem to rise higher and higher. The contrary appearances would happen, if he went to the

northward. This proves that the earth is not a plane surface, but a curve in the direction south and north. By an observation nearly similar to this, the traveller may prove the curvature of the earth, in an east and west direction.

The globular figure of the earth may be also inferred from the operation of *levelling*, or the art of conveying water from one place to another; for in this process, it is found necessary to make an allowance between the true and apparent level; or in other words, for the figure of the earth. For the true level is not a straight line, but a curve which falls below the straight line about eight inches in a mile, four times eight in two miles, nine times eight in three miles, sixteen times eight in four miles, always increasing as the square of the distance.

What the earth loses of its sphericity by mountains and vallies, is very inconsiderable; the highest eminence bearing so little proportion to its bulk, as to be scarcely equivalent to the minutest protuberance on the surface of a lemon.

It is proper, however, to acquaint the young pupil, that though we call our earth a globe, and that when speaking in general terms, it may be considered as such; yet in the strictness of truth, it must be observed, that it is not exactly and perfectly a sphere, *but a spheriod, flattened a little towards the poles, and swelling at the equator*; the equatorial diameter being about thirty-four miles longer than the diameter from pole to pole. This difference bears, therefore, too small a proportion to the diameter to

be represented on globes. M. *Cassini*, from *Picard*'s measure of a degree, asserted, that the earth was an oblong or prolate spheriod, flattened at the equator, and protuberant at the poles; while *Newton* and *Huygens*, from a consideration of the known laws and the diurnal motion of the earth, concluded that the figure of the earth was that of an oblate spheriod, flattened at the poles, protuberant at the equator. To decide this important question, Louis the XIV. ordered two degrees of the meridian to be measured, one under the equator, the other as near the pole as possible. For this purpose, the Royal Academy of Sciences sent Messrs. *Maupertuis*, *Clairault*, *Camus*, and *Le Monnier*, to Lapland: they set out from France in 1735, and returned in the spring of the year 1736, having satisfactorily accomplished the purpose for which they were sent. Messrs. *Godin*, *Condamine*, and *Bouguer*, were sent on the southern expedition: to these the King of Spain joined Don *George Juan*, and Don *Anthony de Uloa*, who left Europe in the year 1735, and after encountering innumerable hardships and difficulties, returned to Europe at differeat times, and by different ways, in 1744, 1745, 1746. The result of this arduous task was a complete confirmation of *Newton*'s theoretical investigation. The difference between the equatorial and polar dimensions, when compared with the earth's semi-diameter, is but an inconsiderable quantity, amounting in the whole to an elevation of little more than $16\frac{1}{2}$ of 3970; that is to less than a 240th part of the distance from the surface of the earth to

the centre. If a meridional section of such a sphe-riod were laid down upon paper, the eye would not distinguish it from a perfect circle.

OF THE DIURNAL MOTION OF THE EARTH.

Though it is this motion which gives us the grate-ful vicissitudes of day and night, adjusted to the times of labour and rest; yet young people generally find some difficulty in conceiving that the earth moves; the more so, because, in order to allow it, they must give up, in a great measure, the evidence of their exterior senses, of which the impressions are at their age exceeding strong and lively. It will, therefore, be necessary for the tutor to prove to them, that they can by no means infer that the earth is at rest, because it appears so, and convince them by a variety of *facts*, that reason was given to correct the *fallacies of the senses.*

To this end we shall here point oùt some instances, where apparent motion is produced in a body at rest, by the real motion of the spectator. Let us suppose a man in a ship to be carried along by a brisk gale, in a direction parallel to a shore, at no great distance from him; while he keeps his eye on the deck, the mast, the sails, or any thing about the ship, that is to say, while he sees nothing but some part of the vessel on board of which he is, and consequently every part of which moves with him, he will not perceive that the ship moves at all. Let

him, after this, look to the shore, and he will see the houses, trees, and hills, run from him in a direction contrary to the motion of the vessel; and supposing him to have received no previous information on the subject, he might naturally conclude, that the apparent motion of these bodies was real.

In a similar situation to this, we may conceive the inhabitants of the earth; who, in early times, knew nothing of the true structure or laws of the universe, saw the sun, the stars and the planets, rise and set, and perform an apparent revolution about the earth. They had no idea of the motion of the earth, and therefore all this appearance seemed reality. But as it is highly reasonable to suppose, that as soon as the slightest hint should be given to the man, of the motion of the vessel, he would begin to form a new opinion, and conceive it to be more rational, that so small a thing as the ship should move, rather than all that part of the earth which was open to his view; so, in the same manner, no sooner was an idea formed of the vast extent and greatness of the universe, with respect to this earth, than mankind began to conceive it would be more rational that the earth should move than the whole fabric of the heavens.

By another familiar instance it will be easy to shew the young pupil, that as the eye does not perceive its own motion, it always judges from appearances. Let a person go into a common windmill, and desire the miller to turn the mill round, while he is sitting within with his eyes fixed on the upright

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post in the centre thereof; this post, though at rest, will appear to him to turn round with considerable velocity, the real motion of the mill being the cause of the apparent motion of the swivel post. Seafaring people are furnished with various instances to illustrate this subject; those who are busy in the hold of a ship at anchor, cannot by any perception determine whether the ship has swung round or not by the turn of the tide. When a ship first gets under-way with a light breeze, she may be going at a good rate before those who are between decks can perceive it. Having thus obviated the objections which arise from the testimony of the senses, we may now proceed to consider the arguments which tend more directly to prove the motion of the earth.

All the celestial motions will, on this supposition, be incomparably more simple and moderate.

This opinion is much more agreeable to our notions of final causes, and our knowledge of the economy of nature; for if the earth be at rest, and the stars, &c. move round it once in 24 hours, their velocity must be immense; and it is certainly more agreeable to reason, that one single body, and that one of the smallest, should revolve on its own axis in 24 hours, than that the whole universe should be carried round it in the same time, with inconceivable velocity.

The rotation of the earth round its axis is analagous to what is observed in the sun, and most of the planets; it being highly probable, that the earth, which is itself one of the planets, should have the

same motion as they have, for producing the same effect: and it would be as absurd in us to contend for the motion of the whole heavens round us in 24 hours, rather than allow a diurnal motion to our globe, as it would be for the inhabitants of Jupiter to insist that our globe and the whole heavens, must revolve round them in ten hours, that all its parts might successively enjoy the light, rather than grant a diurnal motion to their habitation.

All the phenomena relative to this subject, are as easily solved on the supposition of the earth's motion, as on the contrary hypothesis.

Besides the foregoing considerations, there are several arguments to be deduced from the *higher parts of astronomy*, which *demonstrably* prove the diurnal motion of the earth.

Before we enter into a further explanation of phenomena, it will be necessary to define some of the principal circles of the globe. The reader will comprehend more fully these definitions, and attain more accurate ideas of these circles, by placing, while he is reading them, a terrestrial globe or armillary sphere before him. It may, however, be necessary to premise, that we are at liberty to suppose as many circles as we please to be described on the earth; and the plane of any of these to be continued from the earth until it marks a corresponding circle in the concave sphere of the heavens.

Among these circles, the *horizon* is the most frequently named. Properly speaking, there are two circles by this name, but distinguished from each

other by added epithets, the one being called the *sensible*, the other the *rational horizon*.

In general terms, the *horizon* may be defined to be an imaginary circle, that separates the visible from the invisible part of the heavens.

If a spectator supposes the floor or plane on which he stands, to be extended every way, till it reach the starry heavens, this plane is his *sensible horizon*.

The *rational horizon* is a circle, whose plane is parallel to the former, but passing through the centre of the earth.

The *rational horizon* divides the concave sphere of the heavens into two equal parts, or hemispheres; the objects that are in the upper hemisphere will be visible; such as are in the lower hemisphere will be invisible to the spectator.

Though the globe of the earth appears so large to those who inhabit it, yet it is so minute a speck when compared to the immense sphere of the heavens, that at that distance the planes of the rational and sensible horizons coincide: or in other words, the distance between them in the sphere of the heavens is too small for admeasurement.

To illustrate this, let A B C D, *plate* 3, *fig.* 1, represent the earth; z h n o the sphere of the starry heaven. If an inhabitant of the earth stand upon the point A, his sensible horizon is *s e*, his rational one *h o*; the distance between the planes of these two horizons is A F, the semi-diameter of the earth, which is measured in a great circle upon the sphere of the heaven, by the angle *e* F *o*, or the arc *e o*;

this arc in so small a circle, *z h n o*, would amount to several degrees, and consequently the difference between the sensible and rational horizon would be great enough to be measured by observation. If we represent the sphere of the heaven by a larger circle, the semi-diameter of the earth A F, measured in this circle, will amount to fewer degrees; for the arc E O is less than the arc *e o*; and the larger the sphere of the heaven is, in proportion to the globe of the earth, the less sensible is the difference between the two horizons. Now as the sphere of the earth is but as a point when compared to the starry heaven, the difference between the sensible and rational horizon will be insensible.

From what has been said, it appears that the only distinction between the sensible and rational horizon, arises from the distance of the object we are looking at.

The *sensible horizon* is an imaginary circle, which terminates our view, when the objects we are looking at are upon the earth's surface.

The *rational horizon* is an imaginary circle, which terminates our view, when the objects we are looking at are as remote as the heavenly bodies.

As the *rational horizon* divides the apparent celestial sphere into two equal hemispheres, and serves as a boundary, from which to measure the elevation or depression of celestial objects; those in the upper, or visible hemisphere, are said to be high, or elevated above the horizon; and those in the other hemisphere are called low, or below the horizon.

The earth being a spherical body, the horizon, or limits of our view, must change as we change our place; and therefore every place upon the earth has a different horizon. Thus, if a man lives at *a*, *plate* 3, *fig*.2, his horizon is G C; if he lives at *b*, his horizon is H D; if at *c*, it is A E. From hence we obtain another proof of the sphericity of the earth; for if it were flat, all the inhabitants thereof would have the same horizon.

The point in the heavens, which is directly over the head of a spectator, is called the *zenith*.

That point which is directly under his feet, is called the *nadir*.

If a man lives at *a*, *plate* 3, *fig*. 2, his zenith is A, his nadir E: if he lives at *b*, his zenith is B, his nadir F. Consequently the zenith and horizon of an observer remain fixed in the heavens, so long as he continues in the same place; but he no sooner changes his position, than the horizon touches the earth in another point, and his zenith answers to a different point in the heavens.

The *axis* of the earth is an imaginary line, conceived to be drawn through the centre of the earth, upon which line its revolutions are made.

The *poles* of the earth are the extremities of its axis, or those two points on its surface, where its axis terminates; one of these is called the *north*, and the other the *south pole*. The poles of the heavens, or of the world, are those two points in the heavens, where the axis of the earth, if produced, would terminate; so that the north pole of the heavens is

exactly over the north pole of the earth, and the south pole of the heavens is directly over the south pole of the earth.

The *equator* is an imaginary circle, which is supposed to be drawn round the earth's surface, in the middle between the two poles. It divides the earth into two equal parts, one of which is called the *northern*, the other the *southern hemisphere*.

If we suppose the plane of the earth's equator to be extended all ways, as far as the heavens, it will mark there a circle, that will divide the heavens into two equal parts; this circle is called sometimes the *equinoctial*, sometimes the *celestial equator*.

The *meridian* of any place is a circle supposed to pass through that place and the poles of the earth; we may therefore imagine as many meridians as there are places upon the earth, because any place that is ever so little to the east or west of another place, has a different meridian.

By the foregoing definition, we see that the meridian of any place is immoveably fixed to that place, and carried round along with it by the rotation of the earth. The meridian marks upon the plane of the horizon the north and south points.

The circle which the sun appears to describe every year, in the concave sphere of the heavens, is called the *ecliptic* It is thus denominated, because in all eclipses the moon is either in or near the plane of it. But as the earth moves round the sun, in the plane of the ecliptic, it is likewise the plane of the earth's orbit.

If we conceive a zone, or belt, about sixteen degrees broad, in the concave sphere of the heaven, with the ecliptic passing through the middle of it, this zone is called the *zodiac*. The stars in the zodiac were divided by the ancients into twelve equal parts or signs, to correspond with the months of the year; and because the number *twelve* with them was always expressive of fulness or completion, it is used in that sense in sacred writ. The signs are named, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces.

We may imagine as many circles as we please drawn on a globe, parallel to the equator, and these will decrease in their diameter, as they approach nearer the poles. The *tropics* are two lesser circles of this kind, parallel to the equator, and $23\frac{1}{2}$ degrees distant from it; one in the northern hemisphere, which is called the *tropic of Cancer*; the other in the southern, which is called the *tropic of Capricorn*. If we conceive the planes of these circles expanded, till they reach the starry heaven, the sun will be seen to move in that circle which corresponds to the tropic of Cancer on the longest summer's day, and in that circle which answers to the tropic of Capricorn on the shortest winter's day.

The polar circles are two lesser circles, conceived to be described at $23\frac{1}{2}$ degrees distance from each pole.

The axis of the earth is inclined to the plane of

the ecliptic, and makes with it an angle of $66\frac{1}{2}$ degrees; therefore the plane of the earth's equator cannot coincide with the plane of the ecliptic, but these two planes make with one another an angle of $23\frac{1}{2}$ degrees.

OF THE ANNUAL MOTION OF THE EARTH.

The foregoing definitions being understood, we may now proceed in the description of the phenomena of our system. It is owing to the industry of modern astronomers, that the annual motion of the earth has been fully evinced; for, though this motion had been known to, and adopted by many among the ancient philosophers, yet they were not able to give their opinions that degree of probability, which is attainable from modern discoveries, much less the evidence arising from those demonstrative proofs of which we are now in possession. We shall, therefore, enumerate some of the reasons which induce astronomers to believe that the earth moves round the sun, and then explain further the nature of this motion, calculated to afford us the useful and delightful variety of the seasons, the mutual allay of immoderate heat and cold, as also for the successive growth and recruit of vegetation.

The celestial motions become incomparably more simple, and free from these looped contortions which must be supposed in the other case, and which are not only extremely improbable, but incompatible with what we know of motion,

This opinion is also more reasonable, on account of the extreme minuteness of the earth, when compared with the immense bulk of the Sun, Jupiter, and Saturn; and there are no known laws of motion, according to which so great a body as the sun can revolve about so small a one as the earth.

The sun is the fountain of light and heat, which it darts through the whole system; it ought, therefore, to be in the centre, that its influence may be regularly diffused through the whole heavens, and communicated in just gradations to the whole system.

When we consider the sun as the centre of the system, we find all the bodies moving round it, agreeable to the universal laws of gravity : but upon any other consideration, we are left in the dark.

The motion of the earth round the sun accords with that general harmony and universal law which all the other moving bodies in the system observe, namely, *that the squares of the periodic times are as the cubes of the distances*; but if the sun moves round the earth, that law is destroyed, and the general order of symmetry in nature interrupted.

It is incontestibly proved by observation, a motion having been discovered in all the fixed stars, which arises from a combination of the motion of light with the motion of the earth in its orbit.

It will be clearly shewn in its place, that Venus and Mercury move round the sun in orbits that are between it and the earth; that the orbit of the earth is situated between that of Venus and Mars; and

that the orbits of Mars, Jupiter, &c. are exterior to, and include the other three.

OF THE APPARENT MOTION OF THE SUN, ARISING FROM THE EARTH'S ANNUAL MOTION ROUND IT.

As when a person sails along the sea coast, the shore, the villages, and other remarkable places on land, appear to change their situation, and to pass by him; so it is in the heavens. To a spectator upon the earth, as it moves along its orbit, or sails as it were through celestial space, the sun, the planets, and the fixed stars, appear to change their places.

Apparent change of place is of two sorts; the one is that of bodies at rest, the change of whose place depends solely on that spectator; the other is that of bodies in motion, whose apparent change of place depends as well on their own motion, as on that of the spectator.

We shall first consider only that apparent change which takes place in those which are at rest, and which is owing wholly to the motion of the earth, and shew that the sun, when seen from the earth, will appear to move in the same manner, whether it revolves round the earth, or whether the earth revolves round the sun. Let us suppose the earth at rest, without any motion of its own, and let the sun be supposed to revolve round it in the orbit A B C D, *plate* 4, *fig.* 1; and let E F G H be a circle in the concave sphere of the starry heavens; as the sun

moves in the order of the letters A B C D in its orbit, it will appear to a spectator on the earth to have described the circle E F H G. When the sun is at A, it will appear as if it was among the fixed stars that are at E; when it is at B, it will appear among the fixed stars at F; when at C, among those at H; and when it is at D, it will appear among the fixed stars at G. Indeed, the fixed stars and the sun are not seen at the same time; but we have shewn, that we may tell in what part of the heavens the sun is, or what fixed stars it is near, by knowing those which are opposite to it, or come to the south at midnight. Therefore, if we find that any set of stars, as those at G, for instance, come to the south at midnight, we may be sure that they are opposite to the sun; and consequently, if we could see the stars in that part of the heaven where the sun is, we should find them to be those at F.

Secondly, let us suppose that S is the sun, having no motion of its own, that it rests within the orbit A B C D, in which we shall now suppose the earth to move, in the order of the letters A B C D. Upon this supposition, when the earth is at A, the sun will appear in that part of the heavens where the stars, H, are; when the earth is at B, the sun will appear in that part of the heavens where the stars, G, are; when the earth is at C, the sun will appear in that part of the heavens where the stars, E, are; and as the earth revolves round the sun in the orbit A B C D, the sun will appear to a spectator on the earth to describe the circle G H E F.

Thus, whether the earth be at rest, and the sun revolves in the orbit A B C D; or the sun be at rest, and the earth revolves in the same orbit, a spectator on the earth will see the sun describe the same circle E F G H, in the concave sphere of the heavens.

Hence, if the plane of the earth's orbit be imagined to be extended to the heavens, it would cut the starry firmament in that very circle, in which a spectator in the sun would see the earth revolve every year; while an inhabitant of the earth would observe the sun to go through the same circle and in the same space of time that the solar spectator would see the earth describe it.

The inhabitants of all the other planets will observe just such motions in the sun as we do, and for the very same reasons; and the sun will be seen from every planet to describe the same circle, and in the same space of time, that a spectator in the sun would observe the planet to do. For example, an inhabitant of Jupiter would think that the sun revolved round him, describing a circle in the heavens in the space of twelve years: this circle would not be the same with our ecliptic, nor would the sun appear to pass through the same stars which he does to us. On the same account, the sun, seen from Saturn, will appear to move in another circle, distinct, from either of the former; and will not seem to finish his period in less time than thirty years. Now, as it is impossible that the sun can have all these motions really in itself, we may safely affirm, that none of them are real, but that they are all ap-

parent, and arise from the motions of the respective planets.

One phenomenon arising from the annual motion of the earth, which has already been slightly touched upon, may now be more fully explained; for as from this motion the sun appears to move from west to east in the heavens, if a star rises or sets along with the sun at any time, it will in the course of a few days rise or set before it, because the sun's apparent place in the heavens will be removed to the eastward of that star. Hence, those stars, which at one time of the year set with the sun, and therefore do not appear at all, shall at another time of the year rise when the sun sets, and shine all the night. And as any one star shifts its place with respect to the sun, and in consequence of that with respect to the hour of the night, so do all the rest. Hence it is that all those stars, which at one time of the year appear on any one side of the pole star in the evening, shall in half a year appear on the contrary side thereof.

OF PHENOMENA OCCASIONED BY THE ANNUAL AND DIURNAL MOTIONS OF THE EARTH.

First, of those that arise from the diurnal motion. As the earth is of a spherical figure, that part of it, which comes at any time under the confined view of an observer, will seem to be extended like a plane; and the heavens will appear as a concave spherical

superficies, divided by the aforesaid plane into two equal parts,* one of which is visible, the other concealed from us by the opacity of the earth.

Now the earth, by its revolution round its axis, carries the spectator and the aforesaid plane from west to east; therefore, all those bodies to the east, which could not be seen because they were below the plane of the horizon, will become visible, or rise above it, when, by the rotation of the earth, the horizon sinks as it were below them. On the other hand, the opposite part of the plane towards the west, rising above the stars on that side, will hide them from the spectator, and they will appear to set, or go below the horizon.

As the earth, together with the horizon of the spectator, continues moving to the east, and about the same axis, all such bodies as are separated from the earth, and which do not partake of that motion, will seem to move uniformly in the same time, but in an opposite direction, that is, from east to west; excepting the celestial poles, which will appear to be at rest. Therefore, when we say, that the whole concave sphere of the heavens appears to turn round upon the axis of the world, whilst the earth is performing one rotation upon its own axis, we must be understood to except the two poles of the world; for these do not partake of this apparent motion.

It is, therefore, on account of the revolution of the earth round its axis, that the spectator imagines

* See page 68 of these Essays.

the whole starry firmament, and every point of the heaven, excepting the two celestial poles, to revolve about the earth from east to west every twenty-four hours, each point describing a greater or lesser circle, as it is more or less remote from one of the celestial poles.

The earth is made to revolve on its axis, in order to give alternate night and day to every part of its surface.

Although every place on the surface is illuminated by all the stars which are above the horizon of that place; yet, when the sun is above the horizon, his light is so strong, that it quite extinguishes the faint light of the stars, and produces *day*. When the sun goes below the horizon, or more properly, when our horizon gets above the sun, the stars give their light, and we are in that state which is called *night*.

Now, as the earth is an opake spherical body, at a great distance from the sun, one-half of it will always be illuminated thereby, while the other half will remain in darkness.

The circle which distinguishes or divides the illuminated face of the earth from the dark side, and is the boundary between light and darkness, is generally called the *terminator*. A line drawn from the centre of the sun to the centre of the earth, is perpendicular to the plane of this circle.

It is plain, that when any given place on the globe first gets into the enlightened hemisphere, the sun is just risen to that part; when it gets half-way, or

to its greatest distance from the terminator, it is then *noon*; and when it leaves the enlightened hemisphere, it is then *sun-set*.

Here it will be necessary to premise a few considerations: First, that on account of the immense distance of the sun from the earth, the rays which proceed from it may be considered as *parallel* to each other. Secondly, that *only one-half* of a globe can be illuminated by parallel rays, and therefore *only one-half of the earth* will be enlightened by the sun at one time.

These considerations will be rendered more forcible, by an attentive survey of *fig.* 1, *plate* 5 ; in which S represents the sun, from whom we suppose parallel rays to flow in all directions. At A, B, C, are represented three different positions of the globe of the earth, the bright part being that which is illuminated by the rays proceeding from the sun; the shaded part, the portion of the globe which is in darkness; of course, the line T T is the terminator, or boundary of light and darkness.

In the globe at C, the poles coincide with the terminator.

In the globe at A, the north pole N is in the enlightened portion, and the south pole in the dark hemisphere; while, in the opposite globe, at B, the southern pole S is in the illuminated part, and the north pole in obscurity

It is evident, that it is day in any given place on the globe, so long as that place continues in the enlightened hemisphere; but when, by the diurnal

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rotation of the earth on its axis, it is carried into the dark hemisphere, it becomes night to that place.

The length of the day and the night depend therefore on the position of the terminator, with respect to the axis of the earth.

If the poles of the earth be situated in the terminator, as at C, every parallel will be divided into two equal parts; and as the uniform motion of the earth causes any given place to describe equal parts of its parallel in equal times, the day and the night would be equal on every parallel of latitude, that is, all over the globe, except at the poles, where the sun would neither rise nor set, but continue in the horizon.

But if, as at A and B, the axis be not in the plane of the terminator, the terminator will divide the equator into two equal parts, but all the circles parallel to it into unequal parts; those circles that are situated towards the enlightened pole, will have a greater part of their circumference in the enlightened than in the dark hemisphere; while similar parallels towards the other pole will have the greater part of their circumference in the dark hemisphere. Whence it follows that the first-mentioned parallels will enjoy longer days than nights; and the contrary will happen to the latter, where the days will be the shortest, and the nights the longest; while at the equator, the days will always be of the same length.

Having shewn, that the vicissitudes in the length of the days and nights are occasioned by the position of the terminator with respect to the axis of the

earth, I have now only to explain what occasions those various positions; which is the more import-ant, as on these depend the diversity in the seasons of the year.

OF THE SEASONS OF THE YEAR.

In considering this subject, you will find further proofs of that DIVINE WISDOM which pervades all the works of GOD, and see, that no other conformation of the system could have given such commodious distributions of light and heat, or imparted fertility and pleasure to so great a part of the revolving globe.

The changes in the position of the terminator are occasioned. 1. By the inclination of the earth's axis to the plane of the ecliptic, or orbit in which it moves. 2. Because through the whole of its annual course, the axis of the earth preserves its position, or continues parallel to itself; that is, if a line be conceived as drawn parallel to the axis, while the earth is in any one point of its orbit, the axis will, in every other position of the earth, be parallel to the said line.

It must be evident to you, that the parallelism of the axis must occasion considerable differences. By a bare inspection of the globes, A, B, *plate* 5, *fig.* 1, you will see that when the earth is in one position of its orbit, the north pole will be turned towards the sun, but, in the opposite part, will be turned

from him. But the absence of the sun's light produces a proportionable degree of cold; hence the seasons are, in the northern and southern parts of the globe, distinctly marked by different degrees of heat and cold. It is this annual turning of the poles towards the sun that occasions the very long days in the northern and southern parts. It is owing to the same cause, that the sun seems to rise higher in the heavens during summer than in winter; and this alternate sinking and rising is perceptible over the whole globe.

If the axis of the earth were perpendicular to the plane of its orbit, the equator and the orbit (or ecliptic) would coincide; and as the sun is always in the plane of the ecliptic, it would in this case be always over the equator, as at C *fig*. 1, and the two poles would be in the terminator, and there would be no diversity in the days and nights, and but one season of the year; but as this is not the case, we may fairly infer that the axis of the earth is not perpendicular to the plane of its orbit.

But if the earth's axis be inclined to the plane of the ecliptic, when the earth is in the situation represented at A, *plate* 5, *fig*. 1, the pole N will be towards the sun, and the pole S will be turned from it; but just the contrary will happen, when the earth, by going half round the sun, has arrived at B, the opposite point in its orbit. Hence the sun will not always be in the equator, but at one time of the year it will appear nearer to one of the poles, and at the opposite season it will appear nearer to the

other.   Here then you find a cause for the change of the seasons; for, when the sun leaves the equator and approaches to one of the poles, it will be summer on that side of the equator, and when the sun departs from thence, and approaches to the other pole, it will be winter.

These ideas may be strengthened, and a clearer notion obtained of the effect produced by the inclination of the earth's axis, by considering *fig.* 2, *plate* 5, in which the ellipsis is supposed to represent the earth's orbit, the eye somewhat elevated above the plane thereof.   The earth is here represented in the first point of each of the twelve signs of the ecliptic, as marked in the figure, with the twelve corresponding months annexed; P, the north pole of the globe; P m, its axis, round which the earth performs its diurnal revolution from west to east; this axis is exhibited as parallel to itself in every part of the orbit; P C E shews the angle of its inclination; e, the pole; e d, the axis of the ecliptic, perpendicular to the plane of the orbit.

In March, when the earth is in the first point of Libra, the sun appears in the opposite point of the ecliptic at Aries.   In September, when the earth is in the first point of Aries, the sun will be in Libra. At these times, the terminator passes through the poles of the world, and divides every parallel into two equal parts, (see C, *fig.* 1;) consequently, the nocturnal and diurnal arcs, or the length of day and night, will be equal in all places over the world.

Conceive the earth to have moved from Libra to

Capricorn in June, the axis, P m, preserving its parallelism by this motion, the north pole will have gradually advanced into the enlightened hemisphere; so that the whole northern polar circle will be therein, while the southern pole is immerged in obscurity; the northern parts of the world will enjoy long days, while they are short in the southern parts. While the earth is moving from Libra through Capricorn to Aries, the north pole remains in the illuminated hemisphere, and will therefore have six months continual day.

But in the other half year, while the earth is moving from Aries through Cancer to Libra, the north pole is turned from the sun, and therefore in darkness, but the south pole is in the illuminated hemisphere. When the earth is at Cancer, the sun is at Capricorn; at this season the nights to us will as much exceed the days, as the days exceeded the nights when the earth was in the opposite point of her orbit.

From the foregoing explanation it is easy to perceive that the inhabitants of the southern hemisphere have the same vicissitudes with those of the northern; though not at the same time, it being winter in one hemisphere, when it is summer in the other.

From what has been said, you must have perceived, that during the course of the earth through her orbit, there are four days particularly to be remarked; these astronomers have distinguished by the names of the *solstitial* and *equinoctial days*. The solstitial days are those on which the sun appears most to the northward and the southward: the equi-

noctial days are those on which he appears in the equator, and the days are equal to the nights.

The annual motion of the earth occasions a daily apparent change in the declination of the sun. Thus, about the 22d of December, when the earth is in Cancer, the sun will be over the tropic of Capricorn; and consequently, by the earth's rotation on its axis, the inhabitants of every part of ·this circle will successively have the sun in their zenith, or in other words, he will be vertical to them that day at noon.

About the 21st of March, the earth is at Libra, and the sun will then appear in Aries; a central solar ray will terminate upon the surface of the earth, in the equator; and therefore the sun appears to be carried round the celestial equator, and is successively vertical to those who live under that circle.

About the 21st of June, when the earth is in Capricorn, a central solar ray terminates on the surface of the earth, in the northern tropic, and for that day the sun appears to be carried round in the tropic of Cancer, and is vertical to those who live under that circle. About the 22d of September, the earth is in Aries, and the sun in Libra, and the central solar ray again terminates at the equator; consequently, the sun again appears in the celestial equator, and is vertical to those that live under it.

We have seen, that as the sun moves in the ecliptic, from the vernal equinox to the tropic of Cancer, it gets to the north of the equator, or its declination towards our pole increases. Therefore, from the vernal equinox, when the days and nights are equal, till the sun comes to the tropic of Cancer, our days

lengthen and our nights shorten; but when the sun comes to the tropic of Cancer, it is then in its utmost northern limit, and returns in the ecliptic to the equator again. During this return of the sun, its declination towards our pole decreases, and consequently the days decrease and the nights increase, till the sun is arrived in the equator again, and is in the autumnal equinoctial point, when the days and nights will again be equal. As the sun moves from thence towards the tropic of Capricorn, it gets to the south of the equator; or its declination towards the south pole increases. Therefore, at that time of the year our days shorten and our nights lengthen, till the sun arrives at the tropic of Capricorn; but when the sun is arrived there, it is then at its utmost southern limit, and returns in the ecliptic to the equator again. During this return, its distance from our pole lessens, and consequently the days will lengthen as the nights shorten, till they become equal, when the sun is come round to the vernal equinoctial point.

Our summer is nearly eight days longer than the winter. By summer is meant here the time that passes between the vernal and autumnal equinoxes; by winter, the time between the autumnal and vernal equinoxes. The ecliptic is divided into six northern, and six southern signs, and intersects the equator at the first of Aries, and the first of Libra. In our summer, the sun's apparent motion is through the six northern, and in winter through the six southern signs; yet the sun is 186 days, 11 hours,

51 minutes, in passing through the six first; and only 178 days, 17 hours, 58 minutes, in passing through the six last. Their difference, 7 days, 17 hours, 53 minutes, is the length of time by which our summer exceeds the winter.

In *plate* 6, *fig.* 1, A B C D represents the earth's orbit; S the sun in one of its foci; when the earth is at B, the sun appears at H, in the first point of Aries; and whilst the earth moves from B through C to D, the sun appears to run through the six northern signs, from ♈ through ♋ to ♎ at F. When the earth is at D, the sun appears at F, in the first point of Libra; and as the earth moves from D through A to B, the sun appears to move through the six southern signs, from ♎ through ♑ to Aries at H.

Hence the line F H, drawn from the first point of Aries through the sun at S, to the first point of ♎, divides the ecliptic into two equal parts; but the same line divides the earth's elliptical orbit into two unequal parts. The greater part B C D is that which the earth describes in the summer, while the sun appears in the northern signs. The lesser part is D A B, which the earth describes in winter, while the sun appears in the southern signs. C, the earth's aphelion, where it moves slowest, is in the greater part; A, its perihelion, is in the lesser part, where the sun moves fastest.

There are, therefore, two reasons why our summer is longer than our winter; first, because the sun continues in the northern signs, while the earth

is describing the greater part of its orbit; and secondly, because the sun's apparent motion is slower while it appears in the northern signs, than whilst it appears in the southern ones.

The sun's apparent diameter is greater in our winter than in summer, because the earth is nearer to the sun when at A in the winter, than it is when at C in the summer. The sun's apparent diameter, in winter, is 32 minutes, 47 seconds; in summer, 31 minutes, 40 seconds.

But if the earth is farther from the sun in summer than in winter, it may be asked, why our winters are so much colder than our summers. To this it may be answered, that our summer is hotter than the winter, first, on account of the greater height to which the sun rises above our horizon in the summer; secondly, the greater length of the days. The sun is much higher at noon in summer than in winter, and consequently, as its rays in summer are less oblique than in winter, more of them will fall upon the surface of the earth. In the summer, the days are very long, and the nights very short; therefore the earth and air are heated by the sun in the day-time, more than they are cooled in the night; and upon this account, the heat will keep increasing in the summer, and for the same reason will decrease in winter, when the nights lengthen.

I should exceed the limits of this Essay, if I were to inquire into the several concurring causes of the temperatures that obtain in various climates; it may be sufficient, therefore, to observe what a remark-

able provision is made in the world, and the several parts of it, to keep up a perpetual change in the degrees of heat and cold. These two are antagonists, or, as Lord Bacon calls them, " the very hands of nature with which she chiefly worketh;" the one expanding, the other contracting bodies, so as to maintain an oscillatory motion in all their parts; and so serviceable are these changes in the natural world, that they are promoted every year, every hour, every moment. From the oblique position of the ecliptic, the earth continually presents a different face to the sun, and never receives his rays two days together in the same direction. In the day and night, the differences are so obvious, that they need not be mentioned, though they are most remarkable in those climates, where the sun at his setting makes the greatest angle with the horizon. Every hour of the day, the heat varies with the sun's altitude, is altered by the interposition of clouds, and the action of winds; and there is little room to doubt, but what the various changes that thus take place, concur in producing many of the smaller and greater phenomena of nature.

Be this however as it may, it is certain that the various irregularities and intemperature of the elements, which seem to destroy nature in one season, serve to revive it in another : the immoderate heats of summer, and the excessive cold of winter, prepare the beauties of the spring, and the rich fruits of autumn. These vicissitudes, which seem to superficial minds the effects of a fortuitous concourse

of irregular causes, are regulated according to weight and measure by that SOVEREIGN WISDOM, *who weighs the earth as a grain of sand, the sea as a drop of water.*

OF THE SOLAR AND SIDERIAL TIME.

I have already shewn, that the daily motion of the sun from east to west, is not a real, but an apparent one, which is owing to the rotation of the earth round its axis. Now if the sun had no other motion but this apparent one, it would seem to go once round the earth, in the time of one complete rotation, or in 23 hours, 56 minutes; which is the case with any of the fixed stars, and is therefore the length of a *siderial* day. But the sun is found to take up a longer time to complete its apparent revolution; for if it is in the south of any particular place at twelve o'clock at noon to-day, it will not complete an apparent revolution, so as to return to the south of that place again, till twelve o'clock at noon on the next day, and consequently the time of this apparent revolution is twenty-four hours.

Let us endeavour to render this subject clearer, by defining in other words the nature of the solar and siderial day.

The *solar day* is that space of time which intervenes between the sun's departing from any one meridian, and its return to the same circle again; which space is also called a natural day; or it is the time

from the noon of one day to the noon of the next.

The *siderial day* is the space of time which happens between the departure of a star from, and its return to the same meridian again.

I am now to shew why these days differ in length, or why the time, that the sun takes up to complete one revolution, is longer than the time the earth takes to revolve once upon its axis.

This difference arises from the sun's annual motion. For the sun does not continue always in the same place in the heaven, as the fixed stars do: but it is seen at M, *plate* 4, *fig.* 2 one day, near the fixed star R, it will have shifted its place the next day, and will be near to some other fixed star L. This motion of the sun is from west to east, and one entire revolution is completed in a year. Suppose, therefore, that the sun, when it is at M, near to the fixed star R, appears in the south of any particular place S; and then imagine the earth to turn once round upon its axis from west to east, or in the direction of S T V W, so that the place may be returned to the same situation; after this rotation is completed, the star R will be in the south of the place as before; but the sun having, in the mean time, moved eastwards, and being near to the star L, or to the east of R, will not be in the south of the place S, but to the eastward of it: upon this account, the place S must move on a little farther, and must come to T before it will be even with the sun again, or before the sun will appear exactly in the south.

This may be illustrated by an instance. The two

hands of a watch are close together, or even with one another at twelve; they both turn round the same way, but the minute hand turns round in a shorter time than the hour hand; when the minute hand has completed one rotation, and is come round to twelve, the hour hand will be before it, or will be at one; so that the minute hand must move more than once round, in order to overtake the hour hand, and be even with it again.

As this subject is of some importance, we shall endeavour to render it more clear, by placing it in a different point of view: the more so, as it may accustom the young pupil to reason on both hypotheses, namely, the motion of the sun, and that of the earth.

The diameter of the earth's orbit is but a physical point in proportion to the distance of the stars; for which reason, and the earth's uniform motion on its axis, any given meridian will revolve from any star to the same star again, in every absolute turn of the earth upon its axis, without the least perceptible difference of time being shewn by a clock which goes exactly true.

' If the earth had only a diurnal, without an annual motion, any given meridian would revolve from the sun to the sun again, in the same quantity of time as from any star to the same star again; because the sun would never change his place with respect to the stars. But as the earth advances almost a degree eastward in its orbit in the time that it turns eastward round its axis, whatever star passes

over the meridian on any day with the sun, will pass over the same meridian on the next day, when the sun is almost a degree short of it, that is 3 min. 56 seconds sooner. If the year contained only 360 days, the sun's apparent place, so far as his motion is equable, would change a degree every day, and then the siderial days would be just four minutes shorter than the solar.

Let A B C D E F G H, *plate* 4, *fig.* 3, be the earth's orbit, in which it goes round the sun every year, according to the order of the letters, that is, from west to east, and turns round its axis the same way, from the sun to the sun again in every twenty-four hours. Let S be the sun, and R a fixed star, at such an immense distance, that the diameter G C of the earth's orbit bears no sensible proportion to that distance; N m n the earth in different points of its orbit. Let N m be any particular meridian of the earth, and N a given po nt, or place, lying under that meridian.

When the earth is at A, the sun S hides the star R, which would always be hid if the earth never moved from A; and consequently as the earth turns rounds its axis, the point N would always come round to the sun and the star at the same time.

But when the earth has advanced through an eighth part of its orbit, or from A to B, its motion round its axis will bring the point N an eighth part of a day, or three hours, sooner to the star than to the sun. For the star will come to the meridian in the same time as though the earth had continued in

its former situation at A, but the point N must re-volve from N to n, before it can have the sun upon its meridian. The arc N n being therefore the same part of a whole circle, as the arc AB, it is plain that any star which comes to the meridian at noon, with the sun, when the earth is at A, will come to it at nine o'clock in the forenoon, when the earth is at B.

When the earth has passed from A to C, one-fourth part of its orbit, the point N will have the star upon its meridian, or at six in the morning, six hours sooner than it comes round to the sun; but the point N must revolve six hours more before it has mid-day by the sun: for now the angle A S C is a right angle, and so is N C n; that is, the earth has advanced 90 degrees on its axis, to carry the point N from the star to the sun; for the star al-ways comes to the meridian when N m is parallel to R S A; because C S is but a point in respect to R S. When the earth is at D, the star comes to the meridian at three in the morning; at E, the earth having gone half round its orbit, N points to the star at midnight, it being then directly opposite to the sun; and, therefore, by the earth's diurnal mo-tion, the star comes to the meridian twelve hours before the sun, and then goes on, till at A it comes to the meridian with the sun again.

Thus it is plain, that one absolute revolution of the earth on its axis (which is always completed when any particular star comes to be parallel to its situa-tion at any time of the day before) never brings the

same meridian round from the sun to the sun again; but that the earth requires as much more than one turn on its axis, to finish a natural day, as it has gone forward in that time, which at a mean state, is a 365th part of a circle.

From hence we obtain a method of knowing by the stars, whether a clock goes true or not. For if through a small hole in a window-shutter, or in a thin plate of metal fixed to a window, we observe at what time any star disappears behind a chimney, or corner of a house, at a little distance; and if the same star disappears the next night, 3 min. 56 seconds sooner by the clock; and on the second, 7 min. 52 seconds sooner; the third night, 11 min. 48 seconds sooner, and so on every night; it is an infallible sign that the machine goes true; otherwise it does not, and must be regulated accordingly. This method may be depended on to nearly half a second*.

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* A telescopic tube with intersected wires at the focus of the first eye glass, fixed against a wall, or the telescope of a theodolite, or other instrument when placed firmly on its stand, are preferable and more accurate instruments. When a telescope on a proper and firm stand, is placed duly in the meridian of the place, for this purpose, it then becomes a meridian or transit telescope, and is the best instrument for adjusting and ascertaining the rate of clocks and chronometers. EDIT.

AN EXPLANATION OF THE PHENOMENA WHICH
ARISE FROM THE MOTION OF THE EARTH, AND
OF THE INFERIOR PLANETS, MERCURY AND
VENUS.

It will be necessary in this place to define more
exactly some words which have been slightly ex-
plained before, and recall the reader's attention to
some definitions that have been already given; and
it is presumed, that these repetitions will not be an
object of complaint, because they will answer the be-
neficial purpose of grounding the reader more firmly
in the knowledge of the science, to which this Essay
is intended as an introduction.

When two planets are seen together in the same
sign of the zodiac, and equally advanced therein, they
are said to be in *conjunction*. But when they are in
opposite signs of the zodiac, they are said to be in
opposition. Thus a planet is said to be in opposition
to the sun, when the earth is between the sun and
the planet.

The *elongation* of a planet is its apparent distance
from the sun. When a planet is in conjunction with
the sun, it has no elongation; when in opposition,
its elongation is 180 degrees.

The *nodes of a planet's orbit* are those two points
where the orbit cuts the plane of the ecliptic. I be-
fore observed, that the orbits of all the planets are
inclined to the plane of the ecliptic, and consequent-
ly cross this plane. In *plate* 3, *fig*. 3, A B C D is the

plane of the ecliptic; E B F D is the orbit of a planet, in which the points B and D are the two nodes.

The *line of the nodes* is a line B D, supposed to be drawn through the sun from one node to the other. The *limits of a planet's orbit* are two points in the middle between the two nodes. The point E is called the greatest northern limit, F the greatest southern limit.

The greatest distance of the earth, or of any planet from the sun, is called its *aphelion*, or higher apsis; its least distance is called the *perihelion*, or lower apsis.

Thus in *plate* 3, *fig.* 4, A is the place of the aphelion, P that of the perihelion.

The axis, P A, *fig.* 4, of any planet's ellipsis, is called the *line of the apsides*: the extreme points of its shortest diameter T V are the places of its mean distance from the sun, and S T, or S V, the line of its *mean distance*.

When a planet moves according to the order of the signs, its motion is said to be *direct*, or *in consequentia*; but when its motion is contrary to the order of the signs, it is said to be *retrograde*, or *in antecedentia*.

The place in the starry heavens that any planet appears in, when seen from the centre of the earth, is called its *geocentric place*. The place where it would be seen in the celestial sphere, by an observer supposed to be in the sun, is called its *heliocentric place*.

OF THE CONJUNCTIONS AND ELONGATIONS OF THE INFERIOR PLANETS VENUS AND MERCURY.

There are two different situations, in which an inferior planet will appear in conjunction with the sun; one when the planet is between the sun and the earth, and the other when the sun is between the earth and the planet. Let A, *plate* 6, *fig.* 2, be the earth in its orbit, E the place of Venus in her orbit E H G, S the sun, F V P Q R T D an arc in the starry heavens. In this situation the sun and Venus are on the same side of the earth, and will appear in the same point of the heavens, so as to be in conjunction. If the earth is at A, and Venus at G, they will also appear to be in conjunction.

If the earth is at A, the sun at S, the planet at E, nearer to the earth than the sun, it is called its *inferior conjunction.* But if the earth is at A, and the planet at G, farther from the earth than the sun, this is called the *superior conjunction* of the planet.

If an inferior planet is at E, the earth at A, and the sun at S, the elongation is nothing, the planet being then in its inferior conjunction. As the planet moves from E to y, its elongation increases; for when it is at y, it appears in the line A y P, while the sun appears in the line A S Q; so that P A Q will be its elongation. When the planet is arrived at x, it appears in the line A x V, which is a tangent to its orbit; and then its elongation is V A Q,

which is the greatest that can be on that side the sun; for after this, the elongation decreases. When the planet is at K, its elongation is P A Q; when at G, it is nothing, because it is then in its superior conjunction; as the planet moves on from G, its elongation again increases; for when it comes to C, it appears in the line A C R, and its elongation is R A Q. When the planet comes to H, a line drawn from the earth through the planet is a tangent to the orbit, and the elongation is T A Q, the greatest it can have when it is on the other side of the sun; for after this, the elongation again decreases.

Hence it is clear, that the inferior planets can never appear far from the sun, but must always accompany it in its apparent motion through the ecliptic. When we see either Venus or Mercury, it is either in the evening in the west, soon after the sun has set; or in a morning, a little before the sun rises. Venus is indeed bright enough sometimes to be seen in the day time, but then she is never far from the sun. The greatest elongation of Venus is about 40, and of Mercury about 33 degrees.

If the earth is at A, *plate* 6, *fig.* 2, when Venus appears in any part of the arc E x G, she is westward from the sun, and therefore rises before him in the morning, and is called the *morning star*. When she appears any where in the arc G H E, she is eastward from the sun, and therefore sets after him; is seen in the evening, and is then the *evening star*.

From the apparent motions of the inferior planets,

we derive an argument to prove the falsity of the Ptolemaic system. If the earth was within the orbit of Venus, as the Ptolemaic system supposes, she might be sometimes on one side of the earth, whilst the sun is on the opposite side; or Venus might be sometimes in opposition to the sun; but Venus is never seen in opposition. Therefore the earth is on the outside of the orbit of Venus, and consequently the Ptolemaic system is not true. The same is also true of Mercury. But this, and some other circumstances relative to the motions of these planets, will be much better understood by means of a planetarium than by a diagram.

OF THE RETROGRADE, DIRECT, AND STATIONARY MOTIONS OF VENUS AND MERCURY.

It is easy to explain these motions on the Copernican system, it being the natural result of the respective situations and motions of the earth and these planets. But on the Ptolemaic system they are inexplicable, without calling in the aid of a very complicated hypothesis.

When the inferior planets are passing from their greatest elongation, on one side of the sun, through their superior conjunction, to their greatest elongation on the other side, their motion, as viewed from the earth, is direct. In order to explain this proposition, we shall first suppose the earth to be at rest at A, *plate* 6, *fig.* 2; and correct this supposition af-

terwards, by shewing that the apparent motion of Venus, or Mercury, seen from the earth, is the same in this respect, whether the earth moves in its orbit, or rests at A.

The proposition to be explained is this; that as Venus, for instance, moves from x, its greatest elongation on one side of the sun, through G its superior conjunction, to H, its greatest elongation on the other side, it will appear to a spectator upon the earth, to move from west to east according to the order of the signs; that is, its geocentric motion will be direct.

The planets move round the sun from west to east, and consequently if there was a spectator at the sun, they would appear to him to move through the zodiac, according to the order of the signs; or in other words, the heliocentric motion of Venus is direct. Now if the sun S, and the earth A are both on the same side of the planet, a spectator at the earth is in the same situation, with respect to the planet and its motion, as if he had been at the sun : for whilst the planet is moving from x, through G, to H, a spectator either at A or S is on the concave side of the planet's orbit; and consequently the planet will appear to move in the same manner from either: but the apparent motion of the planet, when seen from the sun, is direct, and consequently its motion, when seen from the earth, will also be direct.

For when Venus is at x, it appears to a spectator on the earth at A, to be in the line A x V, or is seen among the stars at V; when Venus has moved to K, it is seen among the fixed stars at P; when it has

moved to G, it is in its superior conjunction; when it has moved to C, it appears among the fixed stars at R; and when it is come to H, it appears among the fixed stars at T. Thus whilst Venus has moved in its orbit from x, its greatest elongation on one side of the sun, through G its superior conjunction, to H, its greatest elongation on the other side, it appears to have described the arc V P Q R T in the concave sphere of the heavens; but the letters x K G C H lie from west to east, because they lie in the same direction that the planet moves round the sun; and the letters V P Q R T lie in the same direction with x X G C H. Therefore, as the planet seems to a spectator on the earth, to describe the arc V P Q R T, its apparent motion, seen from the earth, is direct, or from west to east.

The second proposition is this; that while the inferior planets move from their greatest elongation on one side of the sun, through their inferior conjunction, to their greatest elongation on the other side, their geocentric motion is retrograde.

In other words, whilst Venus is moving from its greatest elongation H, *plate* 6, *fig.* 2, through its inferior conjunction E, to its other greatest elongation x, it appears to a spectator upon the earth at A, to move backwards, or from east to west, contrary to the order of the signs.

A spectator at the sun is on the concave side of the planet's orbit, viewing it from withinside. But whilst Venus is moving from its greatest elongation H on one side, through E its inferior conjunction, to x its greatest elongation on the other side, a specta-

tor upon the earth is on the convex side of its orbit, viewing it from without.

Therefore, if a spectator at the sun S would see the planet move one way, a spectator at the earth A will see it move the contrary way; or the geocentric motion will be contrary to its heliocentric motion, and therefore retrograde; for as seen from the sun, its motion is always direct.

That two spectators, one at the earth, the other at the sun, as they are on the contrary sides of the arc H E x, will see the planet apparently move contrary ways, may be rendered more plain by the following familiar consideration. If two men stand with their faces towards each other, and a ball is rolled along upon the ground, this ball will move from the right hand of one of the men towards his left, and from the left hand of the other towards his right. In like manner, if one man is at the earth A, and the other at the sun S, then whilst the planet is describing the arc H e x which is between them, it will appear to move from the right hand of the man at S towards his left, and from the left hand of the man at A towards his right.

Whilst the motion of Venus is direct, or while it is describing the arc x G H, it appears to move from V to T, among the fixed stars. But after it has been carried in its orbit from H to z, it appears in the line A z R, and is seen among the fixed stars at R. When it comes to E, it appears at Q; and when at y, its apparent place in the heavens is at P. Thus as the planet passes from its greatest elongation H on

one side of the sun, through its inferior conjunction E, to its greatest elongation x on the other side, it apparently runs back from T to V, or its motion is retrograde.

Our third proposition is, that Venus is stationary, or has no apparent motion for some time, when it is at its two greatest elongations; that is, when it is at H or x, and its apparent place is either at T or V.

When either of the inferior planets, Venus for instance, is at its greatest elongation H or x, a line drawn from the earth through the planet, as A H T, or A x V is a tangent to the orbit. Now though a right line touches a circle but in one point, yet some part of the circle greater than a point is so near to the tangent, as not to be distinguished from it. Thus the arc b d so nearly coincides with the tangent A H T, that a spectator's eye placed at A, could not distinguish the tangent from this part of the curve. Consequently, while the planet is describ-ing this arc, no other change will be made in its geocentric place, than if it was to move in the tangent.

But the geocentric place of the planet would not be altered, if the planet was to move in the tangent. For if it was to move from T towards A, or from A to V, the apparent place of it in the heavens would in one case be at T, in the other case at V. Therefore, while the planet is at its greatest elonga-tion, and is describing a small arc in its orbit, that nearly coincides with the tangent, its geocentric place does not alter, *but it appears to continue for*

some time in the same part of the heavens, or is *stationary.*

I have hitherto supposed the earth to be at rest, and upon that supposition have explained the progress and regress, the conjunctions and stations of the inferior planets. If this supposition was true, V T, or the arc which the planet at any time describes in its progress, and T V, the arc which it describes in its regress, would always be in the same part of the heavens. The planet, when in conjunction, would always appear at Q among the same fixed stars, and at its elongation, or when it is stationary, it would always appear among the same fixed stars at T on one side of the sun, and at V on the other.

But this supposition is not true; for the earth revolves in its orbit A B O round the sun. Now if the earth is at A, at the time of either conjunction, the planet at this conjunction would appear among the fixed stars at Q, and the arcs of the greatest elongation Q V and Q T, would be on each side of those stars. But if the earth is at B, at the time of either of the conjunctions, then, at the time of this conjunction, the planet will appear in the line B S T, and be seen among the fixed stars at T, and the arcs of the greatest elongation will be on each side of these stars; that is, the conjunctions and elongations will happen in a different part of the heavens, when the earth is at B, from what they happen when the earth is at A. In other respects, the foregoing phenomena will be much the same, notwithstanding the motion of the earth, only the planet will be

more direct in the farthest part of the orbit, and less retrograde in the nearest.

The inferior planets always appear very near the sun; but by the motion of the earth in its orbit, the sun appears in different parts of the heavens, in different times of the year. Therefore the inferior planets, as they are always very near the sun, will also appear in different parts of the heavens, at different times of the year. And consequently their conjunctions and greatest elongations will sometimes happen when they are in one part of the heavens, and sometimes when they are in another part. Venus, seen from the earth, will appear to vibrate in an arc V T, half of which is on one side of the sun's apparent place, and half on the other side.

When an inferior planet, viewed from a superior, moves apparently retrograde, the superior planet has also an apparently retrograde motion.

When a superior planet, viewed from an inferior, appears stationary, the inferior planet viewed at the same time from the superior, is also stationary.

OF THE PHASES OF VENUS.

That the planets are all opake or dark bodies, and consequently shine only by the light they receive from the sun, is plain, because they are not visible when they are in such parts of their orbits as are between the sun and earth, that is, when their illuminated side is turned from us.

The sun enlightens only half a planet at once; the illuminated hemisphere is always that which is turned towards the sun, the other hemisphere of the planet is dark. To speak with accuracy, the sun, being larger than any of the planets, will illuminate rather more than half; but this difference, on account of the great distance of the sun from any of the planets, is so small, that its light may be considered as coming to them in lines physically parallel.

Like other opake bodies, they cast a shadow behind them, which is always opposite to the sun. The line in the planet's body, which distinguishes the lucid from the obscure part, appears sometimes straight, sometimes crooked. The convex part of the curve is sometimes towards the splendid, and the concave towards that which is obscure, and *vice versa*, according to the situation of the eye with respect to the planet, and of the sun which enlightens the planet.

Hence the inferior planets, going round the sun in less orbits than our earth does, will sometimes have more, sometimes less of their illuminated side towards us; and as it is the illuminated part only which is visible to us, Mercury and Venus will, through a good telescope, exhibit the several appearances of the moon, from a fine thin crescent to the enlightened hemisphere.

If we view Venus through a telescope, when she follows the sun's rays on the eastern side, and appears above the horizon after sun-set, we shall see her appear nearly round, and but small; she is at

that time beyond the sun, and presents to us an enlightened hemisphere. As she departs from the sun towards the east, she augments in her apparent size; and on viewing her through a telescope, is seen to alter her figure, abating of her apparent roundness, and appearing successively like the moon in the different stages of her decrease. At length, when she is at her greatest elongation, she is like the moon in her first quarter, and appears as she does, when from a full, she has decreased to a half moon.

After this, as she approaches (in appearance) to the sun, she appears concave in her illuminated part, as the moon when she forms a crescent; thus she continues, till she is hid entirely in the sun's rays, and presents to us her whole dark hemisphere, as the moon does in her conjunction, no part of the planet being then visible.

When she departs out of the sun's rays on the western side, we see her in the morning just before day-break. It is in this situation that Venus is called the *morning star*, as in the other she is called the *evening star*. She at this time appears very beautiful, like a fine thin crescent: just a verge of silver light is seen on her edge. From this period she grows more and more enlightened every day, till she is arrived at her greatest digression or elongation, when she again appears as a half moon, or as the moon in her first quarter: from this time if continued to be viewed with a telescope, she is found to be more and more enlightened, though she is all the while decreasing in magnitude; and thus con-

tinues growing smaller and rounder, till she is again hid or lost in the sun's rays.

Plate 8, *fig*. 1, represents the orbits of Venus and the earth, with the sun in the centre of them. The planet Venus is drawn in eight different situations, with its illuminated hemisphere towards the sun. If we suppose the earth to be at T, when Venus is at A, her dark hemisphere is towards the earth, and she is therefore invisible, except the conjunction happens in her node, for then she appears like a dark spot upon the disc of the sun. When Venus is at B, a little of her enlightened side is turned towards the earth, and therefore she appears sharp-horned; when she is at C, half her enlightened hemisphere is turned towards the earth, and she appears like a half moon; at D, more than half her enlightened hemisphere is towards us, and she appears like the half moon about three days before it is full; at E, the whole enlightened hemispere is towards the earth, Venus is then either behind the sun, or so very near him, that she can hardly be seen; but if she could, she would appear round, like the full moon. At F she is like the moon three days after the full; at G like a half moon again; at H like a crescent, with the points of the horn turned the contrary way to what they were at B. *All this is equally applicable to Mercury.*

Plate 8, *fig*. 2, exhibits the different appearances of Venus, corresponding to her several situations in the foregoing figure; thus when Venus is at A, *fig.* 1, she is quite dark, as at A, *fig*. 2; when she is at B, *fig*. 1, she appears as at B, *fig.* 2, &c.

The inferior planets do not shine brightest when they are full; thus Venus does not appear brightest in her superior conjunction, though her illuminated hemisphere be then turned towards us. Her splendor is more diminished by her being at a greater distance from us; than the conspicuous part of her illuminated disc is increased. Dr. *Halley* has shewn, that Venus is brightest when her elongation from the sun is about 40°. Mercury is in his greatest brightness, when very near his utmost elongation.

OF THE SUPERIOR PLANETS.

I have already observed, that the greatest elongation of either of the inferior planets is less than 90°, or a quarter of a circle; so that they are never far from the sun, but constantly attend it. But the superior planets do not always accompany the sun, as I have shewn that the inferior ones do; they are, indeed, sometimes in conjunction with it, but then they are also sometimes in opposition to, or 180° from it.

Let S, *plate* 6, *fig*. 3, be the sun; A B C D, the orbit of any superior planet, Mars, for instance; E F G, the earth's orbit. If the earth be at E, the sun at S, and the planet at D, the sun and the planet will be both on the same side of the earth; and consequently the planet will appear in *conjunction* with the sun. But, as the orbit of the earth is between the sun and the orbit of the superior planet, it is possible for the earth to be between the sun and the planet, and consequently for the planet and the sun

to be on opposite sides of the earth, or the planet to be in opposition ; thus, if when the earth is at E, Mars be at A, he is then in *opposition* to the sun.

A superior planet is in *quadrature* with the sun, when its geocentric place is 90° from the geocentric place of the sun. If the earth be at E, and Mars at B or C, he is in quadrature with the sun; for the line A E, E B, form a right angle, as do also the lines E A, E C.

OF THE DIRECT, STATIONARY, AND RETROGRADE MOTION OF THE SUPERIOR PLANETS.

As the earth goes round the sun in less time, and in a less orbit than any of the superior planets, it will not be amiss to suppose a superior planet to stand still in some part of its orbit, while the earth goes once round the sun in her's, and consider the appearances the planets would then have, which are these: 1. While the earth is in her most distant se micircle, the apparent motion of the planet would be *direct*. 2. While the earth is in her nearest se-micircle, the planet would be *retrograde*. 3. While the earth is near the points of contact of a line drawn from the planet, so as to be a tangent to the earth's orbit, the planet would be *stationary*.

To illustrate this, let A B C D E F H G, *plate* 7, *fig.* 1, be the orbit of the earth; S, the sun; P Q V O, the orbit of Mars, L M N T, an arc of the ecliptic. Let us now suppose the planet Mars to

continue at P, while the earth goes round in her orbit, according to the order of the letters, A B C, &c. ABCDEFHG may be considered as so many stations, from whence an inhabitant of the earth would view Mars at different times of the year; and if straight lines be drawn from each of these stations, through Mars at P, and be continued to the ecliptic, they will point out the apparent places of Mars in the heavens, at these different stations.

Thus, supposing the earth at A, the planet will be seen among the stars at L; when the earth is arrived at B, the planet will appear at M; and in the same manner when at C, D, and E, it will be seen among the stars at N, R, T; therefore, while the earth moves over the large part of the orbit A B C D E, the planet will have an apparent motion from L to T, and this motion is from west to east, or the same way with the earth; and the planet is said to move *direct*, or according to the order of the signs.

When the earth is near to A and E, the point of contact of the tangent to the earth's orbit, the planet will be *stationary* for a short space of time.

When the earth moves from E to H, the planet seems to return from T to N; but while it moves from H to A, it will appear to move in a contrary direction, and thus be *retrograde* from N to L, where it will again be *stationary*: and, since the part of the orbit which the earth describes in passing from A to E is much greater than the part E H P, though the space T L which the planet describes in direct and retrograde motion is the same, the direct motion

from L to T must be much slower than the retrograde motion from T to L.

When the earth is at C, a line drawn from C through S and P to the ecliptic, shews that Mars is then in conjunction with the sun. But when the earth is at H, a line drawn from H through P, and continued to the ecliptic, would terminate in a point opposite to S; therefore, in this situation Mars would be in opposition to the sun. Thus it appears that the motion of Mars is direct when in conjunction, and retrograde when in opposition.

The retrograde motions of the superior planets happen oftener, the slower their motions are; as the retrograde motions of the inferior planets happen oftener, the swifter their angular motions. Because the retrograde motions of the superior planets depend upon the motions of the earth; but those of the inferior, on their own angular motion. A superior one is retrograde once in each revolution of the earth; an inferior one in every revolution of its own.

OTHER PHENOMENA OF THE SUPERIOR PLANETS.

The superior planets are sometimes nearer the earth than at other times; they also appear larger, or smaller, according to their different distances from us. Thus, suppose the earth to be at C, if Mars be at P, he is the whole diameter of the earth's orbit nearer to us, than if we were at V; and con-

sequently his disc must appear larger at V than it would be at P. In other places, the distances of Mars from the earth are intermediate.

The diameter of the earth's orbit bears a greater ratio to the diameter of the orbit of Mars, than it does to the diameter of the orbit of Jupiter; and a greater to that of Jupiter than of Saturn; consequently the difference between the greatest and least apparent diameters is greater in Mars than in Jupiter; and greater in Jupiter, than in Saturn.

The superior, like the inferior planets, do not always appear in the ecliptic, their orbits being inclined also to that of the earth; one half is therefore above the ecliptic, the other half below it; nor are they ever seen in it but when they are in their nodes.

They also move in an ellipse. They are sometimes nearer to, and sometimes further from the earth. Their apparent diameter varies according to the difference in their distance.

OF THE SECONDARY PLANETS, OR SATELLITES.

It has been already observed, that four of the primary planets, the Earth, Jupiter, Saturn, and the Georgium Sidus, are in their revolutions round the sun, attended by secondary planets.

As the moon turns round the earth, enlightening our night; by reflecting the light she receives from the sun, so do the other satellites enlighten the planets to which they belong, and move round those planets at different periods of time, proportioned to

their several distances; and as the moon keeps company with this earth, in its annual revolution round the sun, so do they severally accompany the planets to which they belong in their several courses round that luminary.

I shall speak here first of the moon, which of all the heavenly bodies, excepting the sun, is the most splendid and brilliant, the inseparable companion and attendant of our earth. In mythology she was considered as Luna, in the heavens the radiant planet of the night, upon earth as the chaste Diana, and as the tremendous Hecate in hell.

OF THE MOON.

If we imagine the plane of the moon's orbit to be extended to the sphere of the heaven, it would mark therein a great circle, which may be called the moon's apparent orbit; because the moon appears to the inhabitants of the earth to move in that circle, through the twelve signs of the zodiac, in a periodical month. This position is illustrated by the following figure; let E F G H I, *plate* 9, *fig*. 3, be the orbit of the earth, S the sun, a b c d the orbit of the moon, when the earth is at E: let A B C D be a great circle in the sphere of the heaven, in the same plane with the moon's orbit.

The moon, by going round her orbit according to the order of letters, appears to an inhabitant of the earth to go round in the great circle A B C D, according to the order of those letters: for when the moon is at a, seen from the earth at E, she appears at

A; when the moon is got to b, she appears at B; when to c, she will appear at C; when arrived at d, she will appear at D. It is true, when the moon is at b, the visual line drawn from E, through the moon, terminates in L; as it does in M, when the moon is at d; but the lines L M and D B being parallel, and not farther distant from each other than the distance of the earth's orbit, are as to sense coincident, their distance measured in the sphere of the heaven being insensible: for the same reason, though the earth moves from E to F, in the time that the moon goes round her orbit, so that at the end of a periodical month the moon will be at a, and is seen from the earth at F, in the line F N; the moon will, notwithstanding, appear at A, the lines F N and E A being parallel, and as to sense coincident: in like manner, in whatever part of her orbit the earth is, as at H or I, the moon, by going round in her orbit, will appear to an inhabitant of the earth to go round in the great circle A B C D.

The plane of the moon's orbit extended to the heaven's, cuts the ecliptic in two opposite points.

The two points where the moon's apparent orbit thus cuts the ecliptic, are called the *moon's nodes*.

The point where the moon appears to cross the ecliptic, as she goes into north latitude, is called the moon's ascending node, of which this is the character ☊; the point where the moon goes into south latitude is her descending node, and is marked thus ☋; the moon's ascending node is often called

the dragon's head; her descending node the dragon's tail.

The *line of the moon's node* is a line drawn from one node to the other.

The extremities of the line of the nodes are not always directed towards the same points of the ecliptic, but continually shift their places from east to west, or contrary to the order of the signs, performing an entire revolution about the earth, in the space of something less than nineteen years.

The moon appears in the ecliptic only when she is in one of her nodes; in all other parts of her orbit she is either in north or south latitude, sometimes nearer to, sometimes further removed from the ecliptic, according as she happens to be more or less distant from the nodes.

When the place, in which the moon appears to an inhabitant of the earth, is the same with the sun's place, she is said to be in *conjunction*. When the moon's place is opposite to the sun's place, she is said to be in *opposition*. When she is a quarter of a circle distant from the sun, she is said to be in *quadrature*. Both the conjunction and the opposition of the moon are termed *syzigies*.

The common lunar month, or the time that passes between any new moon and the next that follows, is called a *synodical month*, or a *lunation*. This month contains 29 days, 12 hours, 44 min. 3 seconds.

A *periodical month* is the time the moon takes up to describe her orbit: or in other words, the time in which the moon performs one entire revolution

about the earth, from any point in the zodiac to the same again ; and contains 27 days, 7 hours, 43 minutes.

If the earth had no revolution round the sun, or the sun had no apparent motion in the ecliptic, the periodical and synodical month would be the same ; but as this is not the case, the moon takes up a longer time to pass from one conjunction to the next, than to describe its whole orbit; or the time between one new moon and the next, is longer than the moon's periodical time.

The moon revolves round the earth from west to east, and the sun apparently revolves round the earth the same way. Now at the new moon, or when the sun and moon are in conjunction, they both set out from the same place, to move the same way round the earth; but the moon moves much faster than the sun, and consequently will overtake it ; and when the moon does overtake it, it will be a new moon again. If the sun had no apparent motion in the ecliptic, the moon would come up to it, or be in conjunction again, after it had gone once round in its orbit ; but as the sun moves forward in the ecliptic, whilst the moon is going round, the moon must move a little more than once round, before it comes even with the sun, or before it comes to conjunction. Hence it is that the time between one conjunction and the next in succession, is something more than the time the moon takes up to go once round its orbit; or a synodical month is longer than a periodical one.

In *plate* 8, *fig.* 3, let S be the sun, C F a part of the earth's orbit, M D a diameter of the moon's orbit when the earth is at A, and m d another diameter parallel to the former, when the earth is at B. Whilst the earth is at A, if the moon be at D, she will be in conjunction ; and if the earth was to continue at A, when the moon had gone once round its orbit, from D through M, so as to return to D again, it would be again in conjunction. Therefore, upon the supposition that the earth has no motion in its orbit, the periodical and synodical months would be equal to one another. But as the earth does not continue at A, it will move forward in its orbit, during the revolution of the moon from A to B ; and as the moon's orbit moves with it, the diameter M D will then be in the position m d ; therefore, when the moon has described its orbit, it will be at d in this diameter m d ; but if the moon is at d, and the sun at S, the moon will not be in conjunction, consequently the periodical month is completed before the synodical. The moon, in order to come to conjunction, when the earth is at B, must be at e, in the diameter e f ; or besides going once round its orbit, it must also describe the arc d e. The synodical month is therefore longer than the periodical, by the time the moon takes up to describe the arc d e.

This may also be explained in another manner, by considering the apparent motion of the sun ; a view of the subject, that may render it more easy to some young minds than the foregoing. Thus let us sup-

pose the earth at rest at E, *plate* 8, *fig.* 4, M the moon in conjunction with the sun at S, while the moon describes her orbit A B C about the earth at E, let the sun advance by his apparent annual motion from S to D. It is plain that the moon will not come in conjunction with the sun again, till, besides describing her orbit, she hath described, over and above, the arc M F corresponding to the arc S D.

OF THE PHASES OF THE MOON.

As the moon goes round the earth in a much smaller orbit than that in which the earth revolves round the sun, sometimes more, sometimes less, and sometimes no part of her enlightened half will be towards us ; hence she is incessantly varying her appearance ; sometimes she looks full upon us, and her visage is all lustre ; sometimes she shews only half her enlightened face, soon she appears as a radiant crescent, in a little time all her brightness vanishes, and she becomes a beamless orb.

The full moon, or opposition, is that state in which her whole disc is enlightened, and we see it all bright, and of a circular figure. The new moon is when she is in conjunction with the sun ; in this state, the whole surface turned towards us is dark, and is therefore invisible to us.

The first quarter of the moon she appears in the form of a semi-circle, but with the circumference turned towards the west. At the last quarter, she

appears again under the form of a semi-circle, but with the circumference turned towards the east

These phases may be illustrated in a very pleasing manner to the pupil, by exposing an ivory ball to the sun, in a variety of positions, by which it may present a greater or smaller part of its illuminated surface to the observer.   If it be held nearly in opposition, so that the eye of the observer may be almost immediately between it and the sun, the greatest part of the enlightened side will be seen; but if it be moved in a circular orbit, towards the sun, the visible enlightened part will gradually decrease, and at last disappear, when the ball is held directly towards the sun.   Or to apply the experiment more immediately to our purpose; if the ball, at any time when the sun and moon are both visible, be held directly between the eye of the observer and the moon, that part of the ball on which the sun shines, will appear exactly of the same figure as the moon itself.

The phases of the moon, like those of Venus, may also be illustrated by a diagram; thus, in *plate* 9, *fig.* 1, let S be the sun, T the earth, A B C D E F G H the orbit of the moon.   The first observation to be deduced from this figure is, that the half of the earth and moon, which is towards the sun, is wholly enlightened by it; and the other half, which is turned from it, is totally dark.   When the moon is in conjunction with the sun at A, her enlightened hemisphere is turned towards the sun, and the dark one towards the earth; in which case we cannot see her,

and it is said to be new moon. When the moon has moved from A to B, a small portion a b of her enlightened hemisphere will be turned towards the earth; which portion will appear of the form represented at B, *fig.* 2, (a figure which exhibits the phases as they appear to us).

As the moon proceeds in her orbit, according to the order of the letters, more and more of her enlightened part is turned towards the earth. When she arives at C, in which position she is said to be in quadrature, one half of that part towards the earth is enlightened, appearing as at C among the phases; this appearance is called a half moon. When she comes to D, the greatest part of that half which is towards us is enlightened; the moon is then said to be gibbous, and of that figure which is seen at D, in *fig.* 2.

When the moon comes to E, she is in opposition to the sun, and consequently turns all her illuminated surface towards the earth, and shines with a full face, for which reason she is called a full moon. As she passes through the other half of her orbit, from E by F G, and H to A again, she puts on the same phases as before, but in a contrary order or position.

As the moon, by reflected light from the sun illuminates the earth, so the earth does more than repay her kindness, in enlightening the surface of the moon, by the sun's reflex light, which she diffuses more abundantly upon the moon, than the moon does upon us; for the surface of the earth is considerably greater than that of the moon, and conse-

quently, if both bodies reflect light in proportion to their size, the earth will reflect much more light upon the moon than it receives from it.

In new a moon, the illuminated side of the earth is fully turned towards the moon, and the Lunarians will have a full earth, as we, in a similar position, have a full moon. And from thence arises that dim light which is observed in the old and new moons, whereby, besides the bright and shining horns, we can perceive the rest of her body behind them, though but dark and obscure. Now when the moon comes to be in opposition to the sun, the earth, seen from the moon, will appear in conjunction with him, and its dark side will be turned towards the moon, in which position the earth will be invisible to the Lunarians; after this, the earth will appear to them as a crescent. In a word, the earth exhibits the same appearance to the inhabitants of the moon, as the moon does to us.

The moon turns about its own axis in the same time that it moves round the earth; it is on this account that she always presents nearly the same face to us: for by this motion round her axis, she turns just so much of her surface constantly towards us, as by her motion about the earth would be turned from us. This motion about her axis is equable and uniform, but that about the earth is unequal and irregular, as being performed in an ellipses; consequently, the same precise part of the moon's surface can never be shewn constantly to the earth; which is confirmed by a telescope, by which we often ob-

serve a little segment on the eastern and western limb, appear and disappear by turns as if her body librated to and fro; this phenomenon is called the moon's *libration.* The lunar motions are subject to several other irregularities, which are fully discussed in the larger works on astronomy.

OF THE SATELLITES OF JUPITER, SATURN, AND
THE GEORGIUM SIDUS.

The existence of all the satellites, except the moon, must have remained unknown, without the assistance of the telescope. By the assistance of this instrument, Jupiter is found to be attended by four, Saturn by seven, and the Georgium Sidus by six.

The satellites are distinguished according to their places; into first, second, &c. the first being that which is nearest the planet. They revolve round their respective primaries in elliptic orbits, the primary planets being in the focus.

The planes of the orbits of the secondary planets produced, intersect the heliocentric orbits of their primaries in two opposite points; which are called their nodes.

Again, the planes of the orbits of the satellites produced, intersect the ecliptic in two opposite points, these are called the geocentric nodes of the satellites.

The orbits of Jupiter's satellites are nearly, but not exactly, in the same plane. This plane produced

makes an angle of about 3° with Jupiter's orbit. The second deviates a little from the rest.

The orbits of Saturn's satellites, except the 5th, which deviates from the rest several degrees, are nearly in the same plane. They are nearly parallel to the plane of the equator. The orbit of the 5th satellite makes an angle with the orbits of its primary of 13° 8'.

The system of Jupiter and his satellites is very large in itself; yet, on account of its immense distance from us, it appears to occupy but a small space in the sphere of the starry heavens, and consequently every satellite of Jupiter appears to us always near its primary, and to have an *oscillatory motion*, like that of a pendulum, going alternately from its greatest digression on one side the planet, to its greatest on the other, sometimes in a straight line, at others in an elliptic curve.

When a satellite is in its superior semi-circle, or that half of its orbit that is more distant from the earth, its motion appears direct to us; when a satellite is in its inferior semi-circle, nearest to the earth, the apparent motion of it is retrograde. Both these motions seem quickest, when the satellite is nearest the centre of the primary, and slower when they are more distant; at the greatest distance they appear stationary for a short time.

The satellites, and their primaries, mutually eclipse each other, in the same manner in which it has been shewn that the earth and the moon do. But

there are three cases in which the satellites disappear to us

The one is, when the satellite is directly beyond the body of its primary, with respect to the *earth*; this is called an *occultation* of the planet.

Another is, when it is directly behind its primary, with respect to the *sun*, and so falls into its shadow, and suffers an eclipse, as the moon, when the earth, is interposed between that and the sun.

The last is, when it is interposed between the earth and its primary; for then it cannot be distinguished from the primary itself.

It is not often that a satellite can be discovered upon the disc of Jupiter, even by the best telescopes, excepting at its first entrance, when, by reason of its being more directly illuminated by the rays of the sun, than the planet itself, it appears like a lucid spot upon it; sometimes however a satellite is seen passing over the disc like a dark spot; this has been attributed to spots on the surface of the satellite, and that the more probably as the satellite has been known to pass over the disc at one time as a dark spot, and at another time to be so luminous, as only to be distinguished from the planet at its ingress and egress. The beginning and endings of these eclipses are easily seen by a telescope, when the planet is in a proper situation; but when it is in conjunction with the sun, the brightness of that luminary renders both the planet and satellite invisible.

By observing the eclipses of Jupiter's satellites, it

was discovered that light is not propagated instantaneously, though it moves with an incredible velocity; so that light reaches from the sun to us in the space of eleven minutes of time, at more than the rate of 100,000 miles in a second.

The orbits of all the satellites of Saturn, except the fifth, are nearly in the same plane, which plane makes an angle with that of Saturn's orbit, of about 31°; this inclination is so great, that they cannot pass either across Saturn or behind it, with respect to the earth, except when they are very near their nodes, so that their eclipses are not near so frequent as those of Jupiter. An occultation of the fourth behind the body of Saturn has been observed, and *Cassini* once saw a star covered by the fourth satellite, so that for 13 minutes they appeared as one.

OF ECLIPSES.

Those phenomena, that are termed *eclipses,* were in former ages beheld with terror and amazement, and looked upon as prodigies that portended calamity and misery to mankind. These fears, and the erronious opinions which produced them, had their source in the hieroglyphical language of the first inhabitants of the earth. We do not, however, imagine that even the most ancient of these knew any more of the laws and motions of the heavenly bodies, than what could be discovered from immediate sight; or that they knew enough of the

lunar system to calculate an eclipse, or even that they ever attempted it.

The word *eclipse* is derived from the Greek, and signifies dereliction, a fainting away or swooning. Now as the moon falls into the shadow of the earth, and is deprived of the sun's enlivening rays, at the time of her greatest brightness, and even appears pale and languid before her obscuration, lunar eclipses were called *lunæ labores*, the struggles or labours of the moon ; to relieve her from these imagined distresses, superstition adopted methods as impotent as they were absurd.

When the moon, by passing between us and the sun, deprived the earth of its light and heat, the sun was thought to turn away his face, as if in abhorence of the crimes of mankind, and to threaten everlasting night and destruction to the world. But thanks to the advancement of science, which, while it has delivered us from the foolish fears and idle apprehensions of the ancients, leaves us in possession of their representative knowledge, enables us to explain the appearances on which it was founded, and points out the perversion and abuse of it.

Any opake body, that is exposed to the light of the sun, will cast a shadow behind it. This shadow is a space deprived of light, into which if another body comes, it cannot be seen for want of light ; the body thus falling within the shadow, is said to be *eclipsed*.

The earth and moon being opake bodies, and deriving their light from the sun, do each of them cast

a shadow behind, or towards the hemisphere opposed to the sun. Now when either the moon or the earth passes through the other's shadow, it is thereby deprived of illumination from the sun, and becomes invisible to a spectator on the body from whence the shadow comes ; and such spectator will observe an eclipse of the body which is passing through the shadow ; while a spectator on the body which passes through the shadow, will observe an eclipse of the sun, being deprived of his light.

Hence there must be three bodies concerned in an eclipse ; 1. the luminous body ; 2. the opake body that casts the shadow ; and, 3. the body involved in the shadow.

OF ECLIPSES OF THE MOON.

As the earth is an opake body, enlightened by the sun, it will cast a shadow towards those parts that are opposite to the sun, and the axis of this shadow will always be in the plane of the ecliptic, because both the sun and the earth are always there.

The sun and the earth are both spherical bodies ; if they were, therefore, of an equal size, the shadow of the earth would be cylidrical, as in *plate* 8, *fig.* 5 ; and would continue of the same breadth at all distances from the earth, and would consequently extend to an infinite distance, so that Mars, Jupiter, or Saturn, might be eclipsed by it ; but as the planets are never eclipsed by the earth, this is not the shape

of the shadow, and consequently the earth is not equal in size to the sun.

If the sun were less than the earth, the shadow would be wider the farther it was from the earth, see *plate* 8, *fig.* 6, and would therefore reach to the orbits of Jupiter and Saturn, and eclipse any of these planets when the earth came between the sun and them; but the earth never eclipses them, therefore this is not the shape of its shadow, and consequently the sun is not less than the earth.

As we have proved that the earth is neither larger nor equal to the sun, we may fairly conclude that it is less; and that the shadow of the earth is a cone, which ends in a point at some distance from the earth, see *plate* 8, *fig.* 7.

The axis of the earth's shadow falls always upon that point of the ecliptic that is opposite to the sun's geocentric place; thus if the sun be in the first point of Aries, the axis of the earth's shadow will terminate in the first point of Libra. It is clear, therefore, *that there can be no eclipse of the moon but when the earth is interposed between it and the sun, that is, at the time of its opposition, or when it is full*; for unless it is opposite to the sun, it never can be in the earth's shadow: and if the moon did always move in the plane of the ecliptic, she would every full moon pass through the body of the shadow, and then it would be a total eclipse of the moon.

We have already observed that the moon's orbit is inclined to the plane of the ecliptic, and only coincides with it in two places, which are termed the

nodes. It may therefore be full moon* without her being in the plane of the ecliptic ; she may be either on the north or the south side of it ; in either of these cases she will not enter into the shadow, but be above it in the one, below it in the other.

To illustrate this, let H G, *plate* 10, *fig*. 1, represent the orbit of the moon, E F the plane of the ecliptic, in which the centre of the earth's shadow always moves, and N the node of the moon's orbit ; A B C D four places of the shadow of the earth in the ecliptic. When the shadow is at A, and the moon at I, there will be no eclipse : when the full moon is nearer the node, as at K, only part of her globe passes through the shadow, and that part becoming dark, it is called a *partial eclipse* ; and it is said to be of so many *digits* as there are *twelfth parts* of the moon's diameter darkened. When the full moon is at M, she enters into the shadow C ; and passing through it, becomes wholly darkened at L, and leaves the shadow at O: as the whole body of the moon is here immersed in the shade, this is called a *total eclipse*; but when the moon's centre passes through that of the shadow, which can only happen when she is in the node at N, it is called a *total and central eclipse*. There will always be such eclipses, when

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* A planet may be in opposition to, or conjunction with, the sun, without being in a right line that passes through the sun and the earth. Astronomers term it in conjunction with the sun, if it be in the same part of the zodiac ; in opposition, if it be in a part of the zodiac, 180° from the sun.

the centre of the moon and axis of the shadow meet in the nodes.

The duration of a central eclipse is so long, as to let the moon go the length of three of its diameters totally eclipsed, which stay in the earth's shadow is computed to be about four hours; whereof the moon takes one hour, from its beginning to enter the shadow, till quite immersed therein; two hours more she continues totally dark; and the fourth hour is taken up from her first beginning to come out of the shadow, till she is quite out of it.

In the begining of an eclipse, the moon enters the western part of the shadow with the eastern part of her limb; and in the end of it, she leaves the eastern part of the shadow with the western part of her limb. All the intermediate time, from her entrance to her quitting the shadow, is reckoned into the eclipse; but only so much into the total immersion, as passes while the moon is altogether obscured.

From the magnitude of the sun, the size of the earth, their distance from each other, the refraction of the atmosphere, and the distance of the moon from the earth, it has been calculated that the shadow of the earth terminates in a point, which does not reach so far as the moon's orbit. The moon is not, therefore, eclipsed by the shadow of the earth alone. The atmosphere, by refracting some of the rays of the sun, and reflecting others, cast a shadow, though not so dark a one as that

which arises from an opake body: when, therefore, we say that the moon is eclipsed, by passing into the shadow of the earth, it is to be understood of the shadow of the earth, together with its atmosphere. Hence it is that the moon is visible in eclipses, the shadow cast by the atmosphere not being so dark as that cast by the earth. The cone of this shadow is larger than the cone of the earth's shadow, the base thereof broader, the axis longer. There have been eclipses of the moon, in which the moon has entirely disappeared: *Hevelius* mentions one of this kind, which happened in August 1647, when he was not able to distinguish the place of the moon, even with a good telescope, although the sky was sufficiently clear for him to see the stars of the fifth magnitude.

All opake bodies, when illuminated by the rays of the sun, cast a shadow from them, which is encompassed by a *penumbra*, or thinner shadow, which every where surrounds the former, growing larger and larger as we recede from the body: in other words, the penumbra is all that space surrounding the shadow, into which the rays of light can only come from some part of that half of the globe of the sun which is turned towards the planet, all the rest being intercepted by the intervening body.

Let S, *plate* 10, *fig.* 2, be the sun, E the planet, then the penumbral cone is F G H. The nearer any part of the penumbra is to the shadow, the less light it receives from the sun; but the further it is, the more it is enlightened; thus the parts of the

penumbra near M are illuminated by those rays of light which come from that part of the sun near to I, all the rest being intercepted by the planet E. In like manner, the parts about N can only receive the light that comes from the part of the sun near to L; whereas the parts of the penumbra at P and Q are enlightened in a much greater degree : for the planet intercepts from P only those rays which come from the sun near L, and hides from Q only a small part of the sun near I.

The moon passes through the penumbra before she enters into the shadow of the atmosphere. This causes her gradually to lose her light, which is not sensible at first; but as she goes into the darker part of the penumbra, she grows paler. The penumbra, where it is contiguous to the shadow, is so dark, that it is difficult to distinguish one from the other. If the atmosphere be serene, every eclipse of the moon is visible at the same instant to all the inhabitants of that side of the earth to which he is opposite.

The moon in a total eclipse, generally appears of a dusky reddish colour, especially towards the edges ; but of a darker towards the middle of the shadow.

OF ECLIPSES OF THE SUN.

The moon, when in conjunction, if near one of her nodes, will be interposed between us and the sun, and will consequently hide the sun, or a part of him, from us, and cast a shadow upon the earth :

this is called an *eclipse of the sun*; it may be either partial or total.

An eclipse of any lucid body is a deficiency or diminution of light, which would otherwise come from it to our eye, and is caused by the interposition of some opake body.

The eclipses of the sun and moon, though expressed by the same word, are in nature very different; the sun, in reality, loses nothing of its native lustre in the greatest eclipses, but is all the while incessantly sending forth streams of light every way round him, as copiously as before. Some of these streams are, however, intercepted in their way towards our earth, by the moon coming between the earth and the sun : and the moon having no light of her own, and receiving none from the sun on that half of the globe which is towards our eye, must appear dark, and make so much of the sun's disc appear so, as is hid from us by her interposition.

What is called an eclipse of the sun, is therefore, in reality, an eclipse of the earth, which is deprived of the sun's light, by the moon's coming between, and casting a shadow upon it. The earth being a globe, only that half of it, which at any time is turned towards the sun, can be enlightened by him at that time ; it is upon some part of this enlightened half of the earth, that the moon's shadow, or penumbra, falls in a solar eclipse.

The sun is always in the plane of the ecliptic ; but the moon being inclined to this plane, and only co-

inciding with it at the nodes, it will not cover either the whole or a part of the sun ; or in other words, the sun will not be eclipsed, unless the moon at that time is in or near one of her nodes.

The moon, however, cannot be directly between the sun and us, unless they are both in the same part of the heavens ; that is, unless they are in conjunction. Therefore, the sun can never be eclipsed but at the new moon, nor even then, unless the moon at that time is in or near one of her nodes.

From hence it is easy to shew, that *the darkness of our Saviour's crucifixion was not owing to an eclipse of the sun.* For the crucifixion happened at the time of the Jewish passover, and the passover, by the appointment of the law, was to be celebrated at the full moon ; the sun could not, therefore, be eclipsed at the time of the passover. An intelligent tutor will find many opportunities of observing to his pupil, that nature, and philosophy, which explains the phenomena of nature, do always agree with divine revelation.

The moon being much smaller than the earth, and having a conical shadow, because she is less than the sun, can only cover a small part of the earth by her shadow ; though, as we have observed before, the whole body of the moon may be involved in that of the earth. Hence an eclipse of the sun is visible but to a few inhabitants of the earth ; whereas an eclipse of the moon may be seen by all those that are on that hemisphere which is turned towards it. In other words, as the moon can never totally

eclipse the earth, there will be many parts of the globe that will suffer no eclipse, though the sun be above their horizon.

An eclipse of the sun always begins on the western, and ends on the eastern side; because the moon moving in her orbit from west to east, necessarily first arrives at and touches the sun's western limb, and goes off at the eastern.

It is not necessary, in order to constitute a *central* eclipse of the sun, that the moon should be exactly in the line of the nodes, at the time of its conjunction; for it is sufficient to denominate an eclipse of the sun *central*, that the centre of the moon be directly between the centre of the sun, and the eye of the spectator; for to him, the sun is then centrally eclipsed. But as the shadow of the moon can cover but a small portion of the earth, it is obvious this may happen when the moon is not in one of her nodes. Further, the sun may be eclipsed centrally, totally, partially, and not at all, at the same time.

A total eclipse of the sun is a very curious spectacle : *Clavius* says that, in that which he observed in Portugal, in 1650, the obscurity was greater, or more sensible than that of the night : the largest stars made their appearance for about a minute or two, and the birds were so terrified, that they fell to the ground.

Thus in *plate* 10, *fig.* 3, let A B C be the sun, M N the moon, h l g part of the cone of the moon's shadow, f d the penumbra of the moon: from this figure it is easy to perceive,

1. That those parts of the earth that are within the circle represented by g h, are covered by the shadow of the moon, so that no rays can come from any part of the sun into that circle, on account of the interposition of the moon.

2. In those parts of the earth where the penumbra falls, only part of the sun is visible; thus between d and g, the parts of the sun near C cannot be seen, the rays coming from thence towards d or g being intercepted by the moon; whereas at the same time, the parts between f and h are illuminated by rays coming from C, but are deprived by the moon of such as come from A.

3. The nearer any part of the earth, within the penumbra, is to the shadow of the moon, as in places near g, l, or h, the less portion of the sun is visible to its inhabitants; the nearer it is to the outside of the penumbra, as towards d, e, or f, the greater portion of the sun may be seen.

4. Out of the penumbra, the entire disc of the sun is visible.

OF THE LIMITS OF SOLAR AND LUNAR ECLIPSES,

The distance of the moon, in degrees and minutes, above or below the ecliptic line, is called her *latitude*. If she be above the ecliptic, she is said to have north; if below it, south latitude.

If the latitude at any time exceed the sum of the

semi-diameter of the moon, equal to $16\frac{1}{4}$ min. and the earth's shadow equal to $45\frac{1}{4}$ minutes, the moon at that time cannot be eclipsed ; but will either pass under or over the shadow, according as she happens to be above or below the ecliptic line.

The distance from the node, either before or after it, corresponding to the above extent, is about 12 degrees, which is consequently the limit of lunar eclipses : for when a full moon happens within 12 degrees of the nodes, she will be eclipsed ; and the nearer to the nodes, the greater will the eclipse be.

If at the new moon, the latitude exceeds the sum of the semi-diameters of the sun $16\frac{1}{4}$ minutes, and of the moon $16\frac{1}{4}$ minutes, we should see no eclipse of the sun from the centre of the earth. But as we view the luminaries from the surface, which is much higher, we are obliged to take in the semi-diameter of the earth as seen from the moon. Then, if the latitude of the moon be greater than the sum of these three numbers, $94\frac{3}{4}$ minutes, the sun will not be eclipsed ; for the moon will pass either over or under his disc, according as she is above or below the ecliptic line. The distance from the node on either side agreeing to the above-mentioned extent, is the 18 degrees, which is the utmost limit of solar eclipses ; whence it follows, that if the sun and moon, at the time of new moon, happen to be within 18 degrees of the node, the sun will be eclipsed.

OF THE PERIOD OF ECLIPSES.

If the places of the moon's nodes were fixed, eclipses would always happen nearly at the same time of the year; but as they have a motion of about 3 min. 11 sec. every day backwards, or contrary to the order of the signs, the succeeding eclipse must recede likewise; and in one revolution of the nodes, which is completed in 18 years, 224 days, 3 hours, they will revolve in a retrograde manner through the year, and return to the same places again.

But there is a more correct period, called the Chaldean Saros, which is 18 years, 11 days, 7 hours, 43 min. for in that time the sun and moon advance just as far beyond a complete direct revolution in the ecliptic, as the nodes want of completing their retrograde one: consequently as the sun and moon meet the nodes at the end of that period, the same solar and lunar aspects, which happened 18 years, 11 days, 7 hours, 43 minutes ago, will return, and produce eclipses of both luminaries, for many ages, the same as before.

Of ancient astronomical observations much has been said, with very little foundation, by many modern writers: the oldest eclipses of the moon that *Hipparchus* could make any use of, went no higher than the year before Christ 721. Whatever observations,

therefore, the Chaldeans had before this, were pro-
bably very rude and imperfect.*

OF PARALLAX AND REFRACTION.

Astronomy is subject to many difficulties, besides
those which are obvious to every eye. When we
look at any star in the heavens, we do not see it in
its real place ; the rays coming from it, when they
pass out of the purer ethereal medium, into our
coarser and more dense atmosphere, are *refracted*,
or bent in such a manner, as to shew the star higher
than it really is. Hence we see all the stars before
they rise, and after they set ; and never, perhaps, see
any one in its true place in the heavens. There is
another difference in the apparent situation of the
heavenly bodies, which arises from the stations in
which an observer views them. This difference in
situation is called the *parallax* of an object.

OF PARALLAX.

The *parallax* of any object is the difference be-
tween the places that the object is referred to in the
celestial sphere, when seen at the same time from
two different places within that sphere. Or, it is

* *Costard's* History of Astronomy.

the angle under which any two places in the inferior orbits are seen from a superior planet, or even the fixed stars.

The parallaxes principally used by astronomers, are those which arise from considering the object as viewed from the centres of the earth and the sun, from the surface and centre of the earth, and from all three compounded.

The difference between the place of a planet, as seen from the sun, and the same as seen from the earth, is called the parallax of the annual orbit; in other words, the angle at any planet, subtended between the sun and the earth, is called the parallax of the earth's or annual orbit.

The diurnal parallax is the change of the apparent place of a fixed star, or planet, of any celestial body, arising from its being viewed on the surface, or from the centre of the earth.

The annual parallax of all the planets is very considerable, but that of the fixed stars is imperceptible.

The fixed stars have no diurnal parallax; the moon, a considerable one; that of the planets is greater or less, according to their distances.

To explain the parallaxes with respect to the earth only, let H S W, *plate* 7, *fig.* 2, represent the earth; T, the centre thereof; O R G, part of the moon's orbit; P r g, part of a planet's orbit; Z a A, part of the starry heavens. Now, to a spectator at S, upon the surface of the earth, let the moon appear in G, that is, in the sensible horizon of S, and it

will be referred to A ; but if viewed from the centre T, it will be referred to the point D, which is its true place.

The Arc, A D, will be the moon's parallax ; the angle, S G T, the parallactic angle ; or the parallax is expressed by the angle under which the semi-diameter T S of the earth is seen from the moon.

If the parallax be considered with respect to different planets, it will be greater or less as those objects are more or less distant from the earth ; thus the parallax A D of G is greater than the parallax A d of g.

If it be considered with respect to the same planet, it is evident that the horizontal parallax, or the parallax when the object is in the horizon, is greatest of all, and diminishes gradually, as the body rises above the horizon, until it comes to the zenith, where the parallax vanishes, or becomes equal to nothing. Thus A D and a d, the horizontal parallaxes of G and g, are greater than a B and a b, the parallaxes of R and r ; but the objects.O and P, seen from S or T, appear in the same place Z, or the zenith.

By knowing the parallax of any celestial object, its distance from the centre of the earth may be easily obtained by trigonometry. Thus if the distance of G from T be sought, in the triangle S T G, S T being known, and the angle S G T determined by observation, the side T G is thence known.

The parallax of the moon may be determined by two persons observing her from different stations at

K

the same time; she being vertical to the one and horizontal to the other. It is generally concluded to be about 57'.

But the parallax most wanted is that of the sun, whereby his absolute distance from the earth is known; and hence the absolute distances of all the other planets would be also known, from the second Keplerian law. But the parallax of the sun, or the angle under which the semi-diameter of the earth would appear at that distance, is so exceeding small, that a mistake of a second will cause an error of several millions of miles.

OF REFRACTION.

As one of the principal objects of astronomy is to fix the situation of the several heavenly bodies, it is necessary, as a first step, to understand the causes which occasion a false appearance of the place of those objects, and make us suppose them in a different situation from that which they really have. Among these causes *refraction* is to be reckoned. By this term is meant the bending of the rays of light, as they pass out of one medium into another.

The earth is every where surrounded by an heterogeneous fluid, a mixture of air, vapour, and terrestrial exhalations, that extend to the regions of the sky. The rays of light from the sun, moon, and stars, in passing to a spectator upon earth, come through this medium, and are so refracted in their

passage through it, that their apparent altitude is greater than their true altitude.

Let A C, *plate* 7, *fig.* 3, represent the surface of the earth; T, its centre; B P, a part of the atmosphere; H E K, the sphere of the fixed stars; AF, the sensible horizon; G, planet; G D, a ray of light proceeding from the planet to D, where it enters our atmosphere, and is refracted towards the line D T, which is perpendicular to the surface of the atmosphere; and as the upper air is rarer than that near the earth, the ray is continually entering a denser medium, and is every moment bent towards T, which causes it to describe a curve, as D A, and to enter a spectator's eye at A, as if it came from E, a point above G. And as an object always appears in that line in which it enters the eye, the planet will appear at E, higher than its true place, and frequently above the horizon A F, when its true place is below it, at G.

This refraction is greatest at the horizon, and decreases very fast as the altitude increases, insomuch that the refraction at the horizon differs from the refraction at a very few degrees above the horizon, by about one-third part of the whole quantity. At the horizon, in this climate, it is found to be about 33'. In climates nearer to the equator, where the air is purer, the refraction is less; and in the colder climates, nearer to the pole, it increases exceedingly, and is a happy provision for lengthening the appearance of the light at those regions so remote from the sun. *Gassendus* relates, that some Hol-

landers, who wintered in Nova Zembla, in lat. 75°, were surprized with a sight of the sun seventeen days before they expected him in the horizon. This difference was owing to the refraction of the atmosphere in that latitude. To the same cause, together with the peculiar obliquity of the moon's orbit to the ecliptic, some of these very northern regions are indebted for an uninterrupted light from the moon much more than half the month, and sometimes almost as long as it is capable of affording any light to other parts of the earth.

Through this refraction we are favoured with the sight of the sun about three minutes and a quarter before it rises above the horizon, and also as much every evening after it sets below it ; which in one year amounts to more than forty hours.

It is to this property of refraction that we are also indebted for that enjoyment of light from the sun, when he is below the horizon, which produces the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is owing to this, that the sun illuminates the whole hemisphere at once : deprived of the atmosphere, he would have yielded no light, but when our eyes were directed towards him ; and even when he was in meridian splendor, the heavens would have appeared dark, and as full of stars as on a fine winter's night. The rays of light would have come to us in straight lines ; the appearance and disappearance of

the sun would have been instantaneous; we should have had a sudden transition from the brightest sun-shine to the most profound darkness, and from thick darkness to a blaze of light. Thus by refraction we are prepared gradually for the light of the sun, the duration of its light is prolonged, and the shades of darkness softened.

To it we must attribute another curious pheno-menon, mentioned by *Pliny*; for he relates, that the moon had been eclipsed once in the west, at the same time that the sun appeared above the horizon in the east. *Mæstlinus*, in *Kepler*, speaks of another instance of the same kind which fell under his own observation.

OF THE FIXED STARS.

No part of the universe gives such enlarged ideas of the structure and magnificence of the heavens, as the consideration of the number, magnitude, and distance of the fixed stars. We admire, indeed with propriety, the vast bulk of our own globe; but, when we consider how much it is surpassed by most of the heavenly bodies, what a point it degenerates into, and how little more even the vast orbit in which it revolves would appear, when seen from some of the fixed stars, we begin to conceive more just ideas of the extent of the universe, and of the boundaries of creation.

The most conspicuous and brightest of the fixed stars of our horizon is Sirius. The earth, in moving

round the sun is 190 millions of miles nearer to this star in one part of its orbit, than in the opposite; yet the magnitude of the star does not appear to be in the least altered, or its distance affected by it; so that the distance of the fixed stars is great beyond all computation. The unbounded space appears filled, at proper distances, with these stars; each of which is probably a sun, with attendant planets rolling round it. In this view, what and how amazing, is the structure of the universe!

Though the fixed stars are the only marks by which astronomers are enabled to judge of the course of the moveable ones, and we have asserted their relative positions do not vary, yet this assertion must be confined within some limits; for many of them are found to undergo particular changes, and perhaps the whole are liable to some peculiar motion, which connects them with the universal system of created nature. Dr. *Herschel* even goes so far as to suppose, that there is not, in strictness of speaking, one fixed star in the heavens; but that there is a general motion of all the starry systems, and consequently of the solar one, among the rest.

There are some stars, whose situation and place were heretofore known and marked with precision, that are no longer to be seen: new ones have also been discovered, that were unknown to the ancients, while numbers seem gradually to vanish. There are others which are found to have a periodical increase and decrease of magnitude; and it is probable that the instances of these changes would have been more

numerous, if the ancients had possessed the same accurate means of examining the heavens as are used at present.

New stars offer to the mind a phenomenon more surprising, and less inexplicable, than almost any other in the science of astronomy. I shall select a few instances of the more remarkable ones, for the instruction of the young pupil: a consideration of the changes that take place, at so immense a distance as the stars are known to be from him, may elevate his mind to consider the immensity of *his* power, who regulates and governs all these wide extended motions; " who hath measured the waters in the hollow of his hand, and meted out heaven with a span."

It was a new star discovered by *Hipparchus*, the chief of the ancient astronomers, that induced him to compose a catalogue of the fixed stars, that future observers might learn from his labours, whether any of the known stars disappeared, or new ones were produced. The same motives engaged the illustrious *Tycho Brahe* to form, with unremitting labour and assiduity, another new catalogue of the stars.

Of new stars, the first of which we have a good account, is that which was discovered in the constellation Cassiopea, in the month of November of the year 1572; a time when astronomy was sufficiently cultivated, to enable the astronomers to give the account with precision. It remained visible about sixteen months; during this time, it kept its

place in the heavens, without the least variation. It had all the radiance of the fixed stars, and twinkled like them; and was in all respects like Sirius, excepting that it surpassed it in brightness and magnitude. It appeared larger than Jupiter, who was at that time in his perigree; and was scarce less bright than Venus.

It was not by degrees that it acquired this diameter, but shone forth at once of its full size and brightness, as if of instantaneous creation. It continued about three weeks in full and entire splendor, during which time it might be seen even at noon day, by those who had good eyes and knew where to look for it. Before it had been seen a month, it became visibly smaller, and from thence continued diminishing in magnitude till March 1574, when it entirely disappeared. As it decreased in size, it varied in colour; at first, its light was white, and extremely bright; it then became yellowish, afterwards of a ruddy colour, like Mars; and finished with a pale livid white, resembling that of Saturn.

In August 1596, *Fabricius* observed a new star in the neck of the Whale. In 1637, *Phocyllides Holwarda* observed it again, and not knowing that it had been seen before, took it for a new discovery: he watched it's place in the heavens, and saw it appear again the succeeding year, nine months after it's disappearance. It has been since found to be every year very regular in its period, except that in 1672 it was missed by *Hevelius,* and not seen again till 1676. *Bulliadus* determined the periodical

time between this star's appearing in its greatest brightness, and returning to it again, to be about 333 days; observing further, that this star did not appear at once in its full magnitude and brightness, but by degrees arrived at them.

Three changeable, or re-apparent stars have been discovered in the constellation of the Swan; the first was seen by *Jansonius*, in 1600; the second was discovered in 1670; the third by *Kirchius*, in 1686.

In the latter end of September, 1604, a new star was discovered near the heel of the right foot of Serpentarius. *Kepler*, in describing it, says, that it was precisely round, without any kind of hair, or tail; that it was exactly like one of the stars, except that in the vividness of its lustre, and the quickness of its sparkling, it exceeded any thing he had ever seen before. It was every moment changing into some of the colours of the rainbow, as yellow, orange, purple, and red; though it was generally white, when it was at some distance from the vapours of the horizon. Those in general who saw it, agreed that it was larger than any other fixed star, or even any of the planets, except Venus: it preserved its lustre and size for about three weeks; from this time it grew gradually smaller. Kepler supposes that it disappeared some time between October, 1605, and the February following, but on what day is uncertain.

Besides these several re-apparent stars, so well characterized and established by the earliest among

the modern astronomers, there have been many discovered since, by *Cassini*, *Maraldi*, and others; Mr. Montanere speaks of having observed above one hundred changes among the fixed stars.

The star Algol, in Medusa's head, has been observed long since to appear of different magnitudes, at different times. The period of it has been lately settled by *J. Goodrick*, Esq. of York. It periodically changes from the first to the fourth magnitude; the time employed from one greatest diminution to the other, was, anno 1783, at a mean 2 days, 20 hours, 49 minutes, 3 seconds.

The causes of these appearances cannot be assigned at present, with any degree of probability; perhaps they have some analogy to the spots on the sun, which at some times appear in greater numbers than at others, some of them bigger than the whole earth; or perhaps they are owing to some real motions of the stars themselves.

There are several stars that appear single to the naked eye, which are, on examination with a telescope, found to consist of two, three, &c. The number of double stars observed before the time of Dr. *Herschel*, was but small; but this celebrated astronomer has noted upwards of four hundred; among these, some that are double, others that are treble, double double, quadruple, double treble, and multiple; his catalogue gives the comparative size of these stars, their colour as they appeared to him, with several other very curious particulars.

OF NEBULÆ, AND OF HERSCHEL'S IDEAS RE-
SPECTING THE CONSTRUCTION OF THE UNI-
VERSE.

Besides those appearances of the fixed stars al-
ready noticed, there is another which deserves par-
ticular attention, namely, *the nebulæ*, or *parts of the
heavens which appear brighter than the rest*. The
most remarkable among these is, that large irre-
gular zone or band of whitish light which crosses
the ecliptic in Cancer and Capricorn, and is in-
clined thereto in an angle of about 60 degrees ; it is
a circle bisecting the celestial sphere, irregular in
breadth and brightness, and in many places divided
into double streams. The principal part runs through
the *Eagle*, the *Swan*, *Cassiopea*, *Perseus*, and *Au-
riga:* it continues its course by the head of *Mono-
ceros*; along by the greater *Dog*, through the *Ship*,
under the *Centaur's Feet* ; till having passed the
Altar, the *Scorpion's Tail*, and the *Bow of Aquarius*,
it ends at last where it began.

This curious appearance is owing to a multitude
of small stars, which are too minute to be distin-
guished by the naked eye ; yet, blending their light
together, form that whitness which occupies so large
a tract of the heavens. The milky way may be
considered as a constellation of telescopic stars ; a
sea of them, of great breadth, and of a whitish co-
lour, encompassing the whole heavens : even before
astronomy reaped any benefit from improvements in

optics, *Democritus* considered it as formed of clusters of small stars.

Mr. *Herschel's* large telescope completely resolved the whitish appearance of the milky way into stars. Having viewed and gauged this bright zone in all directions, he found it composed of shining stars, whose number increases and diminishes in proportion to its apparent brightness to the naked eye.

The portion of the milky way that he first observed, was that about the hand and club of Orion. Here he found an astonishing multitude of stars, which he attempted to number. By estimating the number contained in the field of his telescope at once, and computing, from a mean of these, how many might be contained in a given portion of the milky way, in the most vacant places, about that part, he found 63 stars ; other six fields contained 110, 60, 70, 90, 70, and 74 stars : a mean of these gives 79 for the number of stars in each field ; so that, allowing 15 minutes for the diameter of his field of view, a belt of fifteen degrees long, and two degrees broad, could not contain less than 50,000 stars, large enough to be distinctly numbered ; besides which, he suspected twice as many more, which could be seen only now and then by faint glimpses, for want of sufficient light.

In the most crouded parts of the milky way, he has had a field of view of 588 stars, and these continued for many minutes ; so that in one quarter of an hour's time not less than 116,000 stars have passed through the field of his telescope. He endea-

vours to shew, that the powers of his telescope are such, that it will not only reach the stars at 497 times the distance of Sirius, so as to distinguish them, but that it also shews the united lustre of the accumulated stars that compose a milky nebulosity at a far greater distance. From these considerations, it is highly probable, that as his twenty feet telescope does not shew such a nebulosity in the milky way, it goes already far beyond the extent thereof; and therefore a more powerful instrument would remove all doubt, by exposing a milky nebulosity beyond the stratum, which could then no longer be mistaken for the dark ground of the heavens.

To a spectator placed in indefinite space, all very remote objects appear to be equally distant from the eye. To judge of the milky way only from phenomena, we must of course consider it as a vast ring of stars scattered promiscuously round the celestial regions; but a more perfect view of the subject will shew us, that the appearance, &c. of this beautiful object arise from our eccentric view. Mr. *Wright*, in his " Original Theory of the Universe, 1750," and Dr. *Herschel* since, in " The Philosophical Transactions," have shewn, that this appearance may be accounted for, by assuming it's figure as much more extended towards the apparent zone of illumination, than in any other direction.

Suppose, says Dr. *Herschel*, a number of stars arranged between *two parallel planes* infinitely extended every way, but at a given considerable dis-

tance from each other; and calling this a *siderial stratum*, an eye placed somewhere within it, will see all the stars in the directions of the planes *projected into a great circle*, lucid on account of the accumulation of stars; while the rest of the heavens, at the sides, will only seem scattered over with constellations, more or less crowded, according to the distance of the planes, or numbers of the stars contained in the thickness or sides of the stratum.

If the eye be placed *without* the stratum, but at no very great distance, the appearance of the stars within it would form one of the lesser circles of the sphere, which would be more or less contracted, according to the distance of the eye.

He considers our *sun* as placed in that stratum of stars which forms our milky way, and as not far from the place where some smaller stratum branches out from it. Every star in the stratum has its own galaxy, only with such variations, in form and lustre, as may arise from their particular situations.

According to Dr. *Herschel*, the universe consists of *nebulæ*, or immense collections of innumerable stars, each individual of which is a sun, not only equal, but much superior to our's: yet none of the celestial bodies, in our system, are nearer to one another than we are to *Sirius*, who is supposed to be 400,000 times further than the sun from us; that is, thirty-eight millions of millions of miles. The extent of the nebulæ is such in some places, that the light of a star placed at its extreme boundary, sup-

posing it to fly with the velocity of twelve millions of miles every minute, must have taken near 3000 years to reach us.

Not content with these conjectures, our indefatigable astronomer endeavours to trace the *origin* of nebulous stars, and gives us hints concerning their *antiquity*. *Supposing* some to have a greater air of vigour than others, he attempts to shew that they are at distant periods separated and subdivided, and even *decay*. These compositions and decompositions he pretends to account for, and points out some that he considers as having sustained greater ravages of time than others! It is not here only that even his very conjectures surpass all human credulity, for you will find him assigning the boundaries of the vast periods requisite for forming nebulæ, and hazarding conjectures concerning others, as if they were the *laboratories of the universe!*

If you are attentive to astronomical writers, you will perceive that much of our knowledge of astronomy is founded upon conjecture, though dressed up with all the parade of mathematical demonstration. You will find much of their reasoning weak; and you will often find them arguing in a circle; and this particularly with respect to the densities, magnitudes, distances, and other affections of the planets. Many of their conclusions are deduced from analogy; a species of reasoning that in its best form amounts only to probability. Many of their ideas are supported upon an assumed attractive power, which they modify at pleasure.

Though in a popular work it is impossible to enter into a discussion of these points, yet it may be useful to say something concerning the value of conjecture, &c. in physical sciences. The world has been so long befooled by hypotheses in all parts of science, that it is now necessary to treat them with contempt. Conjectures and hypotheses are the invention and works of men, and must therefore bear proportion to the skill and capacity of the inventor ; and will always be very unlike the works of God, which it is the business of philosophy to discover.

It is natural for men to judge of things less known, by some similitude they observe, or think they observe, between them and things more familiar, or better known : in many cases we have no other way of judging. Analogical reasoning is not therefore to be always rejected ; but it ought always to be observed, that this kind of reasoning can only afford probable evidence, that it may lead into error, and that it varies in the degrees of its force according to the nature of the truths from which we reason, according to their greater or less extent, and according as the instances compared are more or less similar.

OF COMETS.

Comets are a kind of stars, appearing at unexpected times in the heavens, and of singular and various figures, descending from far distant parts of

of the system, with great rapidity, surprizing us with the singular appearance of a train or tail; and after a short stay are carried off to distant regions, and disappear.

They were imagined in ancient times to be prodigies hung out by the immediate hand of God in the heavens, and intended to alarm the world. Their nature being now better understood, they are no longer terrible: but as there are still many who think them to be heavenly warnings, portents of future events, it may not be improper for the tutor to inform his pupil, that the Architect of the universe has framed every part according to divine order, and subjected all things to laws and regulations; that he does not hurl at random stars and worlds, and disorder the system of the whole glorious frame, to produce false apprehensions of distant events; fears without foundation, and without use. Religion glories in the test of reason, of knowledge, and of true wisdom: it is every way connected with, and is always elucidated by them. From philosophy we may learn, that the more the works of the Lord are understood, the more he must be adored; and that his superintendancy over every portion is more clearly evinced, and more fully expressed, by their unvaried course, than by ten thousand variations.

The existence of an universal connection between all the parts of nature is now generally allowed. Comets undoubtedly form a part of this great chain; but of the part they occupy, and of the uses for which they exist, we are equally ignorant. It is a

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portion of science whose perfection is reserved for some distant day, when these bodies, and their vast orbits, may, by long and accurate observation, be added to the known parts of the solar system ; when astronomy will appear as a new science, after all our discoveries, great as we at present imagine them to be.

The astronomy of comets is very imperfect ; for but little can be known with certainty where but little can be seen. Comets afford few observations on which to ground conjecture, and are for the greatest part of their course beyond the reach of human vision ; but that they are not meteors in the air is plain, because they rise and set in the same manner as the moon and stars. They are called comets from their having a long tail, somewhat resembling the appearance of hair : some, however, have appeared without this appendage, as well defined and round as planets. Imperfect as our knowledge is concerning them, *mathematicians* have even ventured to calculate the sizes of their orbits, which they have made so great as to surpass the ordinary bounds of credulity.

It is generally supposed that they are planetary bodies, making part of our system, revolving round the sun in extreme long elliptic curves ; that as the orbit of a comet is more or less eccentric, the distance to which they recede from the sun will be greater or less. Very great difference has been found by observation in this respect ; even so great, that the sides of the elliptic orbit in some cases dege-

nerate almost into right lines. They are very numerous ; 450 are supposed to belong to our solar system.

It is supposed that those comets, which go to the greatest distance from the sun, approach the nearest to him at their return.

Their motions in the heavens are not all direct, or according to the order of the signs, like those of the other planets. The number of those which move in a retrograde manner, is nearly equal to those whose motion is direct.

The orbits of most of them are inclined in very large angles to the plane of the ecliptic.

The velocity with which they move is variable in every part of their orbit: when they are near the sun, they move with incredible swiftness; when very remote from him, their motion is inconceivably slow.

When they appear, they come in a direct line towards the sun, as if they were going to fall into his body ; and after having disappeared for some time, in consequence of his extreme brightness, they fly off on the other side as fast as they came, continually losing their splendor, till at last they totally disappear. Their apparent magnitude is very different ; sometimes seeming not bigger than the fixed stars, at other times equal in diameter to Venus. *Hevelius* observed one in 1652, which was not inferior to the moon in size, though not so bright: its light pale and dim, its aspect dismal.

A great number of comets are seen in the hemi-

sphere towards the sun, than in the opposite ; and are generally invisible at a smaller distance than that of Jupiter. Mr. *Brydone* observed one at Palermo, in July 1770, which, in twenty-four hours, described an arch in the heavens upwards of fifty degrees in length ; so that if it was far distant from the sun, it must have moved at the rate of upwards of sixty millions of miles in a day.

They differ also in form from the other planets, consisting of a large internal body, which shines with the reflected light of the sun, and is encompassed with a very large atmosphere, apparently of a fine matter, resembling that of the aurora borealis : this is called the head of the comet, and the internal part the nucleus. When a comet arrives at a certain distance from the sun, an exhalation arises from it, which is called the tail.

The tail is always directed to that part of the heavens which is directly or nearly opposite to the sun, and is greater and brighter after the comet has passed its perihelium. The tail of the comet of 1680 was of a prodigious size, extending from the head to a distance scarcely inferior to that of the sun from the earth.

No satisfactory knowledge has been acquired concerning the cause of that train of light which accompanies the comets. Some philosophers imagine that it is the rarer atmosphere of the comet, impelled by the sun's rays. Others, that it is the atmosphere of the comet rising in the solar atmosphere, by its specific levity : while others imagine that it is a pheno-

menon of the same kind with the aurora borealis, and that this earth would appear like a comet to a spectator placed in another planet.

The number of the comets is certainly very great, considerably beyond any estimation that might be made from the observations we now possess.

Though *astronomers* have bestowed much labour in calculating the periods of comets, and much attention to account for their phenomena, yet experience bears no testimony in favour of their opinions, nor have modern calculators had better success. Indeed the immense distances to which they are supposed to run out, are entirely hypothetical.

There are, who do not think the present astronomy of comets well established ; and as so many small ones are frequently seen, they think that nothing can be determined with certainty, till some better marks are discovered for distinguishing one from another, than any at present known ; and that even the accomplishment of Dr. Halley's prediction is uncertain : for it is very singular, that out of four years, in which three comets appeared, the only one in which no comet was to be seen, should be that very year in which the greatest astronomers that ever existed had foretold the appearance of one ; and in accounting for its non-appearance, Mr. *Clairault* would have been equally supported by cometic evidence, whether he had concluded the comet to have been retarded or accelerated by the action of Jupiter and Saturn. A comet appeared in 1757, as well as in 1755 ; and had he determined the retardation of

the comet to be twice as great as he did, another appeared in 1760 to have verified his calculations.

OF THE TELESCOPIC APPEARANCE OF THE PLANETS.

Though by the telescope we have been led onward in our advances towards a more powerful knowledge of the heavenly bodies, and astronomy being raised from little more than a catalogue of stars into a science; yet by this instrument men have been led into errors, and astronomers have indulged in speculations that equally deviate from sound reason, and the plain dictates of common sense.

The generality of mankind, in all ages, have considered the *sun* as a mass of pure elementary fire, subsisting from the creation, and supported by some unknown cause, without any occasion for the gross fuel necessary for supporting our terrestrial fires. The conjectures of astronomers have neither been so simple nor so rational; limited in their conceptions, they have not been able to perceive how fire of any kind could subsist without fuel, and have therefore supposed the sun and the earth to be of a similar substance, and consequently, that the earth itself would be a sun if set on fire. Sir *Isaac Newton* has even proposed it as a query, whether the sun and fixed stars are not *great earths* made vehemently hot, whose parts are kept from fuming away by the vast weight and density of their superincumbent atmo-

sphere, and whose heat is preserved by the prodi-gious action and re-action of their parts? Others have imagined the sun to be a body of quite a dif-ferent nature, and have even denied him to be pos-sessed of any inherent heat, though they allow him the power of producing it in other bodies. Some have supposed, that the main body of the sun has neither light-nor heat, but that it consists of *a vast dark globe*, surrounded on all sides with a thin covering of aerial or foggy matter immensely splendid, which gives him the power he possesses, &c.

The only foundation for these wild conjectures, is the appearance of the sun through telescopes. By viewing it through these instruments, his face is found to be equally bright in all its parts. A slightly spotted appearance, chiefly on or near the edges, is commonly taken notice of; and very frequently dark spots of various shapes and sizes are perceived traversing the disc from one edge to the other. These spots appear at uncertain intervals, and often change their form while they are passing over the solar disk, or are broken in pieces, enlarge and di-minish by causes of which we are ignorant.

Those who adhere to the conjectures of Sir *Isaac Newton*, suppose the spots to be the smoke of new and immense volcanoes breaking out in the body of the sun himself; while those who are pleased with the suppositions of professor *Wilson*, imagine them to be the dark globe rendered visible by

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the displacement of the shining and surrounding matter.

Though it would be deviating from our plan, to spend our time in speculations on subjects removed so far beyond the reach of human investigation ; yet we can scarce refrain from observing, that there is no foundation for supposing that the sun has any solid body. *Meteors*, resembling that glorious luminary in splendor, have been known to arise in the higher parts of our atmosphere, though their continuance there has been but for a short time. No one supposes that they have any solid body. It is not therefore unreasonable to suppose the sun to be a vast collection of elementary fire and light, which being sent out from him, by means unknown to us, and having accomplished the purposes for which they are designed, perpetually return to him, are sent out again, and so on. Thus the sun continues to burn unsupported by any terrestrial fuel, and without the least tendency to diminution or possibility of decay.

Of the Moon. From the appearance of this luminary through a telescope, it seems probable, that there are great inequalities on her surface. Viewing her at any time, except when full, we see one of the sides notched and toothed, like a saw. Many small points appear like stars at a small distance from the main luminous body, which join it in a little time. These are considered as the tops of high mountains, which catch the light of the sun sooner than the

other parts which are lower. That these very shining parts are higher than the rest of the surface, is evident from the appearance of their shadows, which lengthen and shorten according to their situation with respect to the sun. Some astronomers have undoubtedly made the mountains of the moon extravagantly high; they have been much reduced by modern calculators: Dr. *Herschel* has thought he discovered volcanoes on her disc. And it is supposed she has an atmosphere, because the limb of the sun has been observed to tremble just before the beginning of a solar eclipse, and because the planets become oval at the beginning of an occultation behind the moon.

Mercury being always near the sun, nothing more is distinguished by the telescope, than a variation of his figure, which is sometimes that of a half moon, sometimes a little more or less than half.

Venus, when in the form of a crescent, and at her brightest times, affords a very pleasing telescopic view; her surface being diversified with spots, like the moon. The diurnal motion of this planet, both as to its period and direction, has not hitherto been decidedly ascertained. Dr. *Herschel* concludes from his observations, that its atmosphere is very considerable. He has not been able to find the least trace of mountains, and ridicules those observers who have seen such as exceed four, five or even six times the height of Chimboraco, the highest of our mountains.

Mars always appears round except at the quadra-

tures, when its disc is like that of the moon about three days after the full. Its atmosphere is from the ruddiness of the planet supposed to be very dense : spots are discoverd on his surface, but they do not appear fixed. Dr. *Herschel* has observed two white luminous circles surrounding the poles of this planet, which he supposes to arise from the snow lying about those parts.

The surface of *Jupiter* is distinguished by certain bands or belts, of a duskier colour than the rest of his surface, running parellel to each other and to the plane of his orbit. They are neither regular nor constant in their appearance; sometimes more, sometimes fewer being perceived : their breadth varies, and sometimes one or more spots are formed between the belts.

Saturn's distance does not permit us with common instruments to distinguish many varieties on his surface, but his ring is a fruitful source for astronomical speculation. Dr. *Herschel*, by means of his powerful instruments, has discovered a multiplicity of regular belts, which did not change much during the course of his observations. From these he has found, that Saturn has a pretty quick rotation upon its axis, which he has fixed at 10 h. 16 m. 0 sec. He has also shewn, that the ring of Saturn is divisible into two concentric rings of unequal dimensions and breadth, situated in one plane, which is probably not much inclined to the equator of the planet. These rings are at a considerable distance from each other, the smallest being much less in diameter at the

outside than the largest is at the inside : the two rings are entirely detached from each other, so as plainly to permit the open heavens to be seen through the vacancy between them.

Though much has been unfolded to you in the course of this essay, upon a little consideration, you will find the things, of which you remain ignorant, infinitely exceed those which you know. It is with us as with a child, that thinks if he could but just come to such a field, or climb to the top of such a hill, he should be able to touch the sky; but no sooner is he come thither, than he finds it as far off as it was before.

It may perhaps be useful to point out to you the littleness of human knowledge, even in those subjects of which we have been treating; and this I shall do principally in the words of a late writer.

How far does the universe extend, and where are the limits thereof? Where did the CREATOR "stay his rapid wheels?" where "fix the golden compasses?" Certainly HIMSELF alone is without bounds, but all HIS works are finite. HE must therefore have said, at some point of space,

———— " Be these thy bounds;
" This be thy just circumference, O world!"

Here the Mathematician must be silent, and wave all calculations, as there can be no ratio between bounded and boundless space, even though the

magnitude of the former were taken at the utmost limit man can conceive, or numbers express. But where are the boundaries? Who can tell? All beyond the fixed stars are utterly hid from the children of men.

But what do we know of the fixed stars? A great deal, one would imagine; since, like the MOST HIGH, we too *tell* their *numbers*; yea, and *call them by their names!* But what are those that are named, in comparison with those which our glasses discover? What are two or three thousand, to those we discover in the milky way alone? How many then are there in the whole expanse? But to what end do they serve? To illuminate worlds, and impart light and heat to their several choirs of planets? or to gild the extremities of the solar sphere, and minister to the perpetual circulation of light and spirit?

What are comets? Planets not full formed, or planets destroyed by conflagration? or bodies of an wholly different nature, of which we can form no idea? How easy it is to form a thousand conjectures! how hard to determine any thing concerning them! Can their huge revolutions be even tolerably accounted for on the principles of gravitation and projection? What brings them back, when they have travelled so immensely far? or what whirls them on, when, reasoning justly on the same powers, they should drop into the solar fire?

What is the sun itself? It is undoubtedly the most glorious of all the inanimate creatures; and

its use we know. GOD made it to *rule the day.*
It is

"Of this great world both eye and soul."

But who knows of what substance it is composed, or
even whether it be solid or fluid ? What are the spots
on its surface ? what its real magnitude ? Here is an
unbounded field for conjecture ; but what foundation
for real knowledge ?

What do we know of the feebly-shining bodies,
the planets, that move regularly round the sun ?
Their revolutions we are acquainted with ; but who
can regularly demonstrate to us either their magnitude
or their distance, unless he assumes it in the usual
way, inferring their magnitude from their distance,
and the distance from the magnitude. What are
Jupiter's belts ? What is Saturn's ring ? The
honest ploughman knows as well as the most learned
astronomer.

" Sir *Isaac Newton* certainly discovered more of the
dependencies, connexions, and relations of the great
system of the universe, than had, previous to his
time, been conceded to human penetration : yet was
he forced to bottom all his reasoning on the hypo-
thesis of gravitation ; of which he could give no other
account, than that it was necessary to the conclu-
sions he rested upon it."

OF THE PRECESSION OF THE EQUINOXES.

The equinoctial points, as have been before explained, are those two opposite points, where the ecliptic aud equinoctial cross each other, at the first point of Aries and Libra, and are called the *vernal* and *autumnal* equinoxes. By long, and a continual series of observations, it has been observed, that the above two points have a westerly recession, or motion backwards, contrary to the order of the signs of about 50½ seconds, yearly. This retrograde motion of the equinoctial points, or the nodes of the earth's orbit, as it has been termed, is called the *Precession of the Equinoxes.*

The *solstitial points*, are these two opposite points where the ecliptic touches the tropics, and 90° from the equinoctial points, are consequently subject to the same recession.

To have a clear idea of this subject, the student must be informed, that astronomers begin the year in the spring, when the sun is in that node of the equator or equinoctial point, called *Aries*, or at the vernal equinox ; and that the time the sun takes in his motion from any one equinoctial point, or tropic, round to the same again, is called the *Tropical* or *Natural Year* ; and called by some the *Mean Solar Year*. Its length, by observation, is found to be 365^d 5^h 48$'$ 49$''$.

The time the sun also, by observation, is found to take, in moving from any particular star to the the same star again, is called the *Siderial Year*; and is fixed at 365ᵈ 6ʰ 9′ 12″. The siderial year therefore exceeds the tropical year by 20 minutes 23 seconds in time, and consequently the Julian, or Civil Year, which we adopt at 365 days 6 hours, is nearly a mean between the siderial and tropical.

The whole ecliptic of 360° being passed through by the sun in a tropical year, his daily mean motion is about 59′ 8″, and for the above difference 20′ 23″ in time, his motion will be very near 50¼″, and just so much of a degree sooner will he arrive at the same equinox or solstice than at any star, or fixed point on the heavens, in one annual revolution ; so in respect to the fixeds stars, will cause the equinoctial points, as well as itself, to recede about 30 degrees in 2160 years, and in the whole circle of the equinoctial in about 25920 years. This period has been called the Grand Platonic Year.

The receding of the equinoctial points has thus occasioned an apparent advance of the fixed stars in longitude of about 50″ per year, and from whence it follows, that since the time of Ptolemy in the infant state of astronomy, the zodical figures or constellations have moved forward about one whole sign, and as shewn upon our *New British Celestial Globes*, the constellation of Aries situate in that part of the ecliptic, named Taurus. Taurus in the situation of Gemini, &c. Hence the stars that

rise and set at particular seasons of the year in the times of *Hesiod, Eudoxus, Virgil, Pliny,* &c. at the present period will have a manifest difference in respect to time. It is to the attractive influence of the sun and moon on the redundant matter in the equatorial regions of the earth, that Sir *Isaac Newton* and other astronomers have asserted to occasion this peculiar slow motion. From the earth's motion on its axis, much more matter is accumulated about the equator, than at any other parts of the globe, and the power of the sun and moon's attraction is judged to bring the equator quicker under them, than if there were no such accumulation of matter.

The phenomena of the precession, may be more familiarly understood, by the student placing before him a celestial globe: he must bring the pole of the ecliptic to the brazen meridian, and consider both the ecliptic and its axis to be immoveable, and the earth's axis, or poles of the equinoctial to be in motion round the earth's centre, which he may conceive will form a double cone round the axis of the ecliptic, in the time the equinoctial points circumscribe the ecliptic, which is about 25,920 years, and in that time the earth's axis will describe a circle in the heavens round the pole of the ecliptic, which is stationary on that circle, the earth's axis being inclined 23½ degrees to that of the ecliptic : the circle described by the north pole will be 47 degrees in diameter, twice that of the inclination of the earth's axis. Consequently that point in the heavens which is now the north pole, and very near to the polar

star, as it is called, which is in the tail of Ursa Minor, will be receded from by the earth's axis at the rate of about 1 degree in 72 years. And in 12,960 years will be directed to some other star in the heavens, diametrically opposite in the circle, on the other side of the pole of the ecliptic ; and the north pole of the heavens will then be in a situation $8\frac{1}{2}$ degrees south of the zenith of London, which is at $51\frac{1}{2}$ North. The places also of the equator and two tropics will be very materially changed. And the sun in the same part of the heavens where he now covers the earthly tropics, and makes the shortest days and longest nights in the northern hemisphere; will then be over the earthly tropic of Cancer, and make the days longest and the nights shortest. In 25,920 years, the north pole will have moved quite round, and returned to its present position, and then the apparent motions and situation of the stars will begin to have the same changes over again.

The motion of the apsis of the earth's orbit occasions the difference between the periodical and siderial years : the periodical year is the time of the earth's revolution in its orbit, and is $365^d\ 6^h\ 15'\ 20''$, differing from the natural year or period of the seasons, $26'\ 21''$.

A distinction is made by astronomers between the precession of the equinoxial and solstitial points in the heavens, which only affect the apparent motions, places, and declination of the stars ; and the anticipation of the equinoxes of the earth, which regard the seasons, the latter is owing to a dif-

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ference between the civil and solar year, which is 11 minutes 3 seconds. This excess of the civil or Julian years above the solar, amounts to 11 days in 1,433 years; and consequently so much have our seasons gone back, with respect to the days of the month since the period of the Council of Nice, in A. D. 325, and therefore in order to restore all the fasts and festivals to the days then settled, it was requisite to suppress 11 nominal days, and that the same seasons in future, might be returned to the same times of the year, to leave out the bisextile day in February at the end of every century of years not divisible by 4, reckoning them only common years, as the 17th, 18th, and 19th centuries, or the years 1700, 1800, 1900, and because a day intercolated every 4th year, was too much, and retaining the bisextile day at the end of these centuries of years, which are divisible by 4, as the 16th, 20th, and 24th centuries, viz. 1600, 2000, 2400, &c. otherwise in length of time the seasons would be quite reversed with regard to the months of the year, in the course of about 23,783 years.

OF THE NUTATION OF THE EARTH'S AXIS.

It is to the late Dr. *Bradley* that we owe the firs observations of the libratory variation of the incli nation of the equator to the ecliptic, and which i termed the *nutation of the earth's axis*. Sir *Isaa Newton*'s theory of attraction had for some time be

fore given grounds for the existence of such a pro-
perty. Its whole effect is said scarcely to exceed 19
seconds.

OF ASTRONOMICAL ABERRATION.

Aberration in astronomy, is the apparent change
of place in the fixed stars, arising from the motion
of the earth, combined with the motion of light.
It is a discovery by the late Dr. *Bradley*, who with
an astronomical instrument called a *Zenith Sector*,
made a number of observations for three years upon
the same stars, and found that their apparent places
differed from their true places about 20 seconds :
and hence proving that the velocity of light is about
10,000 times greater than the earth's velocity in its
orbit. The velocity of the earth is computed at
58,000 an hour ; and therefore light is propagated
from the sun to the earth in 8 minutes and about 10
seconds of times, a distance of 95 millions of miles,
or the distance of the earth at a mean from the sun.
The velocity of light is thus proved to be uniform,
whether originally from the stars, or reflected from
the satellites of Jupiter, as precisely deduced by ob-
servations previously made on these satellites by
Roemer.

OF THE TIDES.

The rising and falling alternately twice in a day
of the waters upon the earth, is one of the most

remarkable of natural phenomena. To the vast penetration of Sir *Isaac Newton*, we are here also beholden for the demonstrations of the moon's action upon this globe, and the manner this admirable effect is produced. The tides are considered as affording a very obvious instance of the mutual gravitations of the celestial bodies to each other.

The attractions of the sun and moon upon the fluid parts of the earth are now considered as the only agents of the tides, and from repeated observations the times of ebbing and flowing are found to be comparable to the periodical revolutions of the moon, particularly, and proportionate to them.

From the greater distance that the sun is from the earth, his attractive power in raising the water must be very considerably less than the power of the moon. In general, the sun counteracts the effects of the moon more than it assists in augmenting the flux and reflux of the sea.

In the course of 24 hours, 48 minutes, the sea is observed to ebb and flow twice: the time of rising being about 6 hours, and the time of falling the same.

From the motion of the moon in her orbit, the lunar day exceeds the solar day, the former being about 24 hours 48 minutes, and the latter 24 hours: hence, the effect of the sun and moon on the tides are not the same every day. The influence of the sun and moon on the equatoreal parts of the earth is greater than towards the poles, from the attractive powers acting less obliquely at the equator than

the poles ; and also the accumulated matter about the equator. The time of high water is about 48 minutes later every day, on account of the moon being about that time in her arrival later daily at the meridian of that place, it being high water at the time that the moon is nearly in the meridian of the place, and the sea having flowed to its highest state, and it is low water at the interval of time, 6 hours before or after this period, when the moon is in or near to either the east or west points of the horizon. Or when at high water at any place, on the meridian of 90 degrees east or west of that place on the earth is low water. But a remarkable circumstance is, that when it is high water at any place, it is also high water at the place where meridian is diametrically opposite, the cause of which is derived from another principle different from the moon's attractions in the other case, and which shall be explained hereafter.

The power of the sun is sufficient to raise the waters, somewhat when on our meridian, and an effect oppositely also then takes place. When it acts in conjunction with the moon, it produces a more powerful effect on the waters, and it is then called *Spring Tides* : when it acts in a direct perpendicular to the moon, it tends to diminish her power, and produce a diminished tide, called *Neap Tides* : hence at the time of new and full moon there must be high tides, and low tides at the two quarters, first and third of the moon. When the sun and moon

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are in the *Syzgies*, or in opposition and conjunction at the time of the equinoxes, there is the highest tides of any, on account of the sun being then in the equator, and the moon in the same situation or very near to it.

The action of the sun is judged to raise the waters of our seas about two feet, and the moon about nine feet; therefore in joint action the elevation will be about eleven feet at the spring tides, and when acting at right angles, be as the other at neap tides, about 7 feet the difference between the two.

The earth and the moon, according to the laws of gravitation and motion, move round their centre of gravity, which centre is as much nearer to the earth than the moon, as the earth is in bulk matter greater than the moon. The earth is judged to contain 40 times as much matter as the moon, therefore, the centre of gravity is 40 times nearer the earth than the moon.

Any body moving with a velocity round one centre acquire a forcible tendency to go off from that centre, which is called the *centrifugal force*, and the attraction or power that keeps it towards the centre is called the *centripetal* force. As an exemplification, let a person whirl round a ball at the end of a string a yard or two long, with his hand, he will be sensible, if he let the cord go, that the ball, or a planetary body, would fly off from the actions of the centrifugal force; but if he held it firm the power of his hand resembling the attractive or centripetal

force, would keep the body circulating in its orbit. It is to this cause that philosophers now attribute the rise of the tides at the opposite parts of the earth to where the moon may be at the same time ; for that part of the earth which is opposite to the moon exacts a greater centrifugal force from its centre, than that which is nearest to the centre of gravity, or facing that and the moon ; and therefore, as that part rises by the centrifugal force, and those opposite the moon by the centripetal force, or moon's attraction as before mentioned.

The time of high water, at any place, is not when the moon is in the meridian, but is generally about three hours afterwards ; the cause given for which is as follows : The moon, when in the meridian, or nearest the zenith of any place, tends to raise the waters at that place ; and this force must evidently be exerted for some time, before the greatest elevation will take place ; for were the moon's attraction to cease altogether, when she has passed the meridian, yet the motions already communicated to the waters, would cause them to ascend for some time afterwards, and therefore they must be much more disposed to ascend when the attractive force is only in a small measure diminutive.

Thus much may suffice to give the young student a general idea of the nature and rationale of the tides. They are subject to much deviation from the general rule given, on account of the various disproportions of the parts of the earth and other local

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circumstances. To have a fuller and more comprehensive view of the subject, the reader must consult other larger and modern treatises on astronomy and navigation, where complete tables and demonstrations are given.

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ESSAY II.

PART I.

A TREATISE

ON THE USE OF THE

TERRESTRIAL AND CELESTIAL GLOBES.

OF THE ADVANTAGES OF GLOBES IN GENERAL, FOR ILLUSTRATING THE PRIMARY PRINCIPLES OF ASTRONOMY AND GEOGRAPHY; AND PARTICULARLY OF THE ADVANTAGES OF THE GLOBES, WHEN MOUNTED IN MY FATHER's MANNER.

Universal approbation, the opinion of those that excel in science, and the experience of those that are learning, all concur to prove that the artificial representations of the earth and heavens, on the terrestrial and celestial globes, are the instruments the best adapted to convey natural and genuine ideas of astronomy and geography to young minds.

This superiority they derive principally from their form and figure, which communicates a more just idea, and gives a more adequate representation of the earth and heavens, than can be formed from any other figure.

To understand the nature of the projection of either sphere in plano, requires more knowledge of geometry than is generally possessed by beginners, its principles are more recluse, and the solution of problems more obscure.*

The motion of the earth upon its axis is one of the most important principles both in geography and astronomy ; on it the greater part of the phenomena of the visible world depends : but there is no invention that can communicate so natural a representation of this motion, as that of a terrestrial globe about its axis. By a celestial globe, the apparent motion of the heavens is always represented in a natural and satisfactory manner.

In order to convey a clear idea of the various divisions of the earth, of the situation of different places, and to obtain an easy solution of the various problems in geography, it is necessary to conceive many imaginary circles delineated on its surface, and to understand their relation to each other. Now, on a globe these circles have their true form ; their intersections and relative positions are visible upon the most cursory inspection. But in projections of

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* See *Keith's* Introduction to Plane and Spherical Trigonometry, 8vo. 1801. EDIT.

the sphere in plano, the form of these circles is varied, and their nature changed; they are consequently but ill adapted to convey to young minds the elementary principles of geography.

On a globe, the appearance of the land and water is perfectly natural and continuous, fitted to convey accurate ideas, and leave permanent impressions on the most tender minds; whereas in planispheres one-half of the globe is separated and disjoined from the other; and those parts, which are contiguous on a globe, are here separated and thrown at a distance from each other. The celestial globe has the same superiority over projections of the heavens in plano.

The globe exhibits every thing in true proportion, both of figure and size; while on a planisphere the reverse may often be observed.

Presuming that these reasons sufficiently evince the great advantage of globes over either planispheres or maps, for obtaining the first principles of astronomical and geographical knowledge, I proceed to point out the pre-eminence of globes mounted in my father's manner, over the common, or rather the old and Ptolemaic mode of fitting them up.

The great and increasing sale of his globes mounted in the best manner may be looked upon at least as a proof of approbation from numbers; to this I might also add, the encouragement they have received from the principal tutors of both our universities, the public sanction of the university of Leyden, the many editions of my father's treatise on their use,

and its translation into Dutch, &c. The recommendation of Messrs. *Arden*, *Walker*, *Burton*, &c. public lecturers in natural philosophy, might also be adduced: but leaving these considerations, I shall proceed to enumerate the reasons which give them, in my opinion a decided preference over every other kind of mounting.*

* The following note from Mr. *Walker*'s Easy Introduction to Geography, in favour of my father's globes, will not, I hope, be deemed improper.

" Simplicity and perspicuity should ever be studied by those who cultivate the young mind; and jarring, opposing, or equivocal ideas should be avoided almost as much as error or falsehood. Our globes, till of late years were equipt with an hour circle, which prevented the poles from sliding through the horizon; hence their rectification was generally for the *place on the earth*, instead of the *sun's place in the ecliptic*; which put the globe into so unnatural and absurd a position respecting the sun, that young people were confounded when they compared it with the earth's positions during its annual rotation round that luminary, and considering the horizon as the boundary of day and night, Being, therefore, sometimes obliged to rectify for the place on the earth, and sometimes for the sun's place in the ecliptic, the two rules clash so unhappily in the pupil's mind, that few remember a single problem a twelvemonth after the end of their tuition. Globes, therefore, with the horary circle, are but partially described in this treatise; the great intention of which is, to make the elevations and depressions of the poles of a terrestrial globe to represent *all* the situations the earth is in to the sun, for every day or hour through the year. The globes of Mr. *Adams* are the most favourable for the above mode of rectification of any plates we have at present; and to make a quiescent globe to represent all the positions of one revolving round the sun, turning on an inclined axis, and keeping that axis altogether parallel to itself, his globes are better adapted than any, I believe, in being."

The earth, by its diurnal revolution on its axis, is carried round from west to east. To represent this real motion of the earth, and to solve problems agreeably thereto, it is necessary that the globe, in the solution of every problem, should be moved from west to east ; and for this purpose, that the divisions on the large brass circle should be on that side which looks westward. Now this is the case in my father's mode of mounting the globes, and the tutor can thereby explain with ease the rationale of any problem to his pupil. But in the common mode of mounting, the globe must be moved from east to west, according to the Ptolemaic system ; and consequently, if the tutor endeavours to shew how things obtain in nature, he must make his pupil unlearn in a degree what he has taught him, and by abstraction reverse the method he has instructed him to use; a practice that we hope will not be adopted by many.

The celestial globe being intended to represent the apparent motions of the heavens, should be moved, when used, from east to west.

Of the phenomena to be explained by the terrestrial globe, the most material are those which relate to the changes in the seasons ; all the problems connected with, or depending upon these phenomena, are explained in a clear, familiar, and natural manner, by the globe, when mounted in my father's mode ; for on rectifying it for any particular day of the month, it immediately exhibits to the pupil the

exact situation of the globe of the earth for that day; and while he is solving his problem, the reason and foundation of it presents itself to the eye and understanding.

The globe may also be placed with ease in the position of a right sphere ; a circumstance exceedingly useful, and which the old construction of the globes did not admit of.

By the application of a moveable meridian, and an artificial horizon connected with it, it is easy to explain why the sun, although he be always in one and the same place, appears to the inhabitants of the earth at different altitudes, and in different azimuths, which cannot be so readily done with the common globes.

On the celestial globe there is a moveable circle of declination, with an artificial sun.

The brass wires placed under the globes, serve to distinguish, in a natural and satisfactory manner, twilight from total darkness, and the reason of the length of its duration.

The next point, wherein they materially differ from other globes, is in the hour circle. Now it must be confessed, that to every contrivance that has been used for this purpose there is some objection, and probably no mode can be hit upon that will be perfectly free from them. The method adopted by my father appears to me the least exceptionable, and to possess some advantages over every other method I am acquainted with. Agreeable

to the opinion of the first astronomers, among others of M. *de la Lande,* he uses the equator for the hour circle, not only as the largest, but also as the most natural circle that could be employed for that purpose, and by which alone the solution of problems could be obtained with the greatest accuracy. As on the terrestrial globe, the longitude of different places is reckoned on this circle; and on the celestial, the right ascension of the stars, &c. it familiarizes the young pupil with them, and their reduction to time. This method does not in the least impede the motion of the globe; but while it affords an equal facility of elevating either the north or south pole, it prevents the pupil from placing them in a wrong position; while the horary wire secures the globe from falling out of the frame.

Another circumstance peculiar to these globes, is the mode of fixing the compass. It is self-evident, that the tutor, who is willing to give correct ideas to his pupil, should always make him keep the globes with the north pole directed towards the north pole of the heavens, and that, both in the solution of problems, and the explanation of phenomena. By means of the compass, the terrestrial globe is made to supply the purpose of a tellurian, when such an instrument is not at hand. I cannot terminate this paragraph, without testifying my disapprobation of a mode adopted by some, of making the globe turn round upon a pin in the pillar on which it is supported; a mode, that, while it can give little

relief to indolence, is less firm in its construction, and tends to introduce much confusion in the mind of the pupil.

In order to prevent that confusion and perplexity which necessarily arises in a young mind, when names are made use of which do not properly characterize the subject, my father found it necessary, with Mr. *Hutchins*, to term that broad wooden circle which supports the globe, and on which the signs of the ecliptic and the days of the month are engraved, the *broad paper circle*, instead of horizon, by which it had been heretofore denominated. The propriety of this change will be evident to all those who consider, that this circle in some cases represents that which divides light from darkness, in others, the horizon, and sometimes the ecliptic. For similar reasons, he was induced to call the brazen circle, in which the globes are suspended, the *strong brass circle*.

In a word, many operations may be performed by these globes, which cannot be solved by those mounted in the common manner; while all that they can solve may be performed by these, and that with a greater degree of perspicuity; and many problems may be performed by these at one view, which on the other globes require successive operations.

But as, notwithstanding their superiority, the difference in price may make some persons prefer the old construction, it may be proper to inform them,

that they may have my *father*'s globes mounted in the *old manner*, at the usual prices.*

* Our late author's recommendation and arguments herein given, in favour of his father's globes, cannot now be fully admitted. There always have been some few inconveniences attending his mode of mounting, which is unnecessary to point out here. Globes being machines of illustration and exemplification only, and not designed for accurate calculation, I have always adopted and advised that mode of construction, which is the most simple and perspicuous to the beginner, in the solving of the problems; I therefore think it very proper to acquaint the reader, that there were lately completed, new sets of plates for 18 and 12-inch globes, under the title of the NEW BRITISH GLOBES. It is now more than 40 years since the plates for the 17-inch of *Senex*'s and the 18-inch of *Adams*'s were engraved, and the important discoveries both geographical and astronomical that have recently been made, have afforded the opportunity of contributing to render the above new globes the most complete of any extant. On the terrestrial are inserted all the latest communications and places, from authentic observations, and engraved from a drawing by Mr. *Arrowsmith*; and on the celestial are placed near 6000 stars, clusters, planetary nebulæ, &c. from the latest observations of Dr. *Maskelyne*, Dr. *Herschel*, &c. as computed by me for the year 1801, so that these globes may be considered as properly adapted for the present century, and to supercede all former globes. For further particulars, I must refer the reader to a Treatise on their uses, with a great variety of problems and examples, that I have compiled, and am now superintending at the press. EDIT.

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ESSAY II.

PART II.

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CONTAINING

A DESCRIPTION OF THE GLOBES

MOUNTED IN THE BEST MANNER;

TOGETHER WITH SOME PRELIMINARY DEFINITIONS.

DEFINITIONS.

BEFORE we begin to describe the globes, it will be proper to take some notice of the properties of a circle, of which a globe may be said to be constituted.

A *line* is generated by the motion of a point.

Let there be supposed two points, the one moveable, the other fixed.

If the moveable point be made to move directly towards the fixed point, it will generate in its motion a straight line.

If a moveable point be carried round a fixed point, keeping always the same distance from it, it will generate a *circle*, or some part of a circle, and the fixed point will be the *centre* of that circle.

All straight lines going from the centre of the circumference of a circle, are equal.

Every straight line that passes through the centre of a globe, and is terminated at both ends by its surface, is called a *diameter*.

The extremities of a diameter are its poles.

If the circumference of a semicircle be turned round its diameter, as on an axis, it will generate a globe, or sphere.

The centre of the semicircle will be the centre of the globe; and as all points of the generating semicircle are at an equal distance from its centre, so all the points of the surface of the generated sphere are at an equal distance from its centre.

DESCRIPTION OF THE GLOBES.

There are two artificial globes. On the surface of one of them the heavens are delineated; this is called the *celestial globe*. The other, on which the surface of the earth is described, is called the *terrestrial globe*.

Fig. 2, plate XVI, represents the celestial, fig. 1, plate XVI, the terrestrial globe, as mounted in my father's manner.

In using the celestial globe, we are to consider ourselves as at the *centre*.

In using the terrestrial globe, we are to suppose ourselves on some point of its *surface*.

The motion of the terrestrial globe represents the *real* motion of the earth.

The motion of the celestial globe represents the *apparent* motion of the heavens.

The motion, therefore, of the celestial globe, is a motion from *east to west*.

But the motion of the terrestrial globe is a motion from *west to east*.

On the surface of each globe several circles are described, to every one of which may be applied what has been said of circles in page 194.

The centre of some of these circles is the same with the centre of the globe; these are, by way of distinction, called *great circles*.

Of these great circles, some are graduated.

The graduated circles are divided into 360°, or equal parts, 90 of which make a quarter of a circle, or a quadrant.

Those circles, whose centres do not pass through the centre of the globe, are called *lesser circles*.

The globes are each of them suspended at the poles in a strong brass circle NZ ÆS, and turn therein upon two iron pins, which are the axis of the globe; they have each a thin brass semicircle N H S, moveable about these poles, with a small thin circle H sliding thereon : it is quadrated each way to 90° from the equator to either pole.

On the terrestrial globe this semicircle is a *moveable meridian*. Its small sliding circle, which is divided into a few of the points of the mariner's compass, is called a *terrestrial* or *visible horizon*.

On the celestial globe this semicircle is a *moveable circle of declination*, and its small brass circle an artificial sun, or planet.

Each globe has a brass wire circle, T W Y, placed

at the limits of the crepusculum, or twilight, which, together with the globe, is mounted in a wooden frame. The upper part, B C, is covered with a broad paper circle, whose plane divides the globe into two hemispheres; and the whole is supported by a neat pillar and claw, with a magnetic needle in a compass-box, marked M, to set the axes of the globes duly north and south.

A DESCRIPTION OF THE CIRCLES DESCRIBED ON THE BROAD PAPER CIRCLE B C; TOGETHER WITH A GENERAL ACCOUNT OF ITS USES.

It contains four concentric circular spaces, the innermost of which is divided into 360°, and numbered into four quadrants, beginning at the east and west points, and proceeding each way to 90°, at the north and south points: these are the four cardinal points of the horizon. The second circular space contains, at equal distances, the thirty-two points of the mariner's compass. Another circular space is divided into twelve equal parts, representing the twelve signs of the zodiac; these are again subdivided into 30 degrees each, between which are engraved their names and characters. This space is connected with a fourth, which contains the calendar of the months and days; each day, on the eighteen-inch globes being divided into four parts, expressing the four cardinal points of the day, according to the Julian reckoning; by which means the

sun's place is very nearly obtained for the common years after bissextile, and the intercalary day is inserted without confusion.

In all positions of the celestial globe, this broad paper circle represents the plane of the horizon, and distinguishes the visible from the invisible part of the heavens ; *but in the terrestrial globe, it is applied to three different uses.*

1. To distinguish the points of the horizon. In this case it represents the *rational* horizon of any place.

2. It is used to represent the circle of *illumination*, or that circle which separates day from night.

3. It occasionally represents the *ecliptic.*

Of the strong Brass Circle N Æ Z S. One side of this strong brass circle is graduated into four quadrants, each containing 90 degrees.

The numbers on two of these quadrants increase from the equator towards the poles ; the other two increase from the poles towards the equator.

Two of the quadrants are numbered from the equator, to show the distance of any point on the globe from the equator. The other two are numbered from the poles, for the more ready setting the globe to the latitude of any place.

The strong brass circle of the celestial globe is called the meridian, because the centre of the sun comes directly under it at noon.

But as there are other circles on the ter-

restrial globe, which are called meridians, we chuse to denominate this the *strong brass circle*, or *meridian*.

The graduated side of the strong brass circle, that belongs to the terrestrial globe, should face the *west*.

The graduated side of the strong brazen meridian of the celestial globe, should face the *east*.

On the strong brass circle of the terrestrial globe, and at about 23½ degrees on each side of the north pole, the days of each month are laid down according to the declination of the sun.

Of the Horary Circles, and their Indices. When the globes are mounted in my father's manner, we use the equator as the hour circle ; because it is not only the most natural, but also the largest circle that can be applied for that purpose.

To make this circle answer the purpose, a semi-circular wire is placed over it, carrying two indices, one on the east, the other on the west side of the the strong brass circle.

As the equator is divided into 360°, or 24 hours, the time of one entire revolution of the earth or heavens, the indices will shew in what space of time any part of such revolution is made among the hours which are graduated below the degrees of the equator on either globe.

As the motion of the terrestrial globe is from west to east, the horary numbers increase according to the direction of that motion : on the celestial globe they increase from the east to the west.

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Of the Quadrant of Altitude, Z A, *fig.* 1. This is a thin, narrow, flexible slip of brass, that will bend to the surface of the globe ; it has a nut, with a fiducial line upon it, which may be readily applied to the divisions on the strong brass meridian of either globe. One edge of the quadrant is divided into 90 degrees, and the divisions are continued to 18 degrees below the horizon,

OF SOME OF THE CIRCLES THAT ARE DESCRIBED UPON THE SURFACE OF EACH GLOBE.

We may suppose as many circles to be described on the surface of the earth as we please, and conceive them to be extended to the sphere of the heavens, marking thereon concentric circles : for as we are obliged, in order to distinguish one place from another, to appropriate names to them, so are we obliged to use different circles on the globes, to distinguish the parts, and their several relations to each other.

Of the Equator, or Equinoctial. This circle goes round the globe exactly in the middle, between the two poles, from which it always keeps at the same distance ; or in other words, it is every where 90 degrees distant from each pole, and is therefore a boundary, separating the northern from the southern hemisphere ; hence it is frequently called *the line* by sailors, and when they sail over it they are said to cross the line.

It is that circle in the heavens in which the sun appears to move on those two days, the one in the spring, the other in the autumn, when the days and nights are of an equal length all over the world ; and hence on the celestial globe it is generally called the *equinoctial*.

It is graduated into 360 degrees. Upon the terrestrial globe the numbers increase from the meridian of London westward, and proceed quite round to 360. They are also numbered from the same meridian eastward, by an upper row of figures, to accommodate those who use the English tables of latitude and longitude.

On the celestial globe, the equatorial degrees are numbered from the first point of Aries eastward, to 360 degrees.

Under the degrees on either globe is graduated a circle of hours and minutes. On the celestial globe the hours increase eastward, from Aries to XII at Libra, where they begin again in the same direction, and proceed to XII at Aries. But on the terrestrial globe, the horary numbers increase by twice twelve hours westward from the meridian of London to the same again.

In turning the globe about, the equator keeps always under one point of the strong brass meridian, from which point the degrees on the said circle are numbered both ways.

Of the Ecliptic. The graduated circle which crosses the equator obliquely, forming with it an angle of about 23½ degrees, is called the ecliptic.

This circle is divided into twelve equal parts, each of which contains thirty degrees. The beginning of each of these thirty degrees is marked with the characters of the twelve signs of the zodiac.

The sun appears always in this circle; he advances therein every day nearly a degree, and goes through it exactly in a year.

The points where this circle crosses the equator are called the *equinoctial points*. The one is at the beginning of Aries, the other at the beginning of Libra.

The commencement of Cancer and Capricorn are called, the *solstitial points*.

The twelve signs, and their degrees, are laid down on the terrestrial globe; but upon the celestial globe, the days of each month are graduated just under the ecliptic.

The ecliptic belongs principally to the celestial globe.

The time or motions in degrees pointed out on the equator, by means of the semicircular wires Æ O, with two points O, that are to be occasionally slid on these two wires, at the minute of the hour, or the degree given.

ESSAY II.

PART III.

THE USE OF THE

TERRESTRIAL GLOBE

MOUNTED IN THE BEST MANNER.

OF LONGITUDE AND LATITUDE, OF TERRESTRIAL
MERIDIANS, AND THE PROBLEMS RELATING TO
LONGITUDE AND LATITUDE.

MERIDIANS are circular lines, going over the
earth's surface, from one pole to the other, and
crossing the equator at right angles.

Whatever places these circular lines pass through,
in going from pole to pole, they are the meridians of
those places.

There are no places upon the surface of the
earth, through which meridians may not be con-
ceived to pass. Every place, therefore, is supposed
to have a meridian line passing over its zenith from
north to south, and going through the poles of the
world.

Thus the meridian of Paris is one meridian ; the
meridian of London is another. This variety of

meridians is satisfactorily represented on the globe, by the moveable meridian, which may be set to every individual point of the equator, and put directly over any particular place.

Whensoever we move towards the east or west, we change our meridian ; but we do not change our meridian if we move directly to the north or south.

The moveable meridian shews that the poles of the earth divide every meridian into two semicircles, one of which passes through the place whose meridian it is, the other through a point on the earth, opposite to that place.

Hence it is, that writers in geography and astronomy generally mean by the *meridian* of any place the *semicircle* which passes through that place ; these, therefore, may be called the geographical meridians.

All places lying under the same semicircle are said to have the same meridian ; and the semicircle opposite to it is called the opposite meridian, or sometimes the opposite part of the meridian.

From the foregoing definitions, it is clear that the meridian of any place is immoveably fixed to that place, and is carried round along with it by the rotation of the globe.

When the meridian of any place is by the revolution of the earth brought to point at the sun, it is noon, or mid-day, at that place.

The plane of the meridian of any place may be imagined to be extended to the sphere of the fixed stars.

When, by the motion of the earth, the plane of a meridian comes to any point in the heavens, as the sun, moon, &c. that point, &c. is then said to come to the meridian. It is in this sense that we generally use the expression of the sun or stars coming to, or passing over the meridian.

The time which elapses between the noon of any one day in a given place, and the noon of the day following in the same place, is called a *natural day*.

All places which lie under the same meridian, have their noon, and every other hour of the natural day, at the same time. Thus when it is one in the afternoon at London, it is also one in the afternoon to every place under the meridian of London.

In order to ascertain the situation of any point, there must first be a settled part of the earth's surface, from which to measure ; and as the point to be ascertained may lie in any part of the earth's surface, and as this surface is spherical, the place from whence we measure must be a circle. It would be necessary, however to establish two such circles ; one to know how far any place may be east or west of another, the second to know its distance north or south of the given point, and thus determine its precise situation.

Hence it has been customary for geographers to fix upon the meridian of some remarkable place, *as a first meridian, or standard* ; and to reckon the distance of any place to the east or west, or its longitude,

by its distance from the first meridian. On English globes, this first meridian is made to pass through London. The position of this first meridian is arbitrary, because on a globe, properly speaking, there is neither beginning nor end. The first person (whose works at least are come down to us) who computed the distance of places by longitudes and latitudes was Ptolemy, about the year after Christ 140.

The *longitude of any place* is its distance from the first meridian, measured by degrees on the equator.

To find the longitude of a place, is to find what degree on the equator the meridian of that place crosses.

All places that lie under the same meridian are said to have the same longitude; all places that lie under different meridians, are said to have different longitudes; this difference may be east or west, and consequently the difference of longitude between any two places, is the distance of their meridians from each other measured on the equator.

Thus if the meridian of any place cuts the equator in a point, which is fifteen degrees east from that point, where the meridian of London cuts the equator, that place is said to differ from London in longitudes 15 degrees eastward.

Upon the terrestrial globe there are 24 meridians, dividing the equator into 24 equal parts, which are the hour circles of the places through which they pass.

The distance of these meridians from each other is 15 degrees, or the 24th part of 360 degrees; thus 15 degrees is equal to one hour.

By the rotation of the earth, the plane of every meridian points at the sun, one hour after that meridian which is next to it eastward; and thus they successively point at the sun every hour, so that the planes of the 24 meridian semicircles being extended, pass through the sun in a natural day.

To illustrate this, suppose the plane of the strong brass meridian to coincide with the sun, bring London to this meridian, and then move the globe round, and you will find these 24 meridians successively pass under the strong brass meridian, at one hour's distance from each other; till in 24 hours the earth will return to the same situation, and the meridian of London will again coincide with the strong brass circle.

By passing the globe round, as in the foregoing article, it will be evident to the pupil, that if one of these meridians, 15 degrees east of London, comes to the strong brass meridian, or points at the sun one hour sooner than the meridian of London, a meridian that is 30 degrees east comes two hours sooner, and so on; and consequently they will have noon, and every other hour, so much sooner than at London : while those, whose meridian is 15 degrees westward from London, will have noon and every other hour of the day, one hour later than at London, and so on in proportion to the difference of longitude. These definitions being well under-

stood, the pupil will be prepared not only to solve, but see the rationale of the following problems.

PROBLEM I. *To find the longitude of any place on the globe.*

The reader will find no difficulty in solving this problem, if he recollects the definition we have given of the word longitude, namely, that it is the distance of any place from the first meridian measured on the equator. Therefore, either set the moveable meridian to the place, or bring the place under the strong brass meridian, and that degree of the equator, which is cut by either of the brazen meridians, is the longitude in degrees and minutes, or the hour and minute of its longitude, expressed in time.

As the given place may lie either east or west of the first meridian, the longitude may be expressed accordingly.

It appears most natural to reckon the longitude always westward from the first meridian; but it is customary to reckon one half round the globe eastward, the other half westward from the first meridian. To accommodate those who may prefer either of these plans, there are two sets of numbers on our globes : the numbers nearest the equator increase westward, from the meridian of London quite round the globe to 360°, over which another set of numbers is engraved, which increase the contrary way ; so

that the longitude may be reckoned upon the equator, either east or west.

Example. Bring Boston, in New England, to the graduated edge of either the strong brass, or of the moveable meridian, and you will find its longitude in degrees to be 70½, or 4 h. 42 min. in time ; Rome 12½ degrees east, or 50 min. in time ; Charles-Town, North-America, is 79 deg. 50 min. west.

PROBLEM II. *To find the difference of longitude between any two places.*

If the pupil understands what is meant by the difference of longitude, the rule for the solution of this problem will naturally occur to his mind. Now the difference of longitude between any two places is the quantity of an angle (at the pole) made by the meridians of those places measured on the equator. To express this angle upon the globe, bring the moveable meridian to one of the places, and the other place under the strong brass circle, and the required angle is contained between these two meridians, the measure or quantity of which is to be counted on the equator.

Example. I find the longitude of Rome to be 12½ east, that of Constantinople to be 29 ; the difference is 17½ degrees. Again, I find Jerusalem has

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35 deg. 25 min. east longitude from London ; and Pekin in China, 116 deg. 52 min. east longitude ; the difference is 81 deg. 27 min. that is, Pekin is 81 deg. 27 min. east longitude from Jerusalem ; or Jerusalem is 81 deg. 27 min. west longitude from Pekin.

If one place is east and the other west of the first meridian, either find the longitude of both places westward, by that set of numbers which increase westward from the meridian of London to 360 deg. and the difference between the number thus found is the answer to the question : or, add the east and west longitudes, and the sum is the difference of longitude; thus the longitude of Rome is 12 deg. 30 min. east; of Charles Town, 79 deg. 50 min. west; their sum, 91 deg. 20 min. is the difference required.

It may be proper to observe here, that *the difference in time is the same with the difference of longitude*, consequently that some of the following problems are only particular cases of this problem, or readier modes of computing this difference.

PROBLEM III. *To find all those places where it is noon, at any given hour of the day, at any given place.*

General rule. Bring the given place to the brass meridian, and set the index to the uppermost XII ;

then turn the globe till the index points to the given hour, and it will be noon to all the places under the meridian.

As the diurnal motion of the earth is from west to east, it is plain that all places which are to the east of any meridian, must necessarily pass by the sun before a meridian which is to the west can arrive at it.

N. B. As in my father's globes, the XII, or first meridian, passes through London, you have only to bring the given hour to the east of London, if in the morning, to the brass meridian, and all those places which are under it will have noon at the given hour; but bring the given hour westward of London, if it be in the afternoon.

When it is 4 h. 50 min. in the afternoon at Paris, it is noon at New Britain, New England, St. Domingo, Terra Firma, Peru, Chili, and Terra del Fuego.

When it is 7 h. 50 min. in the morning at Ispahan, it is noon at the middle of Siberia, Chinese Tartary, China, Borneo.

PROBLEM IV. *When it is noon at any place, to find what hour of the day it is at any other place.*

Rule. Bring the place at which it is noon to the strong brass meridian, and set the hour index to the uppermost XII, and then turn the globe about till the other place comes under the strong brass

meridian, and the hour index will shew upon the equator the required hour. If to the eastward of the place where it is noon, the hour found will be in the afternoon ; if to the westward, it will be in the forenoon.

Thus, when it is noon at London, it is 50 min. past XII at Rome; 32 min. past VII in the evening at Canton, in China; 15 min. past VII in the morning at Quebec, in Canada.

PROBLEM V. *The hour being given at any place, to tell what hour it is in any other part of the world.*

Rule. Bring the place where the time is required under the strong brass meridian, set the hour index to the given time, then turn the globe, till the other place is under the brass meridian, and the horary index will point to the hour required.

Thus, suppose we are at London at IX o'clock in the morning, what is the time at Canton in China ? Answer, 31 min. past IV in the afternoon. When it is IX in the evening at London, it is about 15 minutes past IV in the afternoon at Quebec, in Canada.

Thus also, when it is III in the afternoon at London, it is 18 minutes past X in the forenoon at Boston. When it is VI in the morning at the Cape of Good Hope, it is 7 min. after midnight at Quebec.

OF LATITUDE.

I have already observed, that the equator divides the globe into two hemispheres, the northern and the southern.

The latitude of a place is its distance from the equator towards the north or south pole, measured by degrees upon the meridian of the place.

All places, therefore, that lie under the equator are said to have no latitude.

All other places upon the earth are said to be in north or south latitude, as they are situated on the north or south side of the equator; and the latitude of any place will be greater or less, according as it is further from, or nearer to the equator.

Lines which keep always at the same distance from each other are called *parallels*.

If a circle, or circular line, be conceived keeping at the same distance from the equator, it will be a parallel to the equator.

Circles of this kind are commonly drawn on the terrestrial globe, on both sides of the equator.

A circle of this kind, at 10 degrees from the equator, is called *a parallel of 10 degrees*.

When any such parallel passes through two places on the globe's surface, those two places have the same latitude.

Hence parallels to the equator are called *parallels of latitude*.

There are four principal lesser circles parallel to the equator, which divide the globe into five unequal parts, called *zones*.

The circle on the north side of the equator is called the *tropic of Cancer*; it just touches the north part of the ecliptic, and shews the path the sun appears to describe, the longest day in summer.

That which is on the south side of the equator is called the *tropic of Capricorn*; it just touches the south part of the ecliptic, and shews the path the sun appears to describe, the shortest day in winter.

The space between these two tropics, which contains about 47 degrees, was called by the ancients the *torrid zone*.

The two polar circles are placed at the same distance from the poles that the two tropics are from the equator.

One of these is called the *northern*, the other the *southern polar circle*.

These include $23\frac{1}{2}$ degrees on each side of their respective poles, and consequently contain 47 degrees equal to the number of degrees included between the tropics.

The space contained within the northern polar circle was, by the ancients, called the *north frigid zone*; and that within the southern polar circle, the *south frigid zone*.

The spaces between either polar circle, and its

nearest tropic, which contain about 43 degrees each, were called by the ancients the *two temperate zones.*

PROBLEM VI. *To find the latitude of any place.*

If the pupil comprehends the foregoing definition, he will find no difficulty in the solution of this and some of the following problems.

Rule. Bring the place to the graduated side of the strong brass meridian, and the degree which is over it is the latitude. Thus, London will be found to have 51 deg. 30 min. north latitude; Constanti-nople. 41 deg. north latitude; and the Cape of Good Hope, 34 deg. south latitude.

PROBLEM VII. *To find all those places which have the same latitude with any given place.*

Suppose the given place to be London; turn the globe round, and all those places which pass under the same point of the strong brass meridian, are in the same latitude.

PROBLEM VIII. *To find the difference of latitude between two places.*

Rule. If the places be in the same hemisphere, bring each of them to the meridian, and subtract the latitude of one from the other. If they are indiffe-

rent hemispheres, add the latitude of one to that of the other.

Example. The latitude of London is 51 deg. 32 min. that of Constantinople 41 deg. their difference is 10 deg. 32 min. The difference between London, 51 deg. 32 min. north, and the Cape of Good Hope, 34 deg. south, is 84 deg. 32 min.

PROBLEM IX. *The latitude and longitude of any place being known, to find that place upon the globe.*

Rule. Seek for the given longitude in the equator, and bring the moveable meridian to that point; then count from the equator on the meridian the degree of latitude either towards the north or south pole, and bring the artificial horizon to that degree, and the intersection of its edge with the meridian is the situation required.

By this problem, any place not represented on the globe may be laid down thereon, and it may be seen where a ship is when its latitude and longitude are known.

Example. The latitude of Smyrna in Asia, is 38 deg. 28 min. north ; its longitude 27 deg. 30 min. east of London ; therefore, bring 27 deg. 30 min. counted eastward on the equator, to the moveable meridian, and slide the diameter of the artificial horizon to 38 deg. 28 min. north-lati-

tude, and its centre will be correctly placed over Smyrna.

It may be proper in this place just to shew the pupil, that *the latitude of any place is always equal to the elevation of the pole of the same place above the horizon.* The reason of this is, that from the equator to the pole are 90 degrees, from the zenith to the horizon are also 90 degrees; the distance of the zenith to the pole is common to both, and therefore if taken away from both, must leave equal remains; that is, the distance from the equator to the zenith, which is the latitude, is equal to the elevation of the pole.

OF FINDING THE LONGITUDE.

As the finding the longitude of places forms one of the most important problems in geography and astronomy, some further account of it, it is presumed, will prove entertaining and useful to the reader:

" For what can be more interesting to a person in a long voyage, than to be able to tell upon what part of the globe he is, to know how far he has travelled, what distance he has to go, and how he must direct his course to arrive at the place he designs to visit ? These important particulars are all determined by knowing the latitude and longitude of the place under consideration. When the discovery of the compass invited the voyager to quit his native shore, and venture himself upon

an unknown ocean, that knowledge, which before he deemed of no importance, now became a matter of absolute necessity. Floating in a frail vessel, upon an uncertain abyss, he has consigned himself to the mercy of the winds and waves, and knows not where he is."*

The following instance will prove of what use it is to know the longitude of places at sea. The editor of Lord *Anson*'s voyage, speaking of the island of Juan Fernandez, adds, " The uncertainty we were in of its position, and our standing in for the main on the 28th of May, in order to secure a sufficient easting, when we were indeed extremely near it, cost us the lives of between 70 and 80 of our men, by our longer continuance at sea ; from which fatal accident we might have been exempted, had we been furnished with such an account of its situation, as we could fully have depended on."

The latitude of a place the sailor can easily discover ; but the longitude is a subject of the utmost difficulty, for the discovery of which so many methods have been devised. It is indeed of so great consequence, that the Parliament of Great Britain proposed a reward of 10,000*l*. if it extended only to one degree of a great circle, or 60 geographical miles ; 15,000*l*. if found to 40 such miles ; and 20,000*l*. to the person that can find it within 30 minutes of a great circle, or 30 geographical miles.

* *Bonnycastle*'s Astronomy.

As I cannot enter fully into this subject in these Essays, it will, I hope, be deemed sufficient, if I give such an account as will enable the reader to form a general idea of the solution of this important problem.

From what has been seen in the preceding pages, it is evident that 15 degrees in longitude answer to one hour in time, and consequently that the longitude of any place would be known, if we knew their difference in time; or in other words, how much sooner the sun, &c. arrives at the meridian of one place, than that of another. The hours and degrees being in this respect commensurate, it is as proper to express the distance of any place in time as in degrees.

Now it is clear, that this difference in time would be easily ascertained by the observation of any instantaneous appearance in the heavens, at two distant places; for the difference in time at which the same phenomenon is observed, will be the distance of the two places from each other in longitude. On this principle, most of the methods in general use are founded.

Thus if a clock, or watch, was so contrived, as to go uniformly in all seasons, and in all places; such a watch being regulated to London time, would always shew the time of the day at London; then the time of the day under any other meridian being found, the difference between that time, and the corresponding London time, would give the difference in longitude.

For suppose any person possessed of one of these time-pieces, to set out on a journey from London, if his time-piece be accurately adjusted, wherever he is, he will always know the hour at London exactly ; and when he has proceeded so far either eastward or westward, that a difference is perceived betwixt the hour shewn by his time-piece, and those of the clocks and watches at the places to which he goes, the distance of those places from London in longitude will be known. But to whatever degree of perfection such movements may be made, yet as every mechanical instrument is liable to be injured by various accidents, other methods are obliged to be used, as the eclipses of the sun and moon, or of Jupiter's satellites. Thus supposing the moment of the beginning of an eclipse was at ten o'clock at night at London, and by account from two observers in two other places, it appears that it began with one of them at nine o'clock, and with the other at midnight ; it is plain, that the place where it began at nine is one hour, or 15 degrees, east in longitude from London ; the other place where it began at midnight, is 30 degrees distant in west longitude from London. Eclipses of the sun and moon do not, however, happen often enough to answer the purposes of navigation ; and the motion of a ship at sea prevents the observations of those of Jupiter's satellites.

If the place of any celestial body be computed, for example, as in an almanack, for every day, or to

parts of days, to any given meridian, and the place of this celestial body can be found by observation at sea, the difference of time between the time of observation and the computed time, will be the difference of longitude in time. The moon is found to be the most proper celestial object, and the observation of her appulses to any fixed star is reckoned one of the best methods for resolving this difficult problem.

LENGTH OF THE DEGREES OF LONGITUDE.

Supposing the earth to be a perfect globe, the length of a degree upon the meridian has been estimated to be 69,1 miles; but as the earth is an oblate spheroid, the length of a degree on the equator will be somewhat greater.

Whether the earth be considered as a spheroid or a globe, all the meridians intersect one another at the poles. Therefore, the number of miles in a degree must always decrease as you go north or south from the equator. This is evident by inspection of a globe, where the parallels of latitude are found to be smaller in proportion as they are nearer the pole. Hence it is that a degree of longitude is no where the same, but upon the same parallel; and that a degree of longitude is equal to a degree of latitude only upon the equator.

The following table shews how many geographical miles, and decimal parts of a mile, would be contained in a degree of longitude, at each degree of la-

titude from the equator to the poles, if the earth was a perfect sphere, and the circumference of its equinoctial line 360 degrees, and each degree 60 geographical miles.

This table enables us to determine the velocity with which places upon the globe revolve eastward; for the velocity is different, according to the distance of the places from the equator, being swiftest as passing through a greater space, and so by degrees slower towards the pole, as passing through a less space in the same time. Now as every part of the earth is moved through the space of its circumference, or 360 degrees, in 24 hours; the space described in one hour is found by dividing 360 by 24, which gives in the quotient 15 degrees; and so many degrees does every place on the earth move in an hour. The number of miles contained in so many degrees in any latitude, is readily found from the table.

Thus under the equator places revolve at the rate of more than 1000 miles in an hour; at London, at the rate of about 640 miles in an hour.

TABLE.

LAT.		LAT.		LAT.	
Deg.	Miles.	Deg.	Miles.	Deg.	Miles.
00	60,00	4	59,86	8	59,42
1	59,99	5	59,77	9	59,26
2	59,96	6	59,67	10	59,08
3	59,92	7	59,56	11	58,89

LAT.		LAT.		LAT.	
Deg.	Miles.	Deg.	Miles.	Deg.	Miles.
12	58,68	39	46,62	66	24,41
13	58,46	40	45,95	67	23,45
14	58,22	41	45,28	68	22,48
15	57,95	42	44,59	69	21,50
16	57,67	43	43,88	70	20,52
17	57,37	44	43,16	71	19,54
18	57,06	45	42,43	72	18,55
19	56,73	46	41,68	73	17,54
20	56,38	47	40,92	74	16,53
21	56,01	48	40,15	75	15,52
22	55,63	49	39,36	76	14,51
23	55,23	50	38,57	77	13,50
24	54,81	51	37,76	78	12,47
25	54,38	52	36,94	79	11,45
26	53,93	53	36,11	80	10,42
27	53,46	54	35,26	81	9,38
28	52,97	55	34,41	82	8,35
29	52,47	56	33,55	83	7,32
30	51,96	57	32,68	84	6,28
31	51,43	58	31,79	85	5,23
32	50,88	59	30,90	86	4,18
33	50,32	60	30,00	87	3,14
34	49,74	61	29,09	88	2,09
35	49,15	62	28,17	89	1,05
36	48,54	63	27,24	90	0,00
37	47,92	64	26,30		
38	47,28	65	25,36		

Another circumstance which arises from this dif-
ference of meridians in time, must detain us a little
before we quit this subject. For from this dif-
ference it follows, that if a ship sails round the
world, always directing her course eastward, she
will at her return home find she has gained one
whole day of those that stayed at home ; that is, if
they reckon it May 1, the ship's company will
reckon it May 2 ; if westward, a day less, or
April 30.

This circumstance has been taken notice of by na-
vigators. " It was during our stay at Mindanao (says
Captain *Dampier*) that we were first made sensible o
the change of time in the course of our voyage : fo
having travelled so far westward, keeping the sam
course with the sun, we consequently have gainec
something insensibly in the length of the particula
days, but have lost in the tale the bulk or numbe
of the days or hours.

" According to the different longitudes of Eng
land and Mindanao, this isle being about 210 de
grees west from the Lizard, the difference of tim
at our arrival at Mindanao ought to have been abou
fourteen hours ; and so much we should have antici
pated our reckoning, having gained it by bearing th
sun company.

" Now the natural day in every place must b
consonant to itself; but going about with, or agains
the sun's course, will of necessity make a differenc
in the calculation of the civil day, between any tw
places. Accordingly, at Mindanao, and other place

in the East Indies, we found both natives and Europeans reckoning a day before us. For the Europeans coming eastward, by the Cape of Good Hope, in a course contrary to the sun and us, wherever we met, were a full day before us in their accounts.

" So among the Indian Mahometans, their Friday was Thursday with us; though it was Friday also with those that came eastward from Europe.

" Yet at the Ladrone islands we found the Spaniards at Guam keeping the same computation with ourselves; the reason of which I take to be, that they settled that colony by a course westward from Spain; the Spaniards going first to America, and thence to the Ladrone islands."

It is clear, from what has been said in the first part of this article, concerning both latitude and longitude, that if a person travels ever so far directly towards east or west, his latitude would be always the same, though his longitude would be continually changing.

But if he went directly north or south, his longitude would continue the same, but his latitude would be perpetually varying.

If he went obliquely, he would change both his latitude and longitude.

The longitude and latitude of places give only their relative distances on the globe; to discover, therefore, their real distance, we have recourse to the following problem.

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PROBLEM X. *Any place being given, to find the distance of that place from another, in a great circle of the earth.*

I shall divide this problem into three cases.

Case 1. If the places lie under the same meridian. Bring them up to the meridian, and mark the number of degrees intercepted between them. Multiply the number of degrees thus found by 60, and they will give the number of geographical miles between the two places. But if we would have the number of English miles, the degrees before found must be multiplied by $69\frac{1}{2}$.

Case 2. If the places lie under the equator. Find their difference of longitude in degrees, and multiply, as in the preceding case, by 60, or $69\frac{1}{2}$.

Case 3. If the places lie neither under the same meridian, nor under the equator. Then lay the quadrant of altitude over the two places, and mark the number of degrees intercepted between them. These degrees multiplied as above-mentioned, will give the required distance.

PROBLEM XI. *To find the angle of position of places.*

The angle of position is that formed between the meridian of one of the places, and a great circle passing through the other place.

Rectify the globe to the latitude and zenith of one of the places, bring that place to the strong brass meridian, set the graduated edge of the quadrant to the other place, and the number of degrees contained between it and the strong brass meridian, is the measure of the angle sought. Thus,

The angle of position between the meridian of Cape Clear, in Ireland, and St. Augustine, in Florida, is about 82 degrees north-westerly; but the angle of position between St. Augustine and Cape Clear, is only about 46 degrees north-easterly.

Hence it is plain, that the line of position, or azimuth, is not the same from either place to the other, as the rhomb-lines are.

PROBLEM XII. *To find the bearing of one place from another.*

The bearing of one sea-port to another is determined by a kind of spiral, called a rhomb-line, passing from one to the other, so as to make equal angles with all the meridians it passes by; therefore, if both places are situated on the same parallel of latitude, their bearing is either east or west from each other; if they are upon the same meridian, they bear north and south from one another; if they lie upon a rhomb-line, their bearing is the same with it; if they do not, observe to which rhomb-line the two places are nearest parallel, and that will shew the bearing sought.

Example. Thus the bearing of the Lizard point from the island of Bermudas is nearly E.N.E ; and that of Bermudas from the Lizard is W.S.W. both nearly upon the same rhomb-line, but in contrary directions.

OF THE TWILIGHT.

That light which we have from the sun before it rises, and after it sets, is called the twilight.

The morning twilight, or day-break, commences when the sun comes within eighteen degrees of the horizon, and continues till sun-rising. The evening twilight begins at sun-setting, and continues till it is eighteen degrees below the horizon.

To illustrate the causes of the various lengths of twilight in different places, a wire circle is fixed eighteen degrees below the surface of the broad paper circle ; so that all those places which are above the wire circle will have twilight, but it will be dark to all those places below it.

I have already observed, that it is owing to the atmosphere that we are favoured with the light of the sun before he is above, and after he is below, our horizon. Hence, though after sun-setting we receive no direct light from the sun, yet we enjoy its reflected light for some time ; so that the darkness of the night does not come on suddenly, but by degrees.

In a right position of the sphere the twilights are

quickly over, because the sun rises and sets nearly in a perpendicular; but in an oblique sphere they last longer, the sun rising and setting obliquely. The greater the latitude of the place, the longer is the duration of the twilight; so that all those who are in 49 degrees of latitude have in the summer, near the solstice, their atmosphere enlightened the whole night, the twilight lasting till sun-rising.

In a parallel sphere, the twilight lasts for several months; so that the inhabitants of this position have either direct or reflex light of the sun nearly all the year, as will plainly appear by the globe.

OF THE DIURNAL MOTION OF THE EARTH, AND THE PROBLEMS DEPENDING ON THAT MOTION.

As the daily motion of the earth about its axis, and the phenomena dependent on it, are some of the most essential points which a beginner ought to have in view, we shall now endeavour to explain them by the globes; and here I think the advantage of globes mounted in my father's manner, over those generally used, will be very evident.

I have already observed, that in globes mounted in our manner, the motion of the terrestrial globe about its axis represents the diurnal motion of the earth, and that the horary index will point out upon the equator the 24 hours of one diurnal rotation, or any part of that time.

I shall now consider the broad paper circle as the

plane which distinguishes light from darkness; that is, the enlightened half of the earth's surface, from that which is not enlightened.

For when the sun shines upon a globe, he shines only upon half of it; that is, one half of the globe's surface is enlightened by him, the other not.

That the enlightened half may be that half which is above the broad paper circle, we must imagine the sun to be in our zenith.

Or let a sun be painted on the ceiling over the terrestrial globe, the diameter of the picture equal to the diameter of the globe.

Then all those places that are above the broad paper circle will be in the sun's light: that is, it will be in all those places.

And all places that are below this circle will be out of the sun's light; that is, in all those places it will be night.

When any place on the earth's surface comes to the edge of the broad paper circle, passing out of the shade into the light, the sun will appear rising at that place.

And when a place is at the edge of the broad paper circle, going out of the light into the shade, the sun will appear at that place to be setting.

When we view the globe in this position, we at once see the situation of all places in the illuminated hemisphere, whose inhabitants enjoy the light of the day. One edge of the broad paper circle shews at what place the sun appears rising at the same time;

and the opposite edge shews at what places the sun is setting at the same time.

The horary index shews how long a place is moving from one edge to the other; that is, how long the day or night is at that place; and, consequently, when the globe is thus situated, you readily discover the time of the sun's rising and setting on any given day, in any place.

TO RECTIFY THE TERRESTRIAL GLOBE.

To rectify the terrestrial globe, is to place it in the same position in which our earth stands to the sun, at all or at any given times.

That half of the earth's surface which is enlightened by the sun is not always the same; it differs according as the sun's declination differs.

To rectify, then, the terrestrial globe, is to bring it into such a position, as that the enlightened half of the earth's surface may be all above the broad paper circle.

On the back side of the strong brass meridian, and on each side of the north pole, the months and days of the month are graduated in two concentric spaces, agreeable to the declination of the sun.

Bring the day of the month that is graduated on the back side of the strong brass meridian, to coincide with the broad paper circle, and the globe is rectified.

Thus set the first of May to coincide with the

broad paper circle, and that half of the earth's surface which is enlightened at any time upon that day, will be all at once above the said circle.

If the horary index be set to XII, when any particular place is brought under the strong brass meridian, it will shew the precise time of sun-rising and sun-setting at that place, according as that place is brought to the eastern or western edge of the broad paper circle.

It will also shew how long any place is in moving from the east to the west side of the illuminated disc, and thence the length of day and night.

It will also point out the length of the twilight, by shewing the time in which the place is passing from the twilight circle to the edge of the broad paper circle on the western side ; or from the edge of this circle on the eastern side, to the twilight wire, and thus determine the length of the whole artificial day.

N. B. The twilight wire is placed at 18 degrees from the broad paper circle.

I shall now proceed to exemplify upon the globes these particulars, at three different seasons of the year, viz. the summer solstice, the winter solstice, and the time or times of the equinoxes.

PROBLEM XIII. *To place the globe in the same situation, with respect to the sun, as our earth is in at the time of the summer solstice.*

Rectify the globe to the extremity of the divisions

for the month of June, or $23\frac{1}{2}$ degrees north declination ; that is, bring these divisions on the strong brass meridian to coincide with the plane of the broad paper circle.

Then that part of the earth's surface, which is within the northern polar circle, will be above the broad paper circle, and will be in the light, and the inhabitants thereof will have no night.

But all that space which is contained within the southern polar circle will continue in the shade ; that is, it will there be continual night.

In this position of the globe, the pupil will observe how much the diurnal arches of the parallels of latitude decrease, as they are more and more distant from the elevated pole.

If any place be brought under the strong brass meridian, and the horary index is set to that XII which is most elevated, and the place be afterwards brought to the western side of the broad paper circle, the hour index will shew the time of sun-rising ; and when the place is moved to the eastern edge, the index points to the time of sun-setting.

The length of the day is obtained by the time shewn by the horary index, while the place on the globe moves from the west to the east side of the broad paper circle.

Thus it will be found, that at London the sun rises about 15 minutes before IV in the morning, and sets about 15 minutes after VIII at night.

At the following places it will be nearly at the times expressed in the table.

	☉ Rising.	☉ Setting.	Length of day.	Twilight.
	h. m.	*h. m.*	*h. m.*	*h. m.*
Cape Horn	8 44	3 16	6 32	2 35
Cape of Good Hope . .	7 9	4 51	9 42	1 43
Rio de Janeiro, in Brazil . .	6 42	5 19	10 38	1 23
Island of St. Thomas, near the equator . . .	6	6	12	1 20
Cape Lucas, California . .	5 12	6 48	13 36	1 35

We also see, that at the same time the sun is rising at London, it is rising at the isles of Sicilly and Madagascar.

And, that at the same time when the sun sets at London, it is setting at the island of Madeira, and at Cape Horn.

And when the sun is setting at the island of Borneo, in the East Indies, it is rising at Florida in America. And many other similar circumstances, relative to other places, are seen as it were by inspection.

PROBLEM XIV. *To explain the situation of the earth with respect to the sun, at the time of the winter solstice.*

Rectify the globe to the extremity of the divisions for the month of December, or to 23½ degrees south declination.

When it will be apparent that the whole space

within the southern polar circle is in the sun's light, and enjoys continual day; whilst that of the northern polar circle is in the shade, and has continual night.

If the globe be turned round, as before, the horary index will shew, that at the several places before-mentioned their days will be respectively equal to what their nights were at the time of the summer solstice.

It will appear, farther, that it is now sun-setting at the same time in those places in which it was sun-rising at the same time at the summer solstice; and, on the contrary, sun-rising at the time it then appeared to set.

PROBLEM XV. *To place the globe in the situation of the earth, at the times of the equinox.*

The sun has no declination at the times of the equinox, consequently there must be no elevation of the pole.

Bring the day of the month when the sun enters the first point of Aries, or day of the month when the sun enters the first point of Libra, to the plane of the broad paper circle; then the two poles of the globe will be in that plane also, and the globe will be in that position which is called a *right sphere*.

For it is a right sphere when the two poles are in the plane of the broad paper circle, because then all those circles which are parallel to the equator will be at right angles to that plane.

If the globe be now turned from west to east, it will plainly appear, that all places upon its surface are twelve hours above the broad paper circle, and twelve hours below it; that is, the days are twelve hours long all over the earth, and the nights are equal to the days; whence these times are called the *times of equinox*.

Two of these occur in every year; the first is the autumnal, the second the vernal equinox.

At these seasons, the sun appears to rise at the same time to all places that are on the same meridian. The sun sets also at the same time in all those places.

Thus, if London, and Mundford on the Gold Coast, be brought to the strong brass meridian, the graduated side of which is in this case the horary index, and they be afterwards carried to the western edge of the broad paper circle, the index will shew that the sun rises at VI at both places; when they are carried to the eastern edge, the index points to VI for the time of sun-setting.

N. B. If London be not the given place, the hour index is to be set to the most elevated XII, while the place is under the graduated edge of the strong brass meridian.

The following circumstances, which usually attend the four cardinal divisions of the year, cannot be better introduced than at this place. At the time of the equinoxes, when the sun passes from one hemisphere into the other, there is almost con-

stantly some disturbance in the weather ; the winds are then generally higher : at the vernal equinox they are for the most part easterly, cold, dry, and searching. The solstitial point of the summer is often distinguished by violent rains, and what we call a midsummer flood. The winter being less rainy than the summer, nothing particularly happens at the winter solstice, but that the frosts commonly set in more severely with some quantity of snow upon the ground.

OF THE ARTIFICIAL OR TERRESTRIAL HORIZON.

The brass circle, which may be slipped from pole to pole on the moveable meridian, has been already described. The circumference of it is divided into eight parts, to which are affixed the initial letters of the mariner's compass.

When the centre of it is set to any particular place, the situation of any other place is seen, with respect to that place ; that is, whether they be east, west, north, or south of it.

It will therefore represent the horizon of that place.

We shall here use the artificial horizon, to shew why the sun, although he be always in one and the same place, appears to the inhabitants of the earth at different altitudes, and in different azimuths.

PROBLEM XVI. *To exemplify the sun's altitude, as observed with an artificial horizon.*

The altitude of the sun is greater or less, according as the line which goes from us to the sun is nearer to, or farther off from our horizon.

Let the moveable circle be applied to any place, as London, then will the horizon of London be thereby represented.

The sun is supposed, as before, to be in the zenith, that is, directly over the terrestrial globe.

If then from London a line go vertically upwards, the sun will be seen at London in that line.

At sun-rising, when London is brought to the west edge of the broad paper circle, the supposed line will be parallel to the artificial horizon, and the sun will then be seen in the horizon.

As the globe is gradually turned from the west towards the east, the horizon will recede from that line which goes from London vertically upwards; so that the line in which the sun is seen gets further and further from the horizon; that is, the sun's altitude increases gradually.

When the horizon, and the line which goes from London vertically upwards, are arrived at the strong brass meridian, the sun is then at his greatest, or meridian altitude for that day, and the line and horizon are at the largest angle they can make with each other.

After this the motion of the globe being continued, the angle between the artificial horizon and

the line which goes from London vertically upwards continually decreases, until London arrives at the eastern edge of the broad paper circle; its horizon then becomes vertical again, and parallel to the line which goes vertically upwards. The sun will again appear in the horizon, and will set.

PROBLEM XVII. *Of the sun's meridian altitude, at the three different seasons.*

Rectify the globe to the time of the winter solstice, by Problem xiv, and place the centre of the visible horizon on London.

When London is at the graduated edge of the strong brass meridian, the line which goes vertically upwards makes an angle of about 15 degrees; this is the sun's meridian altitude at that season to the inhabitants of London.

If the globe be rectified to the times of equinox by Problem xv, the horizon will be farther separated from the line which goes vertically upwards, and makes a greater angle therewith, it being about $38\frac{1}{2}$ degrees; this is the sun's meridian altitude at the time of equinox at London.

Again, rectify to the summer solstice by Problem xiii, and you will find the artificial horizon recede farther from the line which goes from London vertically upwards, and the angle it then makes is about 62 degrees, which shews the sun's meridian altitude at the time of the summer solstice.

Hence flows also the following arithmetical problem.

PROBLEM XVIII. *To find the meridian altitude uni-*
versally.

Add the sun's declination to the elevation of the
equator, if the latitude of the place and the declina-
tion of the sun are both on the same side.

If on contrary sides, subtract the declination from
the elevation of the equator, and you obtain the sun's
meridian altitude.

	°	′
Thus the elevation of the equator at London is	38	28
The sun's declination on the 20th of May	20	8
Their sum, the sun's meridian altitude that day	58	36

	°	′
Again, to the elevation of the equator at London	38	28
Add the sun's greatest declination at the time of the summer solstice	23	29
The sum is the sun's greatest meridian altitude at London	61	57

PROBLEM XIX. *Of the sun's azimuths, as compared*
with the artificial horizon.

The artificial horizon serves also to determine the
sun's azimuths.

An *azimuth* of the sun is denominated from that point of the horizon, to which the sun, or a line going to the sun, is nearest.

Thus if the sun, or a line going to the sun, be nearest the south-east point of the horizon, which point is 45 degrees distant from the meridian, the sun's azimuth is an azimuth of 45 degrees, and the sun will appear in the south-east.

Imagine the sun, as we have done before, to be placed directly over the globe.

In which case, a line going to the sun from any place on the surface of the globe, will have a vertical direction, and will go from that place vertically upwards.

If then we apply the artificial horizon to any place, the point of this horizon to which a vertical line is nearest shews the sun's azimuth at that time.

It is observable, that the point of the horizon, to which such a vertical line is nearest, will be at all times that point which is most elevated.

To exemplify this, let the globe be in the position of a right sphere, and let the artificial horizon be applied to London.

When London is at the western edge of the broad paper circle, which situation represents the time when the sun appears to rise, the eastern point of the artificial horizon being then most elevated, shews that the sun at his rising is due east.

Turn the globe, till London comes to the eastern

Q

edge of the broad paper circle, then the western point of the artificial horizon will be most elevated, shewing that the sun sets due west.

Now place the globe in the position of an oblique sphere; and, if London be brought to the eastern or western side of the broad paper circle, the vertical line will depart more or less from the east and west points, in which case the sun is said to have more or less amplitude.

If the departure be northward, it is called northern amplitude; if southern, it is called southern amplitude.

In whatever position the globe be placed,* when London comes to the strong brass meridian, the most elevated part of the artificial horizon will be the south point of it.

Which shews that at noon the sun will always, and in all seasons, appear in the south.

OF THE ANCIENT DIVISIONS OF THE EARTH INTO ZONES AND CLIMATES.

Climates was a term used by the ancient astronomers to express a division of the earth, which, before the marking down the latitudes of countries into degrees and minutes was in use, served them for dividing the earth into certain portions in the

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* The globe is not supposed in this case, or under this view of things, ever to be elevated above the limits of the sun's declination.

same direction ; so as to speak of any particular place with some degree of certainty, though not with due precision.

It was natural for the earliest observers to remark, for one of the first things, the diversity that there was in the sun's rising and setting ; it was by this they regulated what they called climates ; which are a tract on the surface of the earth of various breadths, being regulated by the different lengths of time between the rising and setting of the sun in the longest day, in different places.

From the equator to the latitude of $66\frac{1}{2}$ north and south, a climate is constituted by the difference of half an hour in the length of the longest day ; and this is sufficient for understanding the ancients. Between the polar circle and the pole, the length of the longest day, in one parallel, exceeds the length of the longest in the next by a month ; but of these the ancients knew nothing.

CLIMATES BETWEEN THE EQUATOR AND POLAR CIRCLES.

Climates.	Hours.	Latitude. D. M.		Breadth. D. M.		Climates.	Hours.	Latitude. D M.		Breadth. D. M.	
1	12½	8	25	8	25	13	18½	59	58	1	29
2	13	16	25	8	00	14	19	61	18	1	20
3	13½	23	50	7	25	15	19½	62	25	1	07
4	14	30	25	6	30	16	20	63	22	0	57
5	14½	36	28	6	08	17	20½	64	06	0	44
5	15	41	22	4	54	18	21	64	49	0	43
7	15½	45	29	4	07	19	21½	65	21	0	32
8	16	49	01	3	32	20	22	65	47	0	22
9	16½	52	00	2	57	21	22½	66	06	0	19
10	17	54	27	2	29	22	23	66	20	0	14
11	17½	56	37	2	10	23	23½	66	28	0	08
12	18	58	29	1	52	24	24	66	31	0	03

Therefore, to discover in what climate a place is, whose latitude does not exceed 66½ degrees, find the length of the longest day in that place, and subtracting twelve hours from that length, the number of half hours in the remainder will specify the climate.

PROBLEM XX. *To find the limits of the climates.*

Elevate the north pole to 23° 28′, the sun's declination on the longest day ; and turn the globe easterly till the intersection of the meridian with the

equator that passes through Libra comes to the horizon, and the hour of VI will then be under the meridian, which in this problem is the hour index, because the sun sets this day at places on the equator as it does every day at VI o'clock. Now turn the globe easterly, till the time under the meridian is 15 min. past VI, and you will find that 8° 34' of that graduated meridian is cut by the horizon ; this is the beginning of the second climate ; and the limits of all the climates may be determined, by bringing successively the time equal to half the length of the longest day under the meridian, and observing the degree of the graduated meridian cut by the horizon.

ZONES.

Zones is another division of the earth's surface, used by the ancients : that part which the sun passes over in a year, comprehending 23½ degrees on each side the equator, was called by the ancients the torrid zone. The two frigid zones are contained between the polar circles. Between the torrid and the two frigid zones are contained the two temperate ones, each being about 43 degrees broad.

The latitude of a place being the mark of its position with respect to the sun, may be considered as a general index to the temperature of the climate : it is, however, liable to very great exceptions ; but to deny it absolutely, would be to deny that the sun is the source of light and heat below.

Nothing can be more hideous or mournful than
the pictures which travellers present us of the polar
regions. The seas, surrounding inhospitable coasts,
are covered with islands of ice, that have been increas-
ing for many centuries : some of these islands are
immersed six hundred feet under the surface of the
sea, and yet often rear up also their icy heads more
than one hundred feet above its level, and are three
or four miles in circumference. The following ac-
count will give some idea of the scenery produced
by arctic weather. At Smearingborough Harbour,
within fifteen degrees of the pole, the country is
full of mountains, precipices, and rocks ; these are
covered with ice and snow. In the vallies are hills
of ice, which seem daily to accumulate. These
hills assume many strange and fantastic appearances;
some looking like churches or castles, ruins, ships
in full sail, whales, monsters, and all the various
forms that fill the universe. There are seven of
these ice-hills, which are the highest in the coun-
try. When the air is clear, and the light shines full
upon them, the prospect is inconceivably brilliant ;
the sun is reflected from them as from glass ; some-
times they appear of a bright hue, like sapphire ;
sometimes variegated with all the glories of the
prismatic colours, exceeding in the magnitude of
lustre and beauty of colour the richest gems in the
world, disposed in shapes wonderful to behold, daz-
zling the eye with the brilliancy of its splendor.
At Spitsbergen, within ten degrees of the pole,
the earth is locked up in ice till the middle

of May ; in the beginning of July the plants are in flower, and perfect their seeds in a month's time : for, though the sun is much more oblique in the higher latitudes than with us, his long continuance above the horizon is attended with an accumulation of heat exceeding that of many places under the torrid zone ; and there is reason to suppose, that the rays of the sun, at any given altitude, produce greater degrees of heat in the condensed air of the polar regions, than in the thinner air of this climate.

Yet, if we look for heat, and the remarkable effects of it, we must go to the countries near the equator, where we shall find a scenery totally different from that of the frigid zone. Here all things are upon a larger scale than in the temperate climates : their days are burning hot ; in some parts their nights are piercing cold ; their rains lasting and impetuous, like torrents ; their dews excessive ; their thunder and lightning more frequent, terrible, and dangerous ; the heat burns up the lighter soil, and forms it into a sandy desart, while it quickens all the moister tracts with incredible vegetation.

The ancients supposed that the frigid zone was uninhabitable from cold, and the torrid from the intolerable heat of the sun ; we now, however, know that both are inhabited. The sentiments of the ancients, therefore, in this respect, are a proof how inadequate the faculties of the human mind are to discussions of this nature, when unassisted by facts.

OF THE ANCIENT DISTINCTION OF PLACES BY THE DIVERSITY OF SHADOWS OF UPRIGHT BODIES AT NOON.

When the sun at noon is in the zenith of any place, the inhabitants of that place were by the ancients called *ascii*, that is, without shadow; for the shadow of a man standing upright, when the sun is directly over his head, is not extended beyond that part of the earth which is directly under his body, and therefore will not be visible.

As the shadow of every opake body is extended from the sun, it follows, that when the sun at noon is southward from the zenith of any place, the shadow of an inhabitant of that place, and indeed of any other opake body, is extended towards the north.

But when the sun is northward from the zenith of any place, the shadow falls towards the south.

Those are called *amphiscii*, that have both kinds of meridian shadows.

Those, whose meridian shadows are always projected one way, are termed *heteroscii*.

PROBLEM XXI. *To illustrate the distinction of ascii, amphiscii, heteroscii, and periscii, by the globe.*

Rectify the globe to the summer solstice, and move the artificial horizon to the equator, the north point will be the most elevated at noon.

Which shews, that to those inhabitants who live at the equator, the sun will at this season appear to the north at noon, and their shadow will therefore be projected southwards.

But if you rectify the globe to the winter solstice, the south point being then the uppermost point at noon, the same persons will at noon have the sun on the south side of them, and will project their shadows northwards.

Thus they are amphiscii, projecting their shade both ways ; which is the case of all the inhabitants within the tropics.

The artificial horizon remaining as before, rectify the globe to the times of the equinox, and you will find that when this horizon is under the strong brass meridian, a line going vertically upwards will be perpendicular to it, and consequently the sun will be directly over the heads of the inhabitants, and they will be ascii, having no noon shade ; their shadow is in the morning projected directly westward, in the evening directly eastward.

The same thing will also happen to all the inhabitants who live between the tropics of Cancer and Capricorn ; so that they are not only ascii, but amphiscii also.

Those who live without the tropics are heteroscii ; those in north latitude have the noon shade always directed to the north, while those in south latitude have it always projected to the south.

The inhabitants of the polar circles are called *peris-*

cii; because, as the sun goes round them continually, their shade goes round them likewise.

OF ANCIENT DISTINCTIONS FROM SITUATION.

These terms being often mentioned by ancient geo-graphical writers to express the different situation of parts of the globe, by the relation which the several inhabitants bore to one another, it will be necessary to take some notice of them.

The *antœci* are two nations which are in or near the same meridian; the one in north, the other in south latitude.

They have therefore the same longitude, but not the same latitude; opposite seasons of the year, but the same hour of the year; the days of the one are equal to the nights of the other, and *vice versa*, when the days of the one are at the longest, they are shortest at the other.

When they look towards each other, the sun seems to rise on the right hand of the one, but on the left of the other. They have different poles elevated; and the stars that never set to the one, are never seen by the other.

Periœci are also two opposite nations, situated on the same parallel of latitude.

They have therefore the same latitude, but differ 180 degrees in longitude; the same seasons of the year, but opposite hours of the day; for when it is twelve at night to the one, it is twelve at noon with

the other. On the equinoctial days, the sun is rising to one, when it is setting to the other.

Antipodes are two nations diametrically opposite, which have opposite seasons and latitude, opposite hours and longitude.

The sun and stars rise to the one, when they set to the other, and that during the whole year, for they have the same horizon.

The day of the one is the night of the other; and when the day is longest with the one, the other has its shortest day.

They have contrary seasons at the same time; different poles, but equally elevated; and those stars that are always above the horizon of one, are always under the horizon of the other.

PROBLEM XXII. *To find the Antœci, the Periœci, and the Antipodes of any place.*

Bring the given place to the strong brass meridian, then in the opposite hemisphere, and under the same degree of latitude with the given place, you will find the Antœci.

The given place remaining under the meridian, set the horary index to XII; then turn the globe, till the other XII is under the index, then you will find the Periœci under the same degee of latitude with the given place.

Thus the inhabitants of the south part of Chili are Antœci to the people of New England, whose Periœci are those Tartars who dwell on the north bor-

ders of China, which Tartars have the said inhabitants of Chili for their Antipodes.

This will become evident, by placing the globe in the position of a right sphere, and bringing those nations to the edge of the broad paper circle.

PROBLEM XXIII. *The day of the month being given, to find all those places on the globe, over whose zenith the sun will pass on that day.*

Rectify the terrestrial globe, by bringing the given day of the month on the back side of the strong brass meridian, to coincide with the plane of the broad paper circle; observe the number of degrees of the brass meridian, which corresponds to the given day of the month.

This number of degrees, counted from the equator on the strong brass meridian, towards the elevated pole, is the point over which the sun is vertical; and all those places, which pass under this point, have the sun directly vertical on the given day.

Example. Bring the 11th of May to coincide with the plane of the broad paper circle, and the said plane will cut eighteen degrees for the elevation of the pole, which is equal to the sun's declination for that day, which being counted on the strong brass meridian towards the elevated pole, is the point over which the sun will be vertical; and all places that are under this degree, will have the sun on their zenith on the 11th of May.

Hence, when the sun's declination is equal to the latitude of any place in the torrid zone, the sun will be vertical to those inhabitants that day; which furnishes us with another method of solving this problem.

OF PROBLEMS PECULIAR TO THE SUN.

PROBLEM XXIV. *To find the sun's place on the broad paper circle.*

Consider whether the year in which you seek the sun's place is bissextile, or whether it is the first, second, or third year after.

If it be the first year after bissextile, those divisions to which the numbers for the days of the months are affixed, are the divisions which are to be taken for the respective days of each month of that year at noon; opposite to which, in the circle of twelve signs, is the sun's place.

If it be the second year after bissextile, the first quarter of a day backwards or towards the left hand, is the day of the month for that year, against which, as before, is the sun's place.

If it be the third year after bissextile, then three quarters of a day backwards is the day of the month for that year, opposite to which is the sun's place.

If the year in which you seek the sun's place be bissextile, then three quarters of a day backwards is the day of the month from the 1st of January to

the 28th of February inclusive. The intercalary, or 29th day, is three-fourths of a day to the left hand from the 1st of March, and the 1st of March itself one quarter of a day forward, from the division marked one; and so for every day in the remaining part of the leap year; and opposite to these divisions is the sun's place.

In this manner the intercalary day is very well introduced every fourth year into the calendar, and the sun's place very nearly obtained, according to the Julian reckoning.

Thus,

A. D.					Sun's place.	Apr. 25.
1788	Bissextile	-	-	-	♉	5° 35'
1789	First year after	-	-	♉	5 21
1790	Second	-	-	-	♉	5 6
1791	Third	-	-	-	♉	4 55

Upon my father's globes there are twenty-three parallels, drawn at the distance of one degree from each other on both sides the equator, which, with two other parallels at 23½ degrees distance, include the ecliptic circle.

The two outermost circles are called the tropics; that on the north side the equator is called the tropic of Cancer; that which is on the south side, the tropic of Capricorn.

Now as the ecliptic is inclined to the equator, in an angle of 23½ degrees, and is included between the tropics, every parallel between these must cross

the ecliptic in two points, which two points shew the sun's place when he is vertical to the inhabitants of that parallel ; and the days of the month upon the broad paper circle answering to those points of the ecliptic, are the days on which the sun passes directly over their heads at noon, and which are sometimes called their two midsummer days.

It is usual to call the sun's diurnal paths parallels to the equator, which are therefore aptly represented by the above-mentioned parallel circles ; though his path is properly a spiral line, which he is continually describing all the year, appearing to move daily about a degree in the ecliptic.

PROBLEM XXV. *To find the sun's declination, and thence the parallel of latitude corresponding thereto.*

Find the sun's place for the given day in the broad paper circle, by the preceding problem, and seek that place in the ecliptic line upon the globe ; this will shew the parallel of the sun's declination among the above-mentioned dotted lines, which is also the corresponding parallel of latitude ; therefore all those places, through which this parallel passes, have the sun in their zenith at noon on the given day.

Thus on the 23d of May the sun's declination will be about 20 deg. 10 min.; and upon the 23d of August it will be 11 deg. 13 min. What has been said

in the first part of this problem, will lead the reader
to the solution of the following.

PROBLEM XXVI. *To find the two days on which
the sun is in the zenith of any given place that is situated
between the two tropics.*

That parallel of declination, which passes
through the given place, will cut the ecliptic line
upon the globe in two points, which denote the
sun's place, against which, on the broad paper
circle, are the days and months required. Thus
the sun is vertical at Barbadoes April 24, and Au-
gust 18.

PROBLEM XXVII. *The day and hour at any place
in the torrid zone being given, to find where the sun is
vertical at that time.*

Rectify the globe to the day of the month, and
you have the sun's declination; bring the given
place to the meridian, and set the hour index to
XII; turn the globe till the index points to the
given hour on the equator; then will the place be
under the degree of the declination previously
found.

Let the given place be London, and time the
11th day of May, at four min. past five in the af-
ternoon; bring the 11th of May to coincide with
the broad paper circle, and opposite to it you will
find 18 degrees of north declination; as London

is the given place, you have only to turn the globe till 4 min. past V westward if it is on the meridian, when you will find Port Royal, in Jamaica, under the 18th degree of the meridian, which is the place where the sun is vertical at that time.

PROBLEM XXVIII. *The time of the day at any one place being given, to find all those places where at the same instant the sun is rising, setting, and on the meridian, and where he is vertical; likewise those places where it is midnight, twilight, and dark night; as well as those places in which the twilight is beginning and ending; and also to find the sun's altitude at any hour in the illuminated, and his depression in the obscure, hemisphere.*

Rectify the globe to the day of the month, on the back side of the strong brass meridian, and the sun's declination for that day; bring the given place to the strong brass meridian, and set the horary index to XII upon the equator; turn the globe from west to east, until the horary index points to the given time. Then

All those places, which lie in the plane of the western side of the broad paper circle, see the sun rising, and at the same time those on the eastern side of it see him setting.

It is noon to all the inhabitants of those places under the upper half of the graduated side of the strong brass meridian, whilst at the same time those under the lower half have midnight.

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All those places which are between the upper surface of the broad paper circle, and the wire circle under it, are in the twilight, which begins to all those places on the western side that are immediately under the wire circle ; it ends at all those which are in the plane of the paper circle.

The contrary happens on the eastern side ; the twilight is just beginning to those places in which the sun is setting, and its end is at the place just under the wire circle.

And those places which are under the twilight wire circle have dark night, unless the moon is favourable to them.

All places in the illuminated hemisphere have the sun's altitude equal to their distance from the edge of the enlightened disc, which is known by fixing the quadrant of altitude to the zenith, and laying its graduated edge over any particular place.

The sun's depression is obtained in the same manner, by fixing the centre of the quadrant at the nadir.

PROBLEM XXIX. *To find all those places within the polar circles on which the sun begins to shine, the time he shines constantly, when he begins to disappear, the length of his absence, as well as the first and last day of his appearance to those inhabitants; the day of the month, or latitude of the place being given.*

Bring the given day of the month on the back side of the strong brass meridian to the plane of the

broad paper circle; the sun is just then beginning to shine on all those places which are in the parallel that just touches the edge of the broad paper circle, and will for several days seem to skim all around, and but a little above their horizon, just as it appears to us at its setting; but with this observable difference, that whereas our setting sun appears in one part of the horizon only, by them it is seen in every part thereof; from west to south, thence east to north, and so to west again.

Or if the latitude be given, elevate the globe to that latitude, and on the back of the strong brass meridian, opposite to the latitude, you obtain the day of the month; then all the other requisites are answered as above.

As the two concentric spaces, which contain the days of the month on the back side of the strong brass meridian, are graduated to shew the opposite days of the year, at 180 degrees distance; when the given day is brought to coincide with the broad paper circle, it shews when the sun begins to shine on that parallel, which is the first day of its appearance above the horizon of that parallel.

And the plane of the broad paper circle cuts the day of the month on the opposite concentric space, when the sun begins to disappear to those inhabitants.

The length of the longest day is obtained by reckoning the number of days between the two opposite days found as above, and their difference from 365, gives the length of their longest night.

PROBLEM XXX. *To make use of the globe as a tellurian, or that kind of orrery which is chiefly intended to illustrate the phenomena that arise from the annual and diurnal motions of the earth.*

Describe a circle with chalk upon the floor, as large as the room will admit of, so that the globe may be moved round upon it; divide this circle into twelve parts, and mark them with the characters of the twelve signs, as they are engraved upon the broad paper circle; placing ♋ at the north, ♑ at the south, ♈ in the east, and ♎ in the west: the mariner's compass under the globe will direct the situation of these points, if the variation of the magnetic needle be attended to.

Note. At London the variation is now 23 degrees from the north-westward.

Elevate the north pole of the globe, so that $66\frac{1}{2}$ degrees on the strong brass meridian may coincide with the surface of the broad paper circle, and this circle will then represent the plane of the ecliptic, or a plane coinciding with the earth's orbit.

Set a small table, or a stool, over the centre of the chalked circle, to represent the sun, and place the terrestrial globe upon its circumference over the point marked ♑, with the north pole facing the imaginary sun, and the north end of the needle pointing to the variation; and the globe will be in the position of the earth with respect to the sun at the time of the summer solstice, about the 21st of June; and

the earth's axis, by this rectification of the globe, is inclined to the plane of the large chalked circle, as well as to the plane of the broad paper circle, in an angle of 66½ degrees; a line, or string, passing from the centre of the imaginary sun to that of the globe, will represent a central solar ray connecting the centres of the earth and sun : this ray will fall upon the first point of Cancer, and describe that circle, shewing it to be the sun's place upon the terrestrial ecliptic, which is the same as if the sun's place, by extending the string, was referred to the opposite side of the chalked circle, there representing the earth's path in the heavens.

If we conceive a plane to pass through the centre of the globe and the sun's centre, it will also pass through the points of Cancer and Capricorn, in the terrestrial and celestial ecliptic ; the central solar ray, in this position of the earth, is also in that plane : this can never happen but at the times of the solstice.

If another plane be conceived to pass through the centre of the globe at right angles to the central solar ray, it will divide the globe into two hemispheres ; that next the centre of the chalked circle will represent the earth's illuminated disc, the contrary side of the same plane will at the same time shew the obscure hemisphere.

The reader may realize this second plane by cutting away a semicircle from a sheet of card paste-

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board, with a radius of about $1\frac{1}{2}$ tenth of an inch greater than that of the globe itself.*

If this plane be applied to 66½ degrees upon the strong brass meridian, it will be in the pole of the ecliptic; and in every situation of the globe round the circumference of the chalked circle, it will afford a lively and lasting idea of the various phenomena arising from the parallelism of the earth's axis, and in particular the daily change of the sun's declination, and the parallels thereby described.

Let the globe be removed from ♑ to ♒, and the needle pointing to the variation as before, will preserve the parallelism of the earth's axis; then it will be plain that the string, or central solar ray, will fall upon the first point of Leo, six signs distant from, but opposite to the sign ♒, upon which the globe stands; the central solar ray will now describe the 20th parallel of north declination, which will be about the 23d of July.

If the globe be moved in this manner point to point round the circumference of the chalked circle, and care be taken at every removal that the north end of the magnetic needle, when settled, points to the degree of variation, the north pole of the globe will be observed to recede from the line connecting the centres of the earth and sun, until the globe is placed upon the point Cancer;

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* Or he may have a plane made of wood for this purpose.

after which, it will at every removal tend more and more towards the said line, till it comes to Capricorn again.

PROBLEM XXXI. *To rectify either globe to the latitude and horizon of any place.*

If the place be in north latitude, raise the north pole; if in south latitude, raise the south pole, until the degree of the given latitude, reckoned on the strong brass meridian under the elevated pole, cuts the plane of the broad paper circle; then this circle will represent the horizon of that place, while the place remains in the zenith, but no longer. This rectification is therefore unnatural, though it is the mode adopted in using the globes when mounted in the old manner.

PROBLEM XXXII. *To rectify for the sun's place.*

After the former rectification, bring the degrees of the sun's place in the ecliptic line upon the globe to the strong brass meridian, and set the horary index to the XIIth hour upon the equator which is most elevated.

Or if the sun's place is to be retained, to answer various conclusions, bring the graduated edge of the moveable meridian to the degree of the sun's place in the ecliptic, and slide the wire which crosses the centre of the artificial horizon thereto;

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then bring its centre, which is in the intersection of the aforesaid wire, and graduated edge of the moveable meridian, under the strong brass meridian as before, and set the horary index to that XII, on the equator which is most elevated.

PROBLEM XXXIII. *To rectify for the zenith of any place.*

After the first rectification, screw the nut of the quadrant of altitude so many degrees from the equator, reckoned on the strong brass meridian towards the elevated pole, as that pole is raised above the plane of the broad paper circle, and that point will represent the zenith of the place.

Note. The zenith and nadir are the poles of the horizon, the former being a point directly over our heads, and the latter, one directly under our feet.

If, when the globe is in this state, we look on the opposite side, the plane of the horizon will cut the strong brass meridian at the complement of the latitude, which is also the elevation of the equator above the horizon.

OF THE SOLUTION OF PROBLEMS, BY EXPOSING THE GLOBES TO THE SUN'S RAYS.

In the year 1679, *J. Moxon* published a treatise on what he called " *The English Globe* ; being (says

he) a stable and immobile one, performing what the ordinary globes do, and much more; invented and described by the Right Hon. the Earl of *Castle-main*." This globe was designed to perform, by being merely exposed to the sun's rays, all those problems which in the usual way are solved by the adventitious aid of brazen meridians, hour indexes, &c.

My father thought that this method might be useful, to ground more deeply in the young pupil's mind those principles which the globes are intended to explain ; and by giving him a different view of the subject, improve and strengthen his mind ; he therefore inserted on his globes some lines, for the purpose of solving a few problems in Lord *Castle-maine*'s manner.

It appears to me, from a copy of *Moxon*'s publication, which is in my possession, that the Earl of *Castlemaine* projected a new edition of his works, as the copy contains a great number of corrections, many alterations, and some additions. It is not very improbable, that at some future day I may republish this curious work, and adapt a small globe for the solution of the problems.

The meridians on our new terrestrial globes being secondaries to the equator, are also hour circles, and are marked as such with Roman figures, under the equator, and at the polar circles. But there is a difference in the figures placed to the same hour circle; if it cuts the IIId hour upon the polar circles, it will cut the IXth hour upon the equator, which is six hours later, and so of all the rest.

Through the great Pacific sea, and the intersec-

tion of Libra, is drawn a broad meridian from pole to pole; it passes through the XIIth hour upon the equator, and the VIth hour upon each of the polar circles; this hour circle is graduated into degrees and parts, and numbered from the equator towards either pole.

There is another broad meridian passing through the Pacific sea, at the IXth hour upon the equator, and the IIId hour upon each polar circle; this contains only one quadrant, or 90 degrees; the numbers annexed to it begin at the northern polar circle, and end at the tropic of Capricorn.

Here we must likewise observe, there are 23 concentric circles drawn upon the terrestrial globe within the northern and southern polar circles, which for the future we shall call polar parallels; they are placed at the distance of one degree from each other, and represent the parallels of the sun's declination, but in a different manner from the 47 parallels between the tropics.

The following problems require the globe to be placed upon a plane that is level, or truly horizontal, which is easily attained, if the floor, pavement, gravel-walk, in the garden, &c. should not happen to be horizontal.

A flat seasoned board, or any box which is about two feet broad, or two feet square, if the top be perfectly flat, will answer the purpose; the upper surface of either may be set truly horizontal, by the help of a pocket spirit level, or plumb-rule, if you raise or depress this or that side by a wedge or two as the spirit level shall direct; if you have a me-

ridian line drawn on the place over which you sub-
stitute this horizontal plane, it may be readily trans-
ferred from thence to the surface just levelled; this
being done, we are prepared for the solution of the
following problems.

It will be necessary to define a term we are
obliged to make use of in the solution of these
problems, namely, the *shade of extuberancy:* by
this is meant that shade which is caused by the
sphericity of the globe, and answers to what we
have heretofore named the terminator, defining
the boundaries of the illuminated and obscure
parts of the globe; this circle was, in the solution
of some of the foregoing problems, represented by
the broad paper circle, but is here realized by the rays
of the sun.

PROBLEM XXXIV. *To observe the sun's altitude,
by the terrestrial globe, when he shines bright, or when
he can but just be discerned through a cloud.*

Elevate the north pole of the globe to 66½ de-
grees; bring that meridian, or hour circle, which
passes through the IXth hour upon the equator,
under the graduated side of the strong brass meri-
dian; the globe being now set upon the horizon-
tal plane, turn it about thereon, frame and all,
that the shadow of the strong brass meridian may
fall directly under itself; or, in other words, that
the shade of its graduated face may fall exactly
upon the aforesaid hour circle; at that instant the

shade of extuberancy will touch the true degree of the sun's altitude upon that meridian, which passes through the IXth hour upon the equator, reckoned from the polar circle ; the most elevated part of which will then be in the zenith of the place where this operation is performed, and is the same whether it should happen to be either in north or south latitude.

Thus we may, in an easy and natural manner, obtain the altitude of the sun, at any time of the day, by the terrestrial globe ; for it is very plain, when the sun rises he brushes the zenith and nadir of the globe by his rays ; and as he always illuminates half of it, (or a few minutes more, as his globe is considerably larger than that of the earth) therefore when the sun is risen a degree higher, he must necessarily illuminate a degree beyond the zenith, and so on proportionably from time to time.

But, as the illuminated part is somewhat more than half, deduct 13 minutes from the shade of extuberancy, and you have the sun's altitude with tolerable exactness.

If you have any doubt how far the shade of extuberancy reaches, hold a pin, or your finger, on the globe, between the sun and point in dispute, and where the shade of either is lost, will be the point sought.

When the sun does not shine bright enough to cast a shadow. Turn the meridian of the globe towards the sun, as before, or direct it so that it may lie in

in the same plane with it, which may be done if you have but the least glimpse of the sun through a cloud ; hold a string in both hands, it having first, been put between the strong brass meridian and the globe ; stretch it at right angles to the meridian, and apply your face near to the globe, moving your eye lower and lower, till you can but just see the sun ; then bring the string held as before to this point upon the globe, that it may just obscure the sun from your sight, and the degree on the afore-said hour circle, which the string then lies upon, will be the sun's altitude required, for his rays would shew the same point if he shone out bright.

Note. The moon's altitude may be observed by either of these methods, and the altitude of any star by the last of them.

PROBLEM XXXV. *To place the terrestrial globe in the sun's rays, that it may represent the natural po-sition of the earth, either by a meridian line, or with-out it.*

If you have a meridian line, set the north and south points of the broad paper circle directly over it, the north pole of the globe being elevated to the latitude of the place ; and, standing upon a level plane, bring the place you are in under the graduated side of the strong brass meridian, then the poles and parallel circles upon the globe will, without sensible error, correspond with those in the heavens, and each point, kingdom, and state,

will be turned towards the real one which it repre-
sents.

If you have no meridian line, then the day of
the month being known, find the sun's declination
as before instructed, which will direct you to the
parallel of the day, amongst the polar parallels,
reckoned from either pole towards the polar circle;
which you are to remember.

Set the globe upon your horizontal plane in the
sun-shine, and put it nearly north and south by the
mariner's compass, it being first elevated to the lati-
tude of the place, and the place itself brought under
the graduated side of the strong brass meridian;
then move the frame and globe together, till the
shade of extuberancy, or term of illumination, just
touches the polar parallel for the day, and the
globe will be settled as before; and if accurately
performed, the variation of the magnetic needle
will be shewn by the degree to which it points in the
compass-box.

And here observe, if the parallel for the day
should not happen to fall on any one of those drawn
upon the globe, you are to estimate a proportionable
part between them, and reckon that the parallel of
the day. If we had drawn more, the globe would
have been confused.

The reason of this operation is, that as the sun il-
luminates half the globe, the shade of extuberancy
will constantly be 90 degrees from the point wherein
the sun is vertical.

If the sun be in the equator, the shade and illu-

mination must terminate in the poles of the world ; and when he is in any other diurnal parallel, the terms of illumination must fall short of, or go beyond either pole, as many degrees as the parallel which the sun describes that day is distant from the equator ; therefore, when the shade of extuberancy touches the polar parallel for the day, the artificial globe will be in the same position, with respect to the sun, as the earth really is, and will be illuminated in the same manner.

PROBLEM XXXVI. *To find naturally the sun's declination, diurnal parallel, and his place thereon.*

The globe being set upon an horizontal plane, and adjusted by a meridian line or otherwise, observe upon which, or between which polar parallel the term of illumination falls; its distance from the pole is the degree of the sun's declination ; reckon this distance from the equator among the larger parallels, and you have the parallel which the sun describes that day ; upon which, if you move a card, cut in the form of a double square, until its shadow falls under itself, you will obtain the very place upon that parallel over which the sun is vertical at any hour of that day, if you set the place you are in under the graduated side of the strong brass meridian.

Note. The moon's declination, diurnal parallel, and place, may be found in the same manner. Likewise, when the sun does not shine bright, his decli-

nation, &c. may be found by an application in the manner of problem xxxiv.

PROBLEM XXXVII. *To find the sun's azimuth natu-turally.*

If a great circle, at right angles to the horizon, passes through the zenith and nadir, and also through the sun's centre, its distance from the meridian in the morning or evening of any day, reckoned upon the degrees of the inner edge of the broad paper circle, will give the azimuth required.

Method I.

Elevate either pole to the position of a parallel sphere, by bringing the north pole in north latitude, and the south pole into south latitude, into the zenith of the broad paper circle, having first placed the globe upon your meridian line, or by the other method before prescribed; hold up a plumb-line, so that it may pass freely near the outward edge of the broad paper circle, and move it so that the shadow of the string may fall upon the elevated pole; then cast your eye immediately to its shadow on the broad paper circle, and the degree it there falls upon is the sun's azimuth at that time, which may be reckoned from either the south or north points of the horizon.

Method II.

If you have only a glimpse, or faint sight of the sun, the globe being adjusted as before, stand on the shady side, and hold the plumb-line on that side also, and move it till it cuts the sun's centre, and the elevated pole at the same time; then cast your eye towards the broad paper circle, and the degree it there cuts is the sun's azimuth, which must be reckoned from the opposite cardinal point.

PROBLEM XXXVIII. *To shew that in some places of the earth's surface, the sun will be twice on the same azimuth in the morning, and twice on the same azimuth in the afternoon: or in other words,*

When the declination of the sun exceeds the latitude of any place, on either side of the equator, the sun will be on the same azimuth twice in a morning, and twice in the afternoon.

Thus, suppose the globe rectified to the latitude of Antigua, which is about 17 degrees of north latitude, and the sun to be in the beginning of Cancer, or to have the greatest north declination; set the quadrant of altitude to the 21st degree north of the east in the horizon, and turn the globe upon its axis, the sun's centre will be on that azimuth at 6 h. 30 min. and also at 10 h. 30 min. in the morning. At 8 h. 30 min. the sun will be as it were stationary, with respect to its azimuth, for some time; as it

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will appear by placing the quadrant of altitude to the 17th degree north of the east in the horizon. If the quadrant be set to the same degrees north of the west, the sun's centre will cross it twice as it approaches the horizon in the afternoon.

This appearance will happen more or less to all places situated in the torrid zone, whenever the sun's declination exceeds their latitude; and from hence we may infer, that the shadow of a dial, whose gnomon is erected perpendicular to an horizontal plane, must necessarily go back several degrees on the same day.

But as this can only happen in the torrid zone, and as Jerusalem lies about 8 degrees to the north of the tropic of Cancer, the retrocession of the shadow on the dial of Ahaz, at Jerusalem, was, in the strictest signification of the word, miraculous.

PROBLEM XXXIX. *To observe the hour of the day in the most natural manner, when the terrestrial globe is properly placed in the sun-shine.*

There are many ways to perform this operation with respect to the hour, three of which are here inserted, being general to all the inhabitants of the earth; a fourth is added, peculiar to those of London, which will answer, without sensible error, at any place not exceeding the distance of 60 miles from this capital.

By a natural style.

Having rectified the globe as before directed, and placed it upon an horizontal plane over your meridian line, or by the other method, hold a long pin upon the illuminated pole, in the direction of the polar axis, and its shadow will shew the hour of the day amongst the polar parallels.

The axis of the globe, being the common section of the hour circles, is in the plane of each ; and as we suppose the globe to be properly adjusted, they will correspond with those in the heavens ; therefore the shade of a pin, which is the axis continued, must fall upon the true hour circle.

II. By an artificial style.

Tie a small string, with a noose, round the ele-vated pole, stretch its other end beyond the globe, and move it so that the shadow of the string may fall upon the depressed axis ; at that instant its shadow upon the equator will give the solar hour to a minute.

But remember, that either the autumnal or vernal equinoctial colure must first be placed under the graduated side of the strong brass meridian, before you observe the hour, each of these being marked upon the equator with the hour XII.

The string in this last case being moved into the

plane of the sun, corresponds with the true hour circle, and consequently gives the true hour.

III.   *Without any style at all.*

Every thing being rectified as before, look where the shade of extuberancy cuts the equator, the colure being under the graduated side of the strong brass meridian, and you obtain the hour in two places upon the equator, one of them going before, and the other following the sun.

Note. If this shade be dubious, apply a pin, or your finger, as before directed.

The reason is, that the shade of extuberancy being a great circle, cuts the equal in half, and the sun, in whatsoever parallel of declination he may happen to be, is always in the pole of the shade; consequently the confines of light and shade will shew the true hour of the day.

IV.   *Peculiar to the inhabitants of London, and any place within the distance of sixty miles from it.*

The globe being every way adjusted as before, and London brought under the graduated side of the strong brass meridian, hold up a plumb-line, so that its shadow may fall upon the zenith point, (which in this case is London itself) and the shadow of the string will cut the parallel of the day upon that point to which the sun is then vertical, and that

hour circle upon which this intersection falls is the hour of the day; and as the meridians are drawn within the tropics, at 20 minutes distance from each other, the point cut by the intersection of the string upon the parallel of the day, being so near the equator, may, by a glance of the observer's eye, be referred thereto, and the true time obtained to a minute.

The plumb-line thus moved is the azimuth; which, by cutting the parallel of the day, gives the sun's place, and consequently the hour circle which intersects it.

From this last operation results a corollary, that gives a second way of rectifying the globe to the sun's rays.

If the azimuth and shade of the illuminated axis agree in the hour when the globe is rectified, then making them thus to agree, must rectify the globe.

Corollary. *Another method to rectify the globe to the sun's rays.*

Move the globe, till the shadow of the plumb-line, which passes through the zenith, cuts the same hour on the parallel of the day that the shade of the pin, held in the direction of the axis, falls upon amongst the polar parallels, and the globe is rectified.

The reason is, that the shadow of the axis represents an hour circle; and by its agreement in the same hour, which the shadow of the azimuth string points out, by its intersection on the parallel of the day, it shews the sun to be in the plane, of the said

parallel ; which can never happen in the morning on the eastern side of the globe, nor in the evening on the western side of it, but when the globe is rectified.

This rectification of the globe is only placing it in such a manner, that the principal great circles and points may concur and fall in with those of the heavens.

The many advantages arising from these problems, relating to the placing of the globe in the sun's rays, the tutor will easily discern, and readily extend to his own, as well as to the benefit of his pupil.

THE

GENERAL PRINCIPLES

OF

DIALLING,

ILLUSTRATED BY

THE TERRESTRIAL GLOBE.

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The art of dialling is of very ancient origin, and was in former times cultivated by all who had any pretensions to science ; and before the invention of clocks and watches it was of the highest import- ance, and is even now used to correct and regulate them.

It teaches us by means of the sun's rays to divide time into equal parts, and to represent on any given surface the different circles into which, for conve- nience, we suppose the heavens to be divided, but principally the hour circles.

The hours are marked upon a plane, and pointed out by the interposition of a body, which receiving the light of the sun, casts a shadow upon the plane. This body is called the axis, when it is parallel, to the axis of the world. It is called the style when it is so placed that only the end of it coincides

with the axis of the earth ; in this case, it is only this point which marks the hours.

Among the various pleasing and profitable amusements which arise from the use of globes, that of dialling is not the least. By it the pupil will gain satisfactory ideas of the principles on which this branch of science is founded ; and it will reward, with abundance of pleasure, those that chuse to exercise themselves in the practice of it.

If we imagine the hour circles of any place, as London, to be drawn upon the globe of the earth, and suppose this globe to be transparent, and to revolve round a real axis, which is opake, and casts a shadow ; it is evident, that whenever the plane of any hour semicircle points at the sun, the shadow of the axis will fall upon the opposite semicircle.*

Let a P C p, *plate* 13, *fig.* 1, represent a transparent globe ; a b c d e f g the hour semicircles, it is clear, that if the semicircle P a p points at the sun, the shadow of the axis will fall upon the opposite semicircle.

If we imagine any plane to pass through the centre of this transparent globe, the shadow of half the axis will always fall upon one side or the other of this intersecting plane.

Thus let A B C D be the plane of the horizon of London ; so long as the sun is above the horizon,

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* *Long's* Astronomy, vol. I. p. 82.

the shadow of the upper half of the axis will fall somewhere upon the upper side of the plane A B C D; when the sun is below the horizon of London, then the shadow of the lower half of the axis E falls upon the lower side of the plane.

When the plane of any hour semicircle points at the sun, the shadow of the axis marks the respective hour-line upon the intersecting plane. The hour-line is therefore a line drawn from the centre of the intersecting plane, to that point where this plane is cut by the semicircle opposite to the hour semicircle.

Thus let A B C D, *plate* 13, *fig.* 1, the horizon of London, be the intersecting plane, when the meridian of London points at the sun, as in the present figure, the shadow of the half axis P E falls upon the line E B, which is drawn from E, the centre of the horizon, to the point where the horizon is cut by the opposite semicircle; therefore E B is the line for the hour of twelve at noon.

By the same method the rest of the hour-lines are found, by drawing for every hour a line, from the centre of the intersecting plane, to that semicircle which is opposite to the hour semicircle.

Thus *plate* 13, *fig.* 2, shews the hour-lines drawn upon the plane of the horizon of London, with only so many hours as are necessary; that is, those hours, during which the sun is above the horizon of London, on the longest day in summer.

If, when the hour-lines are thus found, the semicircles be taken away, as the scaffolding is when the

house is built, what remains, as in *fig.* 2, will be an horizontal dial for London.

If, instead of twelve hour circles, as above described, we take twice that number, we may by the points, where the intersecting plane is cut by them, find the lines for every half hour; if we take four times the number of hour circles, we may find the lines for every quarter of an hour, and so on progressively.

We have hitherto considered the horizon of London as the intersecting plane, by which is seen the method of making an horizontal dial. If we take any other plane for the intersecting plane, and find the points where the hour semicircles pass through it, and draw the lines from the centre of the plane to those points, we shall have the hour-lines for that plane.

Plate 13, *fig.* 3, shews how the hour-lines are found upon a south plane, perpendicular to the horizon. *Fig.* 4, shews a south dial, with its hour-lines, without the semicircle, by means whereof they are found.

The *gnomon* of every sun dial represents the axis of the earth, and is therefore always placed parallel to it; whether it be a wire, as in the figure before us, or the edge of a brass plate, as in a common horizontal dial.

The whole earth, as to its bulk, is but a point, if compared to its distance from the sun; therefore, if a small sphere of glass be placed on any part of the earth's surface, so that its axis be pa-

rallel to the axis of the earth, and the sphere have such lines upon it, and such planes within it, as above described, it will shew the hour of the day as truly as if it were placed at the centre of the earth, and the shell of the earth were as transparent as glass.

A wire sphere, with a thin flat plate of brass within it, is often made use of to explain the principles of dialling.

From what has been said, it is clear that dialling depends on finding where the shadow of a straight wire, parallel to the axis of the earth, will fall upon a given plane, every hour, half hour, &c. the hour-lines being found as above described, which we shall proceed to exemplify by the globe.

Every dial-plane (that is, the plane surface on which a dial is drawn) represents the plane of a great circle, which circle is an horizon to some country or other.

The centre of the dial represents the centre of the earth ; and the gnomon which casts the shade represents the axis, and ought to point directly to the poles of the equator.

The plane upon which dials are delineated may be either, 1. parallel to the horizon ; 2. perpendicular to the horizon ; or, 3. cutting it at oblique angles.

PROBLEM XI. *To construct an horizontal dial for any given latitude, by means of the terrestrial globe.*

Elevate the pole to the latitude of the place, then bring the first meridian under the graduated edge of the strong brazen one, which will then be over the hour XII, or the equator. As our globes have meridians drawn through every fifteen degrees of the equator, these meridians will represent the true circles of the sphere, and will intersect the horizon of the globe, in certain points on each side of the meridian. The distance of these points from the meridian must be carefully noted down upon a piece of paper, as will be seen in the example. The pupil need not, however, take out into his table the distances further than from XII to VI, which is just 90 degrees; for the distances of XI, X, IX, VIII, VII, VI, in the forenoon, are the same from XII as the distances of I, II, III, IV, V, VI, in the afternoon; and these hour lines continued through the centre will give the opposite hour-lines on the other half of the dial.

No more hour-lines need be drawn than what answer to the sun's continuance above the horizon, on the longest day of the year, in the given latitude.

Example. Suppose the given place to be London, whose latitude is 51 deg. 30 min. north.

Elevate the north pole of the globe to 51½ degrees

above the horizon; then will the axis of the globe have the same elevation above the broad paper circle, as the gnomon of the dial is to have above the plane thereof.

Turn the globe, till the first meridian (which on English globes passes through London) is under the graduated side of the strong brazen meridian; then observe and note the points where the hour-circles intersect the horizon; and as on our globes the inner graduated circle, on the broad paper circle, begins from the two sixes, or east and west, we shall begin from thence calling the hour   -   VI   0°   0′ we shall find the other hours intersecting the horizon at the following degrees; - -   V   18° 54′

IV	36	24
III	51	57
II	65	41
I	78	9

which are the respective distances of the above hours from VI upon the plane of the horizon.

To transfer these, and the rest of the hours, upon an horizontal plane, draw the parallel right lines a c, and b d, *plate* 13, *fig.* 5, upon that plane, as far from each other as is equal to the intended thickness of the gnomon of the dial, and the space included between them will be the meridian, or twelve o'clock line upon the dial; cross this meridian at right angles, by the line g h, which will be the six o'clock line; then setting one foot of your compasses in the intersection a, describe the quadrant g e with any convenient radius, or opening

of the compasses ; after this, set one foot of the compasses in the intersection b, as a centre, and with the same radius describe the quadrant f h ; then divide each quadrant into 90 equal parts, or degrees, as in the figure.

Because the hour lines are less distant from each other about noon, than in any other part of the dial, it is best to have the centres of the quadrants at some distance from the centre of the dial-plane, in order to enlarge the hour-distances near XII ; thus the centre of the plane is at A, but the centre of the quadrants is at a and b.

Lay a rule over 78° 9′, and the centre b, and draw there the hour-line of I. Through b, and 65 41, gives the hour-line of II. Through b, 51 57, that of III. Through the same centre, and 36 24, we obtain the hour-line of IV. And through it, and 18 54, that of V. And because the sun rises about four in the morning, continue the hour lines of IV and V in the afternoon, through the centre b to the opposite side of the dial.

Now lay a rule successively to the centre a of the quadrant e g, and the like elevations or degrees of that quadrant 78 9, 65 41, 51 57, 36 24, 18 54, which will give the forenoon hours of XI, X, IX, VIII, and VII ; and because the sun does not set before VIII in the evening on the longest days, conti-nue the hour-lines of VII and VIII in the afternoon, and all the hour-lines will be finished on this dial.

Lastly, through 51½ degrees on either quadrant, and from its centre, draw the right line a g for the

axis of the gnomon a g i, and from g let fall the per-
pendicular g i upon the meridian line a i, and there
will be a triangle made, whose sides are a g, g i, and
i a; if a plate similar to this triangle be made as thick
as the distance between the lines a c and b d, and be
set upright between them, touching at a and b,
the line a g will, when it is truly set, be parallel to
the axis of the world, and will cast a shadow on the
hour of the day.

The trouble of dividing the two quadrants may
be saved, by using a line of chords, which is al-
ways placed upon every scale belonging to a case of
instruments. *

PROBLEM XLI. *To delineate a direct south dial
for any given latitude, by the globe.*

Let us suppose a south dial for the latitude of
London.

Elevate the pole to the co-latitude of your place,
38° 30′, and proceed in all respects as above taught for
the horizontal dial, from VI in the morning to VI in
the afternoon, only the hours must be reversed, as in
plate 13, *fig.* 3 ; and the hypothenuse a g of the gno-
mon a g f, must make an angle with the dial plane
equal to the co-latitude of the place.

As the sun can shine no longer than from VI in
the morning to VI in the evening, there is no occa-
sion for having more than twelve hours upon this dial.

* Or much more so by an appropriate set of dialling lines, placed on
a one-foot box scale, which is sold at our shop, in Holborn.
EDIT.

In solving this problem, we have considered our vertical south dial for the latitude of London, as an horizontal one for the complement of that latitude, or 38 deg. 30 min. all direct vertical dials may be thus reduced to horizontal ones in the same manner. The reason of this will be evident, if the globe be elevated to the latitude of London ; for, by fixing the quadrant of altitude to the zenith, and bringing it to insersect the horizon in the east point, it will point out the plane of the proposed dial.

This plane is at right angles to the meridian, and perpendicular to the horizon ; and it is clear, from the bare inspection of the globe thus elevated, that its axis forms an angle with this plane, which is just the complement of that which it forms with the horizon, and is therefore just equal with the co-latitude of the place ; and that therefore it is most simple to rectify the globe to that co-latitude.

The north vertical dial is the same with the south, only the style must point upwards, and that many of the hours, from its direction can be of no use.

PROBLEM XLII. *To make an erect dial, declining from the South towards the east or west.*

Elevate the pole to the latitude of the place, and screw the quadrant of altitude to the zenith.

Then, if your dial declines towards the east, (which we shall suppose in the present instance)

count in the horizon the degrees of declination from the east point towards the north, and bring the lower end of the quadrant to coincide with that degree of declination at which the reckoning ends.

Then bring the first meridian under the graduated edge of the strong brass meridian, which strong meridian will serve as the horary index.

Now turn the globe westward, and observe the degrees cut in the quadrant of altitude by the first meridian, while the hours XI, X, IX, &c. in the forenoon, pass successively under the brazen one; and the degrees thus cut on the quadrant by the first meridian are the respective distances of the forenoon hours, from XII on the plane of the quadrant.

For the afternoon hours, turn the quadrant of altitude round the zenith, until it comes to the degree in the horizon, opposite to that where it was placed before, namely, as far from the west towards the south, and turn the globe eastward; and as the hours I, II, III, &c. pass under the strong brazen meridian, the first meridian will cut on the quadrant of altitude the number of degrees from the zenith that each of the hours is from XII on the dial.

When the first meridian goes off the quadrant at the horizon, in the forenoon, the hour index will shew the time when the sun comes upon this dial; and when it goes off the quadrant in the af-

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ternoon, it points to the time when the sun leaves the dial.

Having thus found all the hour distances from XII, lay them down upon your dial plane, either by dividing a semicircle into two quadrants, or by the line of chords.

In all declining dials, the line on which the gnomon stands makes an angle with the twelve o'clock line, and falls among the forenoon hour lines, if the dial declines towards the east; and among the afternoon hour lines, when the dial declines towards the west; that is, to the left hand from the twelve o'clock line in the former case, and to the right hand from it in the latter.

To find the distance of this line from that of twelve. This may be considered, 1. If the dial declines from the south towards the east, then count the degrees of that declination in the horizon, from the east point towards the north, and bring the lower end of the quadrant to that degree of declination where the reckoning ends; then turn the globe, until the first meridian cuts the horizon in the like number of degrees, counted from the south point towards the east, and the quadrant and first meridian will cross one another at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of this line from the twelve o'clock line.

The numbers of the first meridian, which are intercepted between the quadrant and the north pole,

is equal to the elevation of the style above the plane of the dial.

The second case is, when the dial declines westward from the south.

Count the declination from the east point of the horizon towards the south, and bring the quadrant of altitude to the degree in the horizon at which the reckoning ends, both for finding the forenoon hours and the distance of the substyle, or gnomon line, from the meridian; and for the afternoon hours, bring the quadrant to the opposite degrees in the horizon, namely, as far from the west towards the north, and then proceed in all respects as before.

It is presumed, that the foregoing instances will be sufficient to illustrate the general principles of dialling, and to give the pupil a general idea of that pleasing science : for accurate and expeditious methods of constructing dials, we must refer him to treatises written expressly on that subject.

NAVIGATION

EXPLAINED BY

THE GLOBE.

Navigation is the art of guiding a ship at sea, from one place to another, in the safest and most convenient manner. In order to attain this, four things are particularly necessary.

1. To know the situation and distances of places.

2. To know at all times the points of the compass.

3. To know the line in which the ship is to be directed from one place to the other.

4. To know, in any part of the voyage, what point of the globe the ship is upon.

The knowledge of the distance and situation of places, between which a voyage is to be made, implies not only a general knowledge of geography, but of several other particulars, as the rocks, sands, streights, rivers, &c. near which we are to sail; the bending out or running in of the shores, the knowledge of the times that particular winds set in, the seasons when storms and hurricanes are to be expected, but especially the tides; these, and many other similar circumstances are to be learned from

sea-charts, journals, &c. but chiefly by observation and experience.

The second particular to be attained, is the knowledge at all times of the points of the compass where the ship is. The ancients, to whom the polarity of the loadstone was unknown, found, in the day-time, the east or west, by the rising or setting of the sun ; and at night, the north, by the polar star. We have the advantage of the mariner's compass, by which, at any time in the wide ocean, and the darkest night, we know where the north is, and consequently the rest of the points of the compass.

Indeed, before the invention of the mariner's compass, the voyages of the Europeans were principally confined to coasting ; but this fortunate discovery has enabled the mariner to explore new seas, and discover new countries, which, without this valuable acquisition, would probably have remained for ever unknown.

The third thing required to be known, is the line which a ship describes upon the globe of the earth, in going from one place to another.

The shortest way from one place to another is an arc of a great circle drawn through the two places.

The most convenient way for a ship, is that by which we may sail from one place to another, directing the ship all the while towards the same point of the compass.

A ship is guided by steering or directing her towards some points of the compass : the line wherein

a ship is directed, is called the ship's course, which is named from the point towards which she sails.

Thus, if a ship sails towards the north-east point, her course is said to be N. E.

In long voyages, a ship's way may consist of a great number of different courses, as from A to B, from B to C, and from C to D, *plate* 13, *fig*. 9 ; when we speak of a ship's course, we consider one of these at a time ; the seldomer the course is changed, the more easily the ship is directed.

If two places, A *and* Z, *plate* 13, *fig*. 7, *lie under the same meridian*, the course from the one to the other is due north and south. Thus, let A Z be part of a meridian ; if A be south of Z, the course from A to Z must be north, and the course from Z to A south. This is evident from the nature of a meridian, that it marks upon the horizon the north and south points, and that every point of any meridian is north or south from every other point of it. From hence we may deduce the following corollary ; that if a ship sails due north or south, she will continue on the same meridian.

If two places lie under the equator, the course from one to the other is an arc of the equator, and is due east or west. Thus, let a z, *fig*. 7, be a part of the equator ; if a be west from z, the course from a to z is east, and the course from z to a is west : for, since the equator marks the east and west points upon the horizon, every point of the equator lies east or west of every other point of it, as may be seen upon the

globe, by placing it as for a right sphere, and bringing a or z, or any of the intermediate points, to the zenith; when it will be evident, that if we are to go from one of these points, a, to the other, z, or to any point on the equator, we must continue our course due east, to arrive at a, or *vice versa*. From hence we may deduce this consequence, that if a ship under the equator sails due east or west, she will continue under the equator.

In the two foregoing cases, the course being an arc of a great circle (the meridian or equator) is the shortest and most convenient way it can sail.

If two places lie under the same parallel, the course from one to the other is due east or west: this may be seen upon the globe, by the following method; bring any point of a parallel to the zenith, and stretch a thread over it, perpendicular to the meridian; the thread will then be a tangent to the parallel, and stand east and west from the point of contact. Hence, if a ship sails in any parallel, due east or west, she will continue in the same parallel. In this case the most convenient course, though not the shortest, from one to the other, is to sail due east or west.

If two places lie neither under the equator, nor on the same meridian, nor in the same parallel, the most convenient, though not the shortest course, from one to the other, is a rhumb.

For, if we would in this case attempt to go the shortest way, in a great circle drawn through the two places, we must be perpetually changing our course.

Thus, in *fig.* 8, whatever is the bearing of K from A, the bearings of all the intermediate points, as B, C, D, E, &c. will be different from it, as well as different from each other, as may be easily seen upon the globe, by bringing the first point, A, to the zenith, and observing the bearing of K from each of them. Thus, suppose when the globe is rectified to the horizon of A, the bearing of K from A be north-east, and the angle of position of K, with regard to A, be 45 degrees; if we bring B to the zenith, we shall have a different horizon, and the bearing and angle of position from K to B will be different from the former; and so on of the other points C, D, E, they will each of them have a different horizon, and K will have a different bearing and angle of position.

From hence we may draw this corollary, that when two places lie one from the other, towards a point not cardinal, if we sail from one place towards the point of the other's bearing, we shall never arrive at the other place. Thus, if K lies north-east from A, if we sail from A towards the north-east, we shall never arrive at K.

A *rhumb* upon the globe is a line drawn from a given place A, so as to cut all the meridians it passes through at equal angles; the rhumbs are denominated from the points of the compass, in a different manner from the winds. Thus, at sea, the north-east wind is that which blows from the north-east point of the horizon towards the ship in which

we are; but we are said to sail upon the N. E. rhumb, when we go towards the north-east.

The rhumb A B C D K, *plate* 13, *fig.* 8, passing through the meridians L M, N O, P Q, makes the angle L A B, N B C, P C D, equal; from whence it follows, that the direction of a rhumb is in every part of it towards the same point of the compass: thus, from every point of a north-east rhumb upon the globe, the direction is towards the north-east, and that rhumb makes an angle of 45 degrees, with every meridian it is drawn through.

Another property of the rhumbs is, that equal parts of the same rhumb are contained between parallels of equal distance of latitude; so that a ship continuing in the same rhumb, will run the same number of miles in sailing from the parallel of 10 to the parallel of 30, as she does in sailing from the parallel of 30 to that of 50.

The fourth thing mentioned to be required in navigation was, to know, at any time, what point of the globe a ship is upon. This depends upon four things: 1. the longitude; 2, the latitude; 3. the course of the ship has run; 4. the distance, that is, the way she has made, or the number of leagues or miles she has run in that course, from the place of the last observation. Now, any two of these being known, the rest may be easily found.

Having thus given some general idea of navigation, we now proceed to the problems by which the cases of sailing are solved on the globe.

PROBLEM XLIII. *Given the difference of latitude and difference of longitude, to find the course and distance sailed.**

Example. Admit a ship sails from a port A, in latitude 38 deg. to another port B, in latitude 5 deg. and finds her difference of longitude 43 deg.

Let the port A be brought to the meridian, and elevate the globe to the given latitude of that port 38 deg. and fixing the quadrant of altitude precisely over it on the meridian, move the quadrant to lie over the second port B, (found by the given difference of latitude and longitude) then will it cut in the horizon 50 deg. 45 min. for the angle of the ship's course to be steered from the port A. Also, count the degrees in the quadrant between the two ports, which you will find 51 deg. this number multiplied by 60, the nautical miles in a degree, will give 3060 for the distance run.

PROBLEM XLIV. *Given the difference of latitude and course, to find the difference of longitude, and distance sailed.*

Example. Admit a ship sails from a port A, in 25 deg. north latitude, to another port B, in 30 deg. south latitude, upon a course of 43 deg.

* See *Martin* on the Globes

Bring the port A to the meridian, and rectify the globe to the latitude thereof, 25 deg. where fix the quadrant of altitude, and place it so as to make an angle with the meridian of 43 deg. in the horizon, and observe where the edge of the quadrant inter- sects the parallel of 30 deg. south latitude, for that is the place of the port B. Then count the number of degrees on the edge of the quadrant intersected between the two ports, and there will be found 73 deg. which, multiplied by 60, gives 4380 miles for the distance sailed. As the two ports are now known, let each be brought to the meridian, and observe the difference of longitude in the equator respectively, which will be found 50 deg.

N. B. Had this problem been solved by *loxodro- mics*, or sailing on a rhumb, the difference of lon- gitude would then have been 52 deg. 30 min. be- tween the two ports.

PROBLEM XLV. *Given the difference of latitude and distance run, to find the difference of longitude, and angle of the course.*

Example. Admit a ship sails from a port A, in latitude 50 deg. to another port B, in latitude 17 deg. 30 min. and her distance run be 2220 miles. Rectify the globe to the latitude of the place A, then the distance run, reduced to degrees, will make 37 deg. which are to be reckoned from the end of the quadrant lying over the port A, under the meridian; then is the quadrant to be moved, till the 37 degrees coincide with the parallel of 17 deg. 30 min. north

latitude ; then will the angle of the course appear in the arch of the horizon, intercepted between the quadrant and the meridian, which will be 32 deg. 40 min. ; and by making a mark on the globe for the port B, and bringing the same to the meridian, you will observe what number of degrees pass under the meridian, which will be twenty, the difference of longitude required.

PROBLEM XLVI. *Given the difference of longitude and course, to find the difference of latitude and distance sailed.*

Example. Suppose a ship sails from A, in the latitude 51 deg. on a course making an angle with the meridian of 40 deg. till the difference of longitude be found just 20 degrees; then rectifying the globe to the latitude of the port A, place the quadrant of altitude so as to make an angle of 40 deg. with the meridian ; then observe at what point it intersects the meridian passing through the given longitude of the port B, and there make a mark to represent the said port; then the number of degrees intercepted between that and the port A, will be 28, which will give 1680 miles for the distance run : and the said mark for the port B, being brought to the meridian, will have its latitude there shewn to be 27 deg. 40 min.

PROBLEM XLVII. *Given the course and distance sailed to find the difference of longitude, and difference of latitude.*

Example. Suppose a ship sails 1800 miles from a port A, 51 deg. 15 min. south-west, on an angle of 45 deg. to another port B.

Having rectified the globe to the port A, fix the quadrant of altitude over it in the zenith, and place it to the south-west point in the horizon; then upon the edge of the quadrant under 30 deg. (equal to 1800 miles from the port A) is the port B; which bring to the meridian, and you will there see the latitude; and at the same time, its longitude on the equator, in the point cut by the meridian.

In all these cases, the ship is supposed to be kept upon the *arch of a great circle*, which is not difficult to be done, very nearly, by means of the globe, by frequently observing the latitude, measuring the distance sailed, and (when you can) finding the difference of longitude; for one of these being given, the place and course of the ship is known at the same time; and therefore the preceding course may be altered, and rectified without any trouble, through the whole voyage, as often as such observations can be obtained, or it is found necessary. Now if any of these *data* are but of the quantity of four or five degrees, it will suffice for correcting the ship's course by the globe, and carrying her directly to the intended port, according to the following problem.

Problem xlviii. *To steer a ship upon the arch of a great circle by the given difference of latitude, or difference of longitude, or distance sailed in a given time.*

Admit a ship sails from a port A, to a very distant port Z, whose latitude and longitude are given, as well as its geographical bearing from A; then,

First, having rectified the globe to the port A, lay the quadrant of altitude over the port Z, and draw thereby the arch of the great circle through A and Z; this will design the intended path or track of the ship.

Secondly, having kept the ship upon the first given course for some time, suppose by an observation you find the latitude of the *present place* of the ship, this added to, or subducted from the latitude of the port A, will give the present latitude in the meridian; to which bring the path of the ship, and the part therein, which lies under the new latitude, is the true place B of the ship in the great arch. To the latitude of B rectify the globe, and lay the quadrant over Z, and it will shew in the horizon the new course to be steered.

Thirdly, suppose the ship to be steered upon this course, till her distance run be found 300 miles, or 5 degrees; then, the globe being rectified to the place B in the zenith, laying the quadrant from thence over the great arch, make a mark at the 5th

degree from B, and that will be the present place of the ship, which call C ; which being brought to the meridian, its latitude and longitude will be known. Then rectify the globe to the place C, and laying the quadrant from thence to Z, the new course to be steered will appear in the horizon.

Fourthly, having steered some time upon this new course, suppose, by some means or other, you come to know the difference of longitude of the present place of the ship, and of any of the preceding places, C, B, A ; as B, for instance ; then bring B to the meridian, and turn the globe about, till so many degrees of the equator pass under the meridian as are equal to the discovered difference of longitude ; then the point of the great arch cut by the meridian is the present place D of the ship, to which the new course is to be found as before.

And thus, by repeating these observations at proper intervals, you will find future places, E, F, G, &c. in the great arch ; and by rectifying the course at each, your ship will be conducted on the great circle, or the nearest way from the port A to Z, by the use of the globe only.

OF

THE USE

OF THE

TERRESTRIAL GLOBE,

WHEN MOUNTED IN THE COMMON MANNER.

———————

ALTHOUGH I have, in the first part of this Essay, laid before my readers the reasons which induce me to prefer my father's manner of mounting the globes to the old or Ptolemaic form, yet as many may be in possession of globes mounted in the old form, and others may have been taught by those globes, I thought it would render these Essays more complete, to give an account of so many of the leading problems, solved on the common globes, as would enable them to apply the remainder of those heretofore solved, to their own use. This is the more expedient, as, since the publication of my father's Treatise, there have been a few attempts to do away some of the inconveniences of the ancient form, particularly that of the old hour-circle, which is now generally placed under the meridian.

I cannot, however, refrain from again observing to the pupil, that the solution of the problems on the

old globes depends upon appearances; that therefore, if he means to content himself with the mere mechanical solution of them, the Ptolemaic globes will answer his purpose; but if he wishes to have clear ideas of the rationale of those problems, he must use those mounted in my father's manner.

The celestial globe is used the same way in both mountings, excepting that in my father's mounting it has some additional circles; but the difference is so trifling, that it is presumed the pupil can find no difficulty in applying the directions there given to the old form.

PROBLEM I. *To find the latitude and longitude of any given place on the globe.*

Bring the place to the east side of the brass meridian, then the degree marked on the meridian over it shews its latitude, and the degree of the equator under the meridian shews its longitude.

Hence, if the longitude and latitude of any place be given, the place is easily found, by bringing the given longitude to the meridian; for then the place will lie under the given degree of latitude upon the meridian.

PROBLEM II. *To find the difference of longitude between any two given places.*

Bring each of the given places successively to the brazen meridian, and see where the meridian cuts the

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equator each time ; the number of degrees contained between those two points, if it be less than 180 degrees, otherwise the remainder to 360 deg. will be the difference of longitude required.

PROBLEM III. *To rectify the globe for the latitude, zenith, and sun's place.*

Find the latitude of the place by Prob. 1, and if the place be in the northern hemisphere, elevate the north pole above the horizon, according to the latitude of the place. If the place be in the southern hemisphere, elevate the south pole above the south point of the horizon, as many degrees as are equal to the latitude.

Having elevated the globe according to its latitude, count the degrees thereof upon the meridian from the equator towards the elevated pole, and that point will be the zenith, or the vertex of the place ; to this point of the meridian fasten the quadrant of altitude, so that the graduated edge thereof may be joined to the said point.

Having brought the sun's place in the ecliptic to the meridian, set the hour index to XII at noon, and the globe will be rectified to the sun's place.

PROBLEM IV. *The hour of the day at any place being given, to find all those on the globe, where it is noon, midnight, or any given hour at that time.*

On the globes when mounted in the common

manner, it is now customary to place the hour-circle under the north pole; it is divided into twice twelve hours, and has two rows of figures, one running from east to west, the other from west to eat; this circle is moveable, and the meridian answers the purpose of an index.

Bring the given place to the brazen meridian, and the given hour of the day on the hour-circle; turn the globe, till the meridian points at the hour desired; then, with all those under the meridian, it is noon, midnight, or any given hour at that time.*

PROBLEM V. *The hour of the day at any place being given, to find the correspondent hour (or what o'clock it is at that time) in any other place.*

Bring the given place to the brazen meridian, and set the hour circle to the given time; then turn the globe about, until the place where the hour is required comes to the meridian, and the meridian will point out the hour of the day at that place.

* Another preferable method, which I generally adopt in the *New British Globes*, is to place the north horary circles and indexes externally on the meridians, and to make the north polar pin with index to unscrew, so that the circle may be slid to any part of the meridian, to admit the entire free passage of the brass meridian through the horizon, and the circle to be brought over any place for problems relative to bearings, &c. upon the terrestrial globe. EDIT.

Thus, when it is noon at London, it is

					H.	M.	
At Rome	-	-	-	-	0	52	P. M.
Constantinople	-	-	-		2	7	P. M.
Vera Cruz	-	-	-		5	30	A. M.
Pekin in China	-	-	-		7	50	P. M.

PROBLEM VI. *The day of the month being given, to find all those places on the globe where the sun will be vertical, or in the zenith, that day.*

Having found the sun's place in the ecliptic for the given day, bring the same to the brazen meridian, observe what degree of the meridian is over it, then turn the globe round its axis, and all places that pass under that degree of the meridian, will have the sun vertical, or in the zenith, that day.

PROBLEM VII. *A place being given in the torrid zone, to find those two days of the year on which the sun will be vertical to that place.*

Bring the given place to the brazen meridian, and mark the degree of latitude that is exactly over it on the meridian ; then turn the globe about its axis, and observe the two points of the ecliptic which pass exactly under that degree of latitude, and look on the horizon for the two days of the year in which the sun is in those points or degrees of the ecliptic, and they are the days required; for on them, and none else, the sun's declination is equal to the latitude of the given place.

PROBLEM VIII. *To find the antœci, periœci, and an-
tipodes of any given place.*

Bring the given place to the brazen meridian, and
having found its latitude, keep the globe in that
position, and count the same number of degrees
of latitude on the meridian, from the equator to-
wards the contrary pole, and where the reckoning
ends, that will give the place of the antœci upon
the globe. Those who live at the equator have no
antœci.

The globe remaining in the same position, bring
the upper XII on the horary circle to the meri-
dian, then turn the globe about till the meridian
points to the lower XII; the place which then
lies under the meridian, having the same latitude
with the given place, is the periœci required.
Those who live at the poles, if any, have no pe-
rœci.

As the globe now stands (with the index at the
lower XII), the antipodes of the given place are
under the same point of the brazen meridian where
its antœci stood before.

PROBLEM IX. *To find at what hour the sun rises
and sets any day in the year at any place, and also upon
what point of the compass.*

Rectify the globe for the latitude of the given
place ; bring the sun's place to the meridian, and
U 3

bring the XII to the meridian ; then turn the sun's place to the eastern edge of the horizon, and the meridian will point out the hour of rising ; if you bring it to the western edge of the horizon, it will shew the setting.

Thus on the 16th day of March, the sun rose a little past six, and set a little before six.

Note. In the summer the sun rises and sets a little to the northward of the east and west points, but in winter, a little to the southward of them. If, therefore, when the sun's place is brought to the eastern and western edges of the horizon, you look on the inner circle, right against the sun's place, you will see the point of the compass upon which the sun rises and sets that day.

PROBLEM X.   *To find the length of the day and night at any time of the year.*

Only double the time of the sun's rising that day, and it gives the length of the night ; double the time of his setting, and it gives the length of the day.

This problem shews how long the sun is with us on any day, and how long he is absent from us on any night.

Thus on the 26th of May, the sun rises about four, and sets about eight ; therefore the day is sixteen hours long, and the night eight.

PROBLEM XI. *To find the length of the longest or shortest day, at any place upon the earth.*

Rectify the globe for that place, bring the beginning of Cancer to the meridian, bring XII to the meridian, then bring the same degree of Cancer to the east part of the horizon, and the meridian will shew the time of the sun's rising.

If the same degree be brought to the western side, the meridian will shew the setting, which doubled (as in the last problem) will give the length of the longest day and shortest night.

If we bring the beginning of Capricorn to the meridian, and proceed in all respects as before, we shall have the length of the longest night and shortest day.

Thus in the Great Mogul's dominions, the longest day is fourteen hours, and the shortest night ten hours. The shortest day is ten hours, and the longest night fourteen hours.

At Petersburgh the longest day is about $19\frac{1}{2}$ hours, and the shortest night $4\frac{1}{2}$ hours; the shortest day $4\frac{1}{2}$ hours, and longest night $19\frac{1}{2}$ hours.

Note. In all places near the equator, the sun rises and sets at six the year round. From thence to the polar circles, the days increase as the latitude increases; so that at those circles themselves, the longest day is twenty-four hours, and the longest night just the same. From the polar circles to the poles, the days continue to lengthen into weeks and months;

so that at the very pole, the sun shines for six months together in summer, and is absent from it six months in winter.

Note. That when it is summer with the northern inhabitants, it is winter with the southern, and the contrary; and every part of the world partakes of an equal share of light and darkness.

PROBLEM XII. *To find all those inhabitants to whom the sun is this moment rising or setting, in their meridian or midnight.*

Find the sun's place in the ecliptic, and raise the pole as much above the horizon as the sun (that day) declines from the equator; then bring the place where the sun is vertical at that hour to the brass meridian; so will it then be in the zenith or centre of the horizon. Now see what countries lie on the western edge of the horizon, for in them the sun is rising; to those on the eastern side he is setting; to those under the upper part of the meridian it is noon day; and to those under the lower part of it, it is midnight.

Thus, on the 25th of April, at six o'clock in the evening, at Worcester,

The sun is rising at New Zealand; and to those who are sailing in the middle of the Great South Sea,

The sun is setting at Sweden, Hungary, Italy, Tunis, in the middle of Negroland and Guinea.

In the meridian (or noon) at the middle of Mexico, Bay of Honduras, middle of Florida, Canada, &c.

Midnight at the middle of Tartary, Bengal, India, and the seas near the Sunda isles.

PROBLEM XIII. *To find the beginning and end of twilight.*

The twilight is that faint light which opens the morning by little and little in the east, before the sun rises ; and gradually shuts in the evening in the west, after the sun is set. It arises from the sun's illuminating the upper part of the atmosphere, and begins always when he approaches within eighteen degrees of the eastern part of the horizon, and ends when he descends eighteen degrees below the western ; when dark night commences, and continues till day breaks again.

To find the beginning of twilight, rectify the globe ; turn the degree of the ecliptic, which is opposite to the sun's place, till it is elevated 18 degrees to the quadrant of altitude above the horizon on the west, so will the index point the hour twilight begins.*

This short specimen of problems by the globes, as commonly mounted, it is presumed, will be sufficient to enable the pupil to solve any other.

* The quadrant of altitude is now generally divided to 18° below 0, so that observing the sun's place 18° below the horizon, will more readily give the duration of twilight. EDIT.

ESSAY II.

PART IV.

OF

THE USE

OF THE

CELESTIAL GLOBE,

AS MOUNTED IN THE COMMON MANNER.

THE celestial globe is an artificial representation of the heavens, having the fixed stars drawn upon it, in their natural order and situation ; whilst its rotation on its axis represents the apparent diurnal motion of the sun, moon, and stars.

It is not known how early the ancients had any thing of this kind : we are not certain what the sphere of *Atlas* or *Musæus* was ; perhaps *Palamedes*, who lived about the time of the Trojan war, had something of this kind ; for of him it is said,

> To mark the signs that cloudless skies bestow,
> To tell the seasons, when to sail and plow,
> He first devised ; each planet's order found,
> Its distance, period, in the blue profound.

From *Pliny* it would seem that *Hipparchus* had a celestial globe with the stars delineated upon it.

It is not to be supposed, that the celestial globe is so just a representation of the heavens as the ter-

restrial globe is of the earth ; because here the stars are drawn upon a convex surface, whereas they naturally appear in a concave one. But suppose the globe were made of glass, then to an eye placed in the centre, the stars which are drawn upon it would appear in a concave surface, just as they do in the heavens.

Or if the reader was to suppose that holes were made in each star, and an eye placed in the centre of the globe, it would view, through those holes, the same stars in the heavens that they represent.

As the terrestrial globe, by turning on its axis, represents the real diurnal motion of the earth ; so the celestial globe, by turning on its axis, represents the apparent diurnal motion of the heavens.

For the sake of perspicuity, and to avoid continual references, it will be necessary to repeat here some articles which have been already mentioned.

The *ecliptic* is that graduated circle which crosses the equator in an angle of about 23½ deg. and the angle is called the obliquity of the ecliptic.

This circle is divided into twelve equal parts, consisting of 30 degrees each ; the beginning of them are marked with characters, representing the twelve signs.

Aries ♈, Taurus ♉, Gemini ♊, Cancer ♋, Leo ♌, Virgo ♍, Libra ♎, Scorpio ♏, Sagittarius ♐, Capricornus ♑, Aquarius ♒, Pisces ♓.

Upon my father's globes, just under the ecliptic, the month, and days of each month, are graduated,

for the readier fixing the artificial sun upon its place in the ecliptic.

The two points where the ecliptic crosses the equinoctial (the circle that answers to the equator on the terrestrial globe) are called the *equinoctial points*: they are at the beginning of Aries and Libra, and are so called, because when the sun is in either of them, the day and night is every where equal.

The first points of Cancer and Capricorn are called *solstitial points*; because when the sun arrives at either of them, he seems to stand, in a manner, still for several days, in respect to his distance from the equinoctial; when he is in one solstitial point, he makes to us the longest day; when in the other, the longest night.

The latitude and longitude of stars are determined from the ecliptic.

The longitude of the stars and planets is reckoned upon the ecliptic; the numbers beginning at the first points of Aries, where the ecliptic crosses the equator, and increasing according to the order of the signs.

Thus, suppose the sun to be in the tenth degree of Leo, we say, his longitude, or place, is four signs, ten degrees; because he has already passed the four signs, Aries, Taurus, Gemini, Cancer, and is ten degrees in the fifth.

The latitude of the stars and planets is determined by their distance from the ecliptic upon a secondary

or great circle passing through its poles, and cross-ing it at right angles.

Twenty-four of these circular lines, which cross the ecliptic at right angles, being fifteen degrees from each other, are drawn upon the surface of our celestial globe; which being produced both ways, those on one side meet in a point on the northern polar circle, and those on the other meet in a point on the southern polar circle.

The points determined by the meeting of these cir-cles are called the poles of the ecliptic, one north, the other south.

From these definitions it follows, that longitude and latitude, on the celestial globe, bear just the same relation to the ecliptic, as they do on the ter-restrial globe to the equator.

Thus, as the longitude of places on the earth is measured by degrees upon the equator, counting from the first meridian; so the longitude of the heavenly bodies is measured by degrees upon the ecliptic, counting from the first point of Aries.

And as latitude on the earth is measured by degrees upon the meridian, counting from the equator; so the latitude of the heavenly bodies is measured by de-grees upon a circle of longitude, counting either north or south from the ecliptic.

The sun, therefore, has no latitude, being al-ways in the ecliptic; nor do we usually speak of his longitude, but rather of his place in the ecliptic, expressing it by such a degree and minute of such a

sign, as 5 degrees of Taurus, instead of 35 degrees of longitude.

The distance of any heavenly body from the equinoctial, measured upon the meridian, is called its declination.

Therefore, the sun's declination, north or south, at any time, is the same as the latitude of any place to which he is then vertical, which is never more than $23\frac{1}{2}$ degrees.

Therefore all parallels of declination on the celestial globe are the very same as parallels of latitude on the terrestrial.

Stars may have north latitude and south declination, and *vice versa*.

That which is called longitude on the terrestrial globe, is called *right ascension* on the celestial; namely, the sun or star's distance from that meridian which passes through the first point of Aries, counted on the equinoctial.

Astronomers also speak of *oblique ascension* and *descension*, by which mean the distance of that point of the equinoctial from the first point of Aries, which in an oblique sphere rises or sets at the same time that the sun or star rises or sets.

Ascensional difference is the difference betwixt right and oblique ascension. The sun's ascensional difference turned into time, is just so much as he rises before or after six o'clock.

The celestial signs and constellations on the surface of the celestial globe, are represented by a vari-

ety of human and other figures, to which the stars that are either in or near them, are referred.

The several systems of stars, which are applied to those images, are called constellations. Twelve of these are represented on the ecliptic circle, and extend both northward and southward from it. So many of those stars as fall within the limits of 8 degrees on both sides the ecliptic circle, together with such parts of their images as are contained within the aforesaid bounds, constitute a kind of broad hoop, belt, or girdle, which is called the *zodiac*.

The names and the respective characters of the twelve signs of the ecliptic, may be learned by inspection on the surface of the broad paper circle, and the constellations from the globe itself.

The zodiac is represented by eight circles parallel to the ecliptic, on each side thereof; these circles are one degree distant from each other, so that the whole breadth of the zodiac is sixteen degrees.

Amongst those parallels, the latitude of the planets is reckoned; and in their apparent motion they never exceed the limits of the zodiac.

On each side of the zodiac, as was observed, other constellations are distinguished; those on the north side are called northern, and those on the south side of it, southern constellations.

OF THE PRECESSION OF THE EQUINOXES.

All the stars which compose these constellations, are supposed to increase their longitude continually; upon which supposition, the whole starry firmament has a slow motion from west to east; insomuch that the first star in the constellation of Aries, which appeared in the vernal intersection of the equator and ecliptic in the time of *Meton*, the Athenian, upwards of 1900 years ago, is now removed about 30 degrees from it.

This change of the stars in longitude, which has now become sufficiently apparent, is owing to a small retrograde motion of the equinoctial points, of about 50 seconds in a year, which is occasioned by the attraction of the sun and moon upon the protuberant matter about the equator. The same cause also occasions a small deviation in the parallelism of the earth's axis, by which it is continually directed towards different points in the heavens, and makes a complete revolution round the ecliptic, in about 25,920 years. The former of these motions is called the *precession of the equinoxes*, the latter the *nutation of the earth's axis*. In consequence of this shifting of the equinoctial points, an alteration has taken place in the signs of the ecliptic; those stars, which in the infancy of astronomy were in Aries, being now got into Taurus, those of Taurus into Gemini, &c. so that the stars which rose and set at any particular season of the year, in the times of *Hesiod, Eudoxes,* and

Virgil, will not at present answer the description given of them by those writers.

PROBLEM I. *To represent the motion of the equinoctial points backwards, or in antecedentia, upon the celestial globe.*

Elevate the north pole, so that its axis may be perpendicular to the plane of the broad paper circle, and the equator will then be in the same plane ; let these represent the ecliptic, and then the poles of the globe will also represent those of the ecliptic ; the ecliptic line upon the globe will at the same time represent the equator, inclined in an angle of $23\frac{1}{2}$ degrees, to the broad paper circle, now called the ecliptic, and cutting it in two points, which are called the equinoctial intersections.

Now if you turn the globe slowly round upon its axis, from east to west, while it is in this position, these points of intersection will move round the same way; and the inclination of the circle, which in shewing this motion represents the equinoctial, will not be altered by such a revolution of the intersecting or equinoctial points. This motion is called the precession of equinoxes, because it carries the equinoctial points backwards amongst the fixed stars.

The poles of the world seem to describe a circle from east to west, round the poles of the ecliptic, arising from the precession of the equinox. It is a very slow motion, for the equinoctial points take up

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72 years to move one degree, and therefore they are 25,920 years in describing 360 degrees, or completing a revolution.

This motion of the poles is easily represented by the above described position of the globe, in which, if the reader remembers, the broad paper circle represents the ecliptic, and the axis of the globe being perpendicular thereto, represents the axis of the ecliptic; and the two points where the circular lines meet will represent the poles of the world, whence, as the globe is slowly turned from east to west, these points will revolve the same way about the poles of the globe, which are here supposed to represent the poles of the ecliptic. The axis of the world may revolve as above, although its situation, with respect to the ecliptic, be not altered; for the points here supposed to represent the poles of the world, will always keep the same distance from the broad paper circle, which represents the ecliptic in this situation of the globe.*

From the different degrees of brightness in the stars, some appear to be greater than others, or nearer to us: on our celestial globe they are distinguished into seven different magnitudes.

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* A globe is sometimes mounted with an apparatus peculiarly for this purpose, and is the best adapted to convey a sufficient idea of this curious phenomenon, and which I have already more clearly explained at page 174.

OF

THE USE

OF THE

CELESTIAL GLOBE

IN THE SOLUTION OF

PROBLEMS RELATIVE TO THE SUN.

EVERY thing that relates to the sun is of such importance to man, that in all things he claims a natural pre-eminence. The sun is at once the most beautiful emblem of the Supreme Being, and under his influence, the fostering parent of worlds; being present to them by his rays, cheering them by his countenance, cherishing them by his heat, adorning them at each returning spring with the gayest and richest attire, illuminating them with his light, and feeding the lamp of life.

To the ancients he was known under a variety of names, each characteristic of his different effects; he was their Hercules, the great deliverer, the restorer of light out of darkness, the dispenser of good, continually labouring for the happiness of a depraved race. He was the Mithra of the Persians, a word derived from love, or mercy, because the whole world is cherished by him, and feels, as it were, the effects of his love.

In the sacred scriptures, the original source of all emblematical writings, our Lord is called our sun, and the sun of righteousness; and as there is but one sun in the heavens, so there is but one true God, the maker and redeemer of all things, the light of the understanding, and the life of the soul.

As in scripture our God is spoken of as a shield and buckler, so the sun is characterized by this mark ⊙, representing a shield or buckler, the middle point the umbo, or boss; because it is love, or life, which alone can protect from fear and death.

His celestial rays, like those of the sun, take their circuit round the earth; there is no corner of it so remote as to be without the reach of their vivifying and penetrating power. As the material light is always ready to run its heavenly race, and daily issues forth with renewed vigour, like an invincible champion, still fresh to labour; so likewise did our redeeming God rejoice to run his glorious race, he excelled in strength, and triumphed, and continues to triumph over all the powers of darkness, and is ever manifesting himself as the deliverer, the protector, the friend, and father, of the human race.*

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* *Horne* on the Psalms.

PROBLEM II. *To rectify the celestial globe.*

To rectify the celestial globe, is to put it in that position in which it may represent exactly the apparent motions of the heavens.

In different places the position will vary, and that according to the different latitudes of the places. Therefore, to rectify for any place, find first, by the terrestrial globe, the latitude of that place.

The latitude of the place being found in degrees, elevate the pole of the celestial globe the same number of degrees and minutes above the plane of the horizon, for this is the name given to the broad paper circle, in the use of the celestial globe.

Thus the latitude of London being 51½ degrees, let the globe be moved till the plane of the horizon cuts the meridian in that point.

The next rectification is for the sun's place, which may be performed as directed in Prob. xxix; or look for the day of the month close under the ecliptic line, against which is the sun's place; place the artificial sun, or small paper patch, over that point, then bring the sun's place to the graduated edge of the strong brazen meridian, and set the hour index to the most elevated XII.

Thus, on the 24th of May the sun is in 3½ degrees of Gemini, and is situated near the Bull's eye and the seven stars, which are not then visible on account of his superior light. If the sun were on that day to suffer a total eclipse, these stars

would then be seen shining with their accustomed brightness.

Lastly. Set the meridian of the globe north and south by the compass.

And the globe will be rectified, or put into a similar position to the concave surface of the heavens, for the given latitude.

PROBLEM III. *To find the right ascension and declination of the sun for any day.*

Bring the sun's place in the ecliptic for the given day to the meridian, and the degree of the meridian directly over it is the sun's declination for that day at noon. The point of the equinoctial cut by the meridian, when the sun's place is under it, will be the right ascension.

Thus, April 19, the sun's declination is 11° 14′ north, his right ascension 27° 30′. On the first of December the sun's declination is 21° 54′ south, right ascension 247° 50′.

PROBLEM IV. *To find the sun's oblique ascension and descension, its eastern and western amplitude, and time of rising and setting, on any given time, in any given place.*

1. Rectify the globe for the latitude, the zenith, and the sun's place. 2. Bring the sun's place to the eastern side of the horizon; then the number of degrees intercepted between a degree of the equi-

noctial at the horizon, and the beginning of Aries, is the sun's oblique ascension. 3. The number of degrees on the horizon intercepted between the east point and the sun's place, is the eastern or rising amplitude. 4. The hour shewn by the index is the time of sun-rising. 5. Carry the sun to the western side of the horizon, and you in the same manner obtain the oblique descension, western amplitude, and time of setting. Thus, at London, May 1,

The sun's oblique ascension - - - - 18° 48'

Eastern amplitude - - - - 24 57 N

Time of rising - - - - - 4 h 40 m

Oblique descension - - - 257° 7'

Western amplitude - - - 26 9

Time of setting - - - - 7 h 4 m

PROBLEM V. *To find the sun's meridian altitude.*

Rectify the globe for the latitude, zenith, and sun's place; and when the sun's place is in the meridian, the degrees between that point and the horizon are its meridian altitude. Thus, on May 17, at London, the meridian altitude of the sun is 57° 55'.

PROBLEM VI. *To find the length of any day in the year, in any latitude not exceeding 66½ degrees.*

Elevate the celestial globe to the latitude, and set the centre of the artificial sun to his place upon the ecliptic line on the globe for the given day, and

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bring its centre to the strong brass meridian, placing the horary index to that XII which is most elevated; then turn the globe till the artificial sun cuts the eastern edge of the horizon, and the horary index will shew the time of sun-rising; turn it to the western side, and you obtain the hour of sun-setting.

The length of the day and night will be obtained by doubling the time of sun-rising and setting, as before.

PROBLEM VII. *To find the length of the longest and shortest days in any latitude that does not exceed* $66\frac{1}{2}$ *degrees.*

Elevate the globe according to the latitude, and place the centre of the artificial sun for the longest day upon the first point of Cancer; but for the shortest day upon the first point of Capricorn: then proceed as in the last problem.

But if the place hath south latitude, the sun is in the first point of Capricorn on their longest day, and in the first point of Cancer on their shortest day.

PROBLEM VIII. *To find the latitude of a place, in which its longest day may be of any given length between twelve and twenty-four hours.*

Set the artificial sun to the first point of Cancer, bring its centre to the strong brass meridian, and set the horary index to XII; turn the globe till it points

to half the number of the given hours and minutes ; then elevate or depress the pole till the artificial sun coincides with the horizon, and that elevation of the pole is the latitude required.

PROBLEM IX. *To find the time of the sun's rising and setting, the length of the day and night, on any place whose latitude lies between the polar circles ; and also the length of the shortest day in any of those latitudes, and in what climate they are.*

Rectify the globe to the latitude of the given place, and bring the artificial sun to his place in the ecliptic for the given day of the month ; and then bring its centre under the strong brass meridian, and set the horary index to that XII which is most elevated.

Then bring the centre of the artificial sun to the eastern part of the broad paper circle, which in this case represents the horizon, and the horary index shews the time of the sun-rising ; turn the artificial sun to the western side, and the horary index will shew the time of the sun-setting.

Double the time of sun-rising is the length of the night, and the double of that of sun-setting, is the length of the day.

Thus, on the 5th day of June, the sun rises at 3 h. 40 m. and sets at 8 h. 20 min. ; by doubling each number it will appear, that the length of this day is 16 h. 40 min. and that of the night 7 h. 20 min.

The longest day at all places in north latitude is, when the sun is in the first point of Cancer. And,

The longest day to those in south latitude, is when the sun is in the first point of Capricorn.

Wherefore, the globe being rectified as above, and the artificial sun placed to the first point of Cancer, and brought to the eastern edge of the broad paper circle, and the horary index being set to that XII which is most elevated, on turning the globe from east to west, until the artificial sun coincides with the western edge, the number of hours counted, which are passed over by the horary index, is the length of the longest day; their complement to twenty-four hours, gives the length of the shortest night.

If twelve hours be subtracted from the length of the longest day, and the remaining hours doubled, you obtain the climate mentioned by ancient historians; and if you take half the climate, and add thereto twelve hours, you obtain the length of the longest day in that climate. This holds good for every climate between the polar circles.

A climate is a space upon the surface of the earth, contained between two parallels of latitude, so far distant from each other, that the longest day in one, differs half an hour from the longest day in the other parallel.

PROBLEM X. *The latitude of a place being given in one of the polar circles, (suppose the northern) to find what number of days (of 24 hours each) the sun doth constantly shine upon the same, how long he is absent, and also the first and last day of his appearance.*

Having rectified the globe according to the latitude, turn it about until some point in the first quadrant of the ecliptic (because the latitude is north) intersects the meridian in the north point of the horizon; and right against that point of the ecliptic, on the horizon, stands the day of the month when the longest day begins.

And if the globe be turned about till some point in the second quadrant of the ecliptic cuts the meridian in the same point of the horizon, it will shew the sun's place when the longest day ends, whence the day of the month may be found, as before; then the number of natural days contained between the times the longest day begins and ends, is the length of the longest day required.

Again, turn the globe about, until some point in the third quadrant of the ecliptic cuts the meridian in the south part of the horizon; that point of the ecliptic will give the time when the longest night begins.

Lastly, turn the globe about, until some point in the fourth quadrant of the ecliptic cuts the meridian in the south point of the horizon; and that point of

the ecliptic will be the place of the sun when the longest night ends.

Or, the time when the longest day or night begins being known, their end may be found by counting the number of days from that time to the succeeding solstice ; then counting the same number of days from the solstitial day, will give the time when it ends.

OF THE EQUATION OF TIME.

It is not possible, in a treatise of this kind, to enter into a disquisition of the nature of time. It is sufficient to observe, that if we would with exactness estimate the quantity of any portion of infinite duration, or convey an idea of the same to others, we make use of such known measures as have been originally borrowed from the motions of the heavenly bodies. It is true, none of these motions are exactly equal and uniform, but are subject to some small irregularities, which, though of no consequence in the affairs of civil life, must be taken into the account in astronomical calculations. There are other irregularities of more importance, one of which is in the inequality of the natural day.

It is a consideration that cannot be reflected upon without surprize, that wherever we look for commensurabilities and equalities in nature, we are always disappointed. The earth is spherical, but not perfectly so ; the summer is unequal, when com-

pared with the winter; the ecliptic disagrees with the equator, and never cuts it twice in the same equinoctial point. The orbit of the earth has an eccentricity more than double in proportion to the spheroidity of its globe; no number of the revolutions of the moon coincide with any number of the revolutions of the earth in its orbit; no two of the planets measure one another: and thus it is, wherever we turn our thoughts, so different are the views of the Creator from our narrow conception of things; where we look for commensuration, we find variety and infinity.

Thus ancient astronomers looked upon the motion of the sun to be sufficiently regular for the mensuration of time; but, by the accurate observations of later astronomers, it is found, that neither the days, nor even the hours, as measured by the sun's apparent motion, are of an equal length, on two accounts.

1st. A natural or solar day of 24 hours, is that space of time the sun takes up in passing from any particular meridian to the same again; but one revolution of the earth, with respect to a fixed star, is performed in 23 hours, 56 minutes, 4 seconds; therefore the unequal progression of the earth through her elliptical orbit, (as she takes almost eight days more to run through the northern half of the ecliptic, than she does to pass through the southern) is the reason that the length of the day is not exactly equal to the time in which the earth performs its rotation about its axis.

2d. From the obliquity of the ecliptic to the equator, on which last we measure time; and as equal portions of one do not correspond to equal portions of the other, the apparent motion of the sun would not be uniform; or, in other words, those points of the equator which come to the meridian, with the place of the sun on different days, would not be at equal distances from each other.

PROBLEM XI. *To illustrate by the globe so much of the equation of time as is in consequence of the sun's apparent motion in the ecliptic.*

Bring every tenth degree of the ecliptic to the graduated side of the strong brass' meridian, and you will find that each tenth degree on the equator will not come thither with it; but in the following order from ♈ to ♋, every tenth degree of the ecliptic comes sooner to the strong brass meridian than their corresponding tenths on the equator; those in the second quadrant of the ecliptic, from ♋ to ♎, come later; from ♎ to ♑, sooner; and from ♑ to ♈, later; whilst those at the beginning of each quadrant come to the meridian at the same time; therefore the sun and clock would be equal at these four times, if the sun was not longer in passing through one half of the ecliptic than the other, and the two inequalities joined together compose that difference which is called the equation of time.

These causes are independent of each other, some-times they agree, and at other times are contrary to one another.

The inequality of the natural day is the cause that clocks or watches are sometimes before, and sometimes behind the sun.

A good and well-regulated clock goes uniformly on throughout the year, so as to mark the equal hours of a natural day of a mean length ; a sun-dial marks the hours of every day in such a manner, that every hour is a 24th part of the time between the noon of that day, and the noon of the day imme-diately following. The time measured by a clock is called equal or true time ; that measured by the sun-dial, apparent time.

THE USE OF THE CELESTIAL GLOBE, IN PRO-BLEMS RELATIVE TO THE FIXED STARS.

The use of the celestial globe is in no instance more conspicuous than in the problems concerning the fixed stars. Among many other advantages, it will, if joined with observations on the stars them-selves, render the practice and theory of other pro-blems easy and clear to the pupil, and vastly facilitate his progress in astronomical knowledge.

The heavens are as much studded over with stars in the day as in the night; only they are then ren-dered invisible to us by the brightness of the solar rays. But when this glorious luminary descends

below the horizon, they begin gradually to appear; when the sun is about 12 degrees below the horizon, stars of the first magnitude become visible; when he is thirteen degrees, those of the second are seen; when fourteen degrees, those of the third magnitude appear; when fifteen degrees, those of the fourth present themselves to view; when he is descended about eighteen degrees, the stars of the fifth and sixth magnitude, and those that are still smaller, become conspicuous, and the azure arch sparkles with all its glory.

PROBLEM XII. *To find the right ascension and declination of any given star.*

Bring the given star to the meridian, and the degree under which it lies is its declination; and the point in which the meridian intersects the equinoctial is its right ascension. Thus the right ascension of Sirius is 99°, its declination 16° 25' south; the right ascension of Arcturus is 211° 32', its declination 20° 20' north.

The declination is used to find the latitude of places; the right ascension is used to find the time at which a star or planet comes to the meridian; to find at any given time how long it will be before any celestial body comes to the meridian; to determine in what order those bodies pass the meridian; and to make a catalogue of the fixed stars.

PROBLEM XIII. *To find the latitude and longitude of a given star.*

Bring the pole of the ecliptic to the meridian, over which fix the quadrant of altitude, and, holding the globe very steady, move the quadrant to lie over the given star, and the degree on the quadrant cut by the star is its latitude ; the degree of the ecliptic cut at the same time by the quadrant is the longitude of the star.

Thus the latitude of Arcturus is 30° 30', N. its longitude 20° 20' of Libra : the latitude of Capella is 22° 22' north, its longitude 18° 8' of Gemini.

The latitude and longitude of stars is used to fix precisely their places on the globe, to refer planets and comets to the stars, and, lastly, to determine whether they have any motion, whether any stars vanish, or new ones appear.

PROBLEM XIV. *The right ascension and declination of a star being given, to find its place on the globe.*

Turn the globe till the meridian cuts the equinoctial in the degree of right ascension. Thus, for example, suppose the right ascension of Aldebaran to be 65° 30', and its declination to be 16° north, then turn the globe about till the meridian cuts the equinoctial in 65° 30', and under the 16° of the me-

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ridian, on the northern part, you will observe the star Aldebaran, or the Bull's eye.

PROBLEM XV.   *To find at what hour any known star passes the meridian at any given day.*

Find the sun's place for that day in the ecliptic, and bring it to the strong brass meridian, set the horary index to XII o'clock, then turn the globe till the star comes to the meridian, and the index will mark the time. Thus, on the 15th of August, Lyra comes to the meridian at 45 minutes past VIII in the evening. On the 14th of September the brightest of the Pleiades will be on the meridian at IV in the morning.

This problem is useful for directing when to look for any star on the meridian, in order to find the latitude of a place, to adjust a clock, &c.

PROBLEM XVI.   *To find on what day a given star will come to the meridian at any given hour.*

Bring the given star to the meridian, and set the index to the proposed hour; then turn the globe till the index points to XII at noon, and observe the degree of the ecliptic then at the meridian; this is the sun's place, the day answering to which may be found on the calendar of the broad paper circle.

By knowing whether the hour be in the morning

or afternoon, it will be easy to perceive which way to turn the globe, that the proper XII may be pointed to ; the globe must be turned towards the west, if the given hour be in the morning ; towards the east, if it be afternoon.

Thus Arcturus will be on the meridian at III in the morning on March the 5th, and Cor Leonis at VIII in the evening on April the 21st.

PROBLEM XVII. *To represent the face of the heavens on the globe for a given hour on any day of the year, and learn to distinguish the visible fixed stars.*

Rectify the globe to the given latitude of the place and day of the month, setting it due north and south by the needle ; then turn the globe on its axis till the index points to the given hour of the night ; then all the upper hemisphere of the globe will represent the visible face of the heavens for that time, by which it will be easily seen what constellations and stars of note are then above our horizon, and what position they have with respect to the points of the compass. In this case, supposing the eye was placed in the centre of the globe, and holes were pierced through the centres of the stars on its surface, the eye would perceive through those holes the various corresponding stars in the firmament ; and hence it would be easy to know the various constellations at sight, and to be able to call all the stars by their names.

Observe some star that you know, as one of the Pointers in the Great Bear, or Sirius ; find the same on the globe, and take notice of the position of the contiguous stars in the same or an adjoining constellation ; direct your sight to the heavens, and you will see those stars in the same situation. Thus you may proceed from one constellation to another, till you are acquainted with most of the principal stars.

" *For example.* The situation of the stars at London on the 9th of February, at 2 min. past IX in the evening, is as follows :

" Sirius, or the Dog-star, is on the meridian, its altitude 22° : Procyon, or the Little Dog-star, 16° towards the east, its altitude $43\frac{1}{2}$: about 24° above this last, and something more towards the east, are the Twins, Castor and Pollux : S. 65° E. and 35° in height, is the bright star Regulus, or Cor Leonis : exactly in the east, and 22° high, is the star Deneb Alased in the Lion's tail : 30° from the east towards the north, Arcturus is about 3° above the horizon : directly over Arcturus, and 31° above the horizon, is Cor Caroli : in the north-east are the stars in the extremity of the Great Bear's tail, Aleath the first star in the tail, and Dubhe the northernmost Pointer in the same constellation : the altitude of the first of these is $30\frac{1}{2}°$, that of the second 41°, and that of the third 56°.

" Reckoning westward, we see the beautiful constellation Orion ; the middle star of the three in his belt, is S. 20° W. its altitude 35° : nine degrees below the belt, and a little more to the west, is

Rigel, the bright star in his heel : above his belt, in a straight line drawn from Rigel between the middle and most northward in his belt, and 9° above it, is the bright star in his shoulder : S. 49° W. and 45½ above the horizon, is Aldebaran, the southern eye of the Bull : a little to the west of Aldebaran, are the Hyades : the same altitude, and about S. 70° W. are the Pleiades : in the W. by S. point is Capella in Auriga, its altitude 73° : in the north-west, and about 42° high, is the constellation Cassiopeia : and almost in the north, near the horizon, is the constellation Cygnus."*

PROBLEM XVIII. *To trace the circles of the sphere in the starry firmament.*

I shall solve this problem for the time of the autumnal equinox ; because that intersection of the equator and ecliptic will be directly under the depressed part of the meridian about midnight ; and then the opposite intersection will be elevated above the horizon ; and also because our first meridian upon the terrestrial globe passing through London and the first point of Aries, when both globes are rectified to the latitude of London and to the sun's place, and the first point of Aries is brought under the graduated side of each of their meridians, we shall have the corresponding face of the heavens and the earth represented as they are with respect to each

* *Bransby's* Use of the Globes.

other at that time, and the principal circles of each sphere will correspond with each other.

The horizon is then distinguished, if we begin from the north and count westward, by the following constellations; the hounds and waist of Bootes, the northern crown, the head of Hercules, the shoulders of Serpentarius, and the Sobieski's shield; it passes a little below the feet of Antinous, and through those of Capricorn, through the Sculptor's frame, Eridanus, the star Rigel in Orion's foot, the head of Monoceros, the Crab, the head of the Little Lion, and lower part of the Great Bear.

The meridian is then represented by the equinoctial colure, which passes through the star marked δ in the tail of the Little Bear, under the north pole, the pole star, one of the stars in the back of Cassiopeia's chair marked β, the head of Andromeda, the bright star in the wing of Pegasus marked γ, and the extremity of the tail of the Whale.

That part of the equator which is then above the horizon, is distinguished on the western side by the northern part of Sobieski's shield, the shoulder of Antinous, the head and vessel of Aquarius, the belly of the western fish in Pisces; it passes through the head of the Whale and a bright star marked δ in the corner of his mouth, and thence through the star marked δ in the belt of Orion, at that time near the eastern side of the horizon.

That half the ecliptic which is then above the horizon, if we begin from the western side, presents to our view Capricornus, Aquarius, Pisces,

Aries, Taurus, Gemini, and a part of the constellation Cancer.

The solstitial colure, from the western side, passes through Cerberus and the hand of Hercules, thence by the western side of the constellation Lyra, and through the Dragon's head and body, through the pole point under the polar star, to the east of Auriga, through the star marked η in the foot of Castor, and through the hand and elbow of Orion.

The northern polar circle, from that part of the meridian under the elevated pole, advancing towards the west, passes through the shoulder of the Great Bear, thence a little to the north of the star marked α in the Dragon's tail, the great knot of the Dragon, the middle of the body of Cepheus, the northern part of Cassiopeia and base of her throne, through Camelopardalus and the head of the Great Bear.

The tropic of Cancer, from the western edge of the horizon, passes under the arm of Hercules, under the Vulture, through the Goose and Fox, which is under the beak and wing of the Swan, under the star called Sheat marked β in Pegasus, under the head of Andromeda, and through the star marked φ in the fish of the constellation Pisces, above the bright star in the head of the Ram marked α, through the Pleiades, between the horns of the Bull, and through a group of stars at the foot of Castor, thence above a star marked δ, between Castor and Pollux, and so through a part of the constellation

Cancer, where it disappears by passing under the eastern part of the horizon.

The tropic of Capricorn, from the western side of the horizon, passes through the belly and under the tail of Capricorn, thence under Aquarius, through a star in Eridanus marked c, thence under the belly of the Whale, through the base of the Chemical Furnace, whence it goes under the Hare at the feet of Orion, being there depressed under the horizon.

The southern polar circle is invisible to the inhabitants of London, by being under our horizon.

ARCTIC AND ANTARCTIC CIRCLES, OR CIRCLES OF PERPETUAL APPARITION AND OCCULTATION.

The largest parallel of latitude on the terrestrial globe, as well as the largest circle of declination on the celestial, that appears entire above the horizon of any place in north latitude, was called by the ancients the *arctic circle*, or circle of perpetual apparition.

Between the arctic circle and the north pole in the celestial sphere, are contained all those stars which never set at that place, and seem to us, by the rotative motion of the earth, to be perpetually carried round above our horizon in circles parallel to the equator.

The largest parallel of latitude on the terrestrial,

and the largest parallel of declination on the celestial globe, which is entirely hid below the horizon of any place, was by the ancients called the *antarctic circle*, or circle of perpetual occultation.

This circle includes all the stars which never rise in that place to an inhabitant of the northern hemisphere, but are perpetually below the horizon.

All arctic circles touch their horizons in the north point, and all antarctic circles touch their horizons in the south point; which point, in the terrestrial and celestial spheres, is the intersection of the meridian and horizon.

If the elevation of the pole be 45 degrees, the most elevated part either of the arctic or antarctic circle will be in the zenith of the place.

If the pole's elevation be less than 45 degrees, the zenith point of those places will fall without its arctic or antarctic circle; if greater, it will fall within.

Therefore, the nearer any place is to the equator, the less will its arctic and antarctic circles be; and on the contrary, the farther any place is from the equator, the greater they are. So that,

At the poles, the equator may be considered as both an arctic and antarctic circle, because its plane is coincident with that of the horizon.

But at the equator (that is, in a right sphere) there is neither arctic nor antarctic circle.

They who live under the northern polar circle, have the tropic of Cancer for their arctic, and that of Capricorn for their antarctic circle.

And they who live on either tropic, have one of the polar circles for their arctic, and the other for their antarctic circles.

Hence, whether these circles fall within or without the tropics, their distance from the zenith of any place is ever equal to the difference between the pole's elevation and that of the equator above the horizon of that place.

From what has been said, it is plain there may be as many arctic and antarctic circles, as there are individual points upon any one meridian between the north and south poles of the earth.

Many authors have mistaken these mutable circles, and have given their names to the immutable polar circles, which last are arctic and antarctic circles, in one particular case only, as has been shewn.

PROBLEM XIX. *To find the circle or parallel of perpetual apparition, or occultation of a fixed star, in a given latitude.*

By rectifying the globe to the latitude of the place, and turning it round on its axis, it will be immediately evident, that the circle of perpetual apparition is that parallel of declination which is equal to the complement of the given latitude northward; and for the perpetual occultation, it is the same parallel southward; that is to say, in other words, all those stars whose declinations exceed the co-latitude, will always be visible, or above the horizon; and all

those in the opposite hemisphere, whose declination exceeds the co-latitude, never rise above the horizon.

For instance ; in the latitude of London 51 deg. 30 min. whose co-latitude is 38 deg. 30 min. gives the parallels desired ; for all those stars which are within the circle, towards the north pole, never descend below our horizon ; and all those stars which are within the same circle, about the south pole, can never be seen in the latitude of London, as they never ascend above its horizon.

OF PROBLEMS RELATING TO THE AZIMUTH, &c.
OF THE SUN AND STARS.

PROBLEM XX. *The latitude of the place and the sun's place being given, to find the sun's amplitude.*

That degree from east to west in the horizon, wherein any object rises or sets, is called the amplitude.

Rectify the globe, and bring the sun's place to the eastern side of the meridian, and the arch of the horizon intercepted between that point and the eastern point will be the sun's amplitude at rising.

If the same point be brought to the western side of the horizon, the arch of the horizon intercepted between that point and the western point, will be the sun's amplitude at setting.

Thus, on the 24th of May the sun rises at four, with 36 degrees of eastern amplitude, that is, 36 degrees from the east towards the north, and sets at eight, with 36 degrees of western amplitude.

The amplitude of the sun at rising and setting increases with the latitude of the place; and in very high northern latitudes, the sun scarce sets before he rises again. *Homer* had heard something of this, though it is not true of the Læstrygones, to whom he applies it.

> Six days and nights a doubtful course we steer;
> The next, proud LAMOS' lofty towers appear,
> And Læstrygonia's gates arise distinct in air.
> The shepherd quitting here at night the plain,
> Calls, to succeed his cares, the watchful swain.
> But he that scorns the chains of sleep to wear,
> And adds the herdsman's to the shepherd's care,
> So near the pastures and so short the way,
> His double toils may claim a double pay,
> And join the labours of the night and day.

PROBLEM XXI. *To find the sun's altitude at any given time of the day.*

Set the centre of the artificial sun to his place in the ecliptic upon the globe, and rectify it to the latitude and zenith; bring the centre of the artificial sun under the strong brass meridian, and set the hour index to that XII which is most elevated; turn the globe to the given hour, and move the graduated edge of the quadrant to the centre of the artificial sun; and that degree on the quadrant,

which is cut by the sun's centre, is the sun's height at that time.

The artificial sun being brought under the strong brass meridian, and the quadrant laid upon its centre, will shew its meridian, or greatest altitude for that day.

If the sun be in the equator, his greatest or meridian altitude is equal to the elevation of the equator, which is always equal to the co-latitude of the place.

Thus on the 24th of May, at nine o'clock, the sun has 44 deg. altitude, and at six in the afternoon 20 degrees.

OF THE AZIMUTHAL OR VERTICAL CIRCLES.

The vertical point, that is, the uppermost point of the celestial globe, represents a point in the heavens, diretly over our heads, which is called our zenith.

From this point circular lines may be conceived crossing the horizon at right angles.

These are called *azimuth* or *vertical circles*. That one which crosses the horizon at 10 degrees distance from the meridian on either side is called an azimuth circle of 10 deg. ; that which crosses at 20 is called an azimuth of 20 degrees.

The azimuth of 90 deg. is called the *prime verti-cal:* it crosses the horizon at the eastern and western points.

Any *azimuth circle* may be represented by the gra-duated edge of the brass quadrant of altitude when

the centre upon which it turns is screwed to that point of the strong brass meridian which answers to the latitude of the place, and the place is brought into the zenith.

If the said graduated edge should lie over the sun's centre or place, at any given time, it will represent the sun's azimuth at that time.

If the graduated edge be fixed at any point, so as to represent any particular azimuth, and the sun's place be brought there, the horary index will shew at what time of that day the sun will be in that particular azimuth.

Here it may be observed, that the *amplitude* and azimuth are much the same.

The amplitude shewing the bearing of any object *when it rises or sets,* from the east and west points of the horizon.

The azimuth the bearing of any object when it is above the horizon, either from the north or south points thereof. These descriptions and illustrations being understood, we may proceed to

PROBLEM XXII. *To find at what time the sun is due east, the day and the latitude being given.*

Rectify the globe; then if the latitude and declination are of one kind, bring the quadrant of altitude to the eastern point of the horizon, and the sun's place to the edge of the quadrant, and the index will shew the hour.

If the latitude and declination are of different

kinds, bring the quadrant to the western point of the horizon, and the point in the ecliptic opposite to the sun's place to the edge of the quadrant, and then the index will shew the hour.

You will easily comprehend the reason of the foregoing distinction, because when the sun is in the equinoctial, it rises due east; but when it is in that part of the ecliptic which is towards the elevated pole, it rises before it is in the eastern vertical circle, and is therefore at that time above the horizon: whereas when it is in the other part of the ecliptic, it passes the eastern prime vertical before it rises, that is below the horizon; whence it is evident, that the opposite point of the ecliptic must then be in the west, and above the horizon. The sun is due east at London at 7 h. 6 min. on the 18th of May. The second of August, at Cape Horn, the sun is due east at 5 h. 10 min.

PROBLEM XXIII. *To find the rising, setting, and culminating of a star, its continuance above the horizon, and its oblique ascension and descension, and also its eastern and western amplitude, for any given day and place.*

1. Rectify the globe to the latitude and zenith, bring the sun's place for the day to the meridian, and set the hour index to XII. 2. Bring the star to the eastern side of the horizon, and its eastern amplitude, oblique ascension, and time of rising, will be found as taught of the sun. 3. Carry the

star to the western side of the horizon; and in the same manner its western amplitude, oblique descension, and time of setting, will be found. 4. The time of rising, subtracted from that of setting, leaves the continuance of the star above the horizon. 5. This remainder, subtracted from 24 hours, gives the time of its continuance below the horizon. 6. The hour to which the index points, when the star comes to the meridian, is the time of its culminating or being on the meridian.

Let the given day be March 14, the place London, the star Sirius; by working the problem you will find

It rises at   -   2 h. 24 min. afternoon.
Culminates at   -   6   57
Sets at   -   -   11   50
Is above the horizon 9   6

Its oblique ascension and descension are 120° 47′, and 77° 15′; its amplitude 27° southward.

PROBLEM XXIV. *The latitude, the altitude of the sun by day, or of a star by night, being given, to find the hour of the day, and the sun or star's azimuth.*

Rectify the globe for the latitude, the zenith, and the sun's place, turn the globe and the quadrant of altitude, so that the sun's place, or the given star, may cut the given degree of altitude, the index will shew the hour, and the quadrant will be the azimuth in the horizon.

Thus on the 21st of August, at London, when the sun's alitude is 36° in the forenoon, the hour is IX, and the azimuth 58° from the south.

At Boston, December 8th, when Rigel had 15° of altitude, the hour was VIII, the azimuth S. E. by E. 7°.

PROBLEM XXV. *The latitude and hour of the day being given, to find the altitude and azimuth of the sun, or of a star.*

Rectify the globe for the latitude, the zenith, and the sun's place, then the number of degrees contained betwixt the sun's place and the vertex is the sun's meridional zenith distance; the complement of which to 90 deg. is the sun's meridian altitude. If you turn the globe about until the index points to any other given hour, then bringing the quadrant of altitude to cut the sun's place, you will have the sun's altitude at that hour; and where the quadrant cuts the horizon, is the sun's azimuth at the same time. Thus May the first, at London, the sun's meridian altitude will be 53½ degrees; and at 10 o'clock in the morning, the sun's altitude will be 46 degrees, and his azimuth about 44 degrees from the south part of the meridian. On the 2d of December, at Rome, at five in the morning, the altitude of Capella is 41 deg. 58 min. its azimuth 60 deg. 50 min. from N. to W.

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PROBLEM XXVI. *The latitude of the place, and the day of the month being given, to find the depression of the sun below the horizon, and the azimuth, at any hour of the night.*

Having rectified the globe for the latitude, the zenith, and the sun's place, take a point in the ecliptic exactly opposite to the sun's place, and find the sun's altitude and azimuth, as by the last problem, and these will be the depression and the altitude required.

Thus, if the time given be the first of November, at 10 o'clock at night, the depression and azimuth will be the same as was found in the last problem.

PROBLEM XXVII. *The latitude, the sun's place, and his azimuth being given, to find his altitude, and the hour.*

Rectify the globe for the latitude, the zenith, and the sun's place; then put the quadrant of altitude to the sun's azimuth in the horizon, and turn the globe till the sun's place meets the edge of the quadrant; then the said edge will shew the altitude, and the index point to the hour.

Thus, May 21st, at London, when the sun is due east, his altitude will be about 24 deg. and the hour about VII in the morning; and when his azimuth is 60 deg. south-westerly, the altitude will be about 44½ deg. and the hour 11¾ in the afternoon.

Thus the latitude and the day being known, and having besides either the latitude, the azimuth, or the hour, the other two may be easily found.

PROBLEM XXVIII. *The latitude of the place, and the azimuth of the sun or of a star being given, to find the hour of the day or night.*

Rectify the globe for the latitude and sun's place, and bring the quadrant of altitude to the given azimuth in the horizon; turn the globe till the sun or star comes to the quadrant, and the index will shew the time. November 5, at Gibraltar, given the sun's azimuth 50 degrees from the south towards the east, the time you will find to be half past VIII in the morning. Given the azimuth of Vega at London, 57 degrees from the north towards the east, February the 8th, the time you will find twenty minutes past II in the morning.

But as it may possibly happen that we may see a star, and would be glad to know what star it is, or whether it may not be a new star, or a comet; how that may be discovered, will be seen under the following

PROBLEM XXIX. *The latitude of the place, the sun's place, the hour of the night, and the altitude and azimuth of any star being given, to find the star.*

Rectify the globe for the latitude of the place, and the sun's place; fix the quadrant of altitude in the

zenith, and turn the globe till the hour index points to the given hour, and set the quadrant of altitude to the given azimuth; then the star that cuts the quadrant in the given altitude, will be the star sought.

Though two stars, that have different right ascensions, will not come to the meridian at the same time, yet it is possible that in a certain latitude they may come to the same vertical circle at the same time; and that consideration gives the following

PROBLEM XXX. *The latitude of the place, the sun's place, and two stars that have the same azimuth, being given, to find the hour of the night.*

Rectify the globe for the latitude, the zenith, and the sun's place; then turn the globe, and also the quadrant about, till both the stars coincide with its edge; the hour index will shew the hour of the night, and the place where the quadrant cuts the horizon, will be the common azimuth of both stars.

On the 15th of March, at London, the star Betelgeule, in the shoulder of Orion, and Regel, in the heel of Orion, were observed to have the same azimuth; on working the problem, you will find the time to be 8 hours 47 minutes.

What hath been observed above, of two stars that have the same azimuth, will hold good likewise of two stars that have the same altitude; from whence we have the following

PROBLEM XXXI. *The latitude of the place, the sun's place, and two stars, that have the same altitude, being given, to find the hour of the night.*

Rectify the globe for the latitude of the place, the zenith, and the sun's place; turn the globe, so that the same degree on the quadrant shall cut both stars, then the hour index will shew the hour of the night.

In the former propositions, the latitude of the place is supposed to be given, or known; but as it is frequently neceffary to find the latitude of the place, especially at sea, how this may be found, in a rude manner at least, having the time given by a good clock or watch, will be seen in the following

PROBLEM XXXII. *The sun's place, the hour of the night, and two stars, that have the same azimuth or altitude, being given, to find the latitude of the place.*

Rectify the globe for the sun's place, and turn it till the index points to the given hour of the night; keep the globe from turning, and move it up and down in the notches, till the two given stars have the same azimuth, or altitude; then the brass meridian will shew the height of the pole, and consequently the latitude of the place.

PROBLEM XXXIII. *Two stars being given, one on the meridian, and the other on the east and west part of the horizon, to find the latitude of the place.*

Bring the star observed on the meridian to the meridian of the globe; then keeping the globe from turning round its axis, slide the meridian up and down in the notches, till the other star is brought to the east or west part of the horizon, and that elevation of the pole will be the latitude of the place sought.

OBSERVATION. From what hath been said, it appears, that of these five things, 1. the latitude of the place; 2. the sun's place in the ecliptic; 3. the hour of the night; 4. the common azimuth of two known fixed stars; 5. the equal altitude of two known fixed stars;—any three of them being given, the remaining two will easily be found.

There are three sorts of rising and settings of the fixed stars, taken notice of by the ancient authors, and commonly called *poetial* risings and settings, because mostly taken notice of by the poets.

These are the *cosmical, achronical,* and *heliacal.**

They are to be found in most authors that treat on the doctrine of the sphere, and are now chiefly used in comparing and understanding passages in the ancient writers; such are *Hesiod, Virgil, Colu-*

* *Costard's* History of Astronomy.

mella, Ovid, Pliny, &c. How they are to be found by calculation, may be seen in *Petavius's* Uranologion, and Dr. *Gregory's* Astronomy.

DEFINITION. *When a star rises or sets at sunrising, it is said to rise or set cosmically.*

From whence we shall have the following

PROBLEM XXXIV. *The latitude of the place being given, to find, by the globe, the time of the year when a given star rises or sets cosmically.*

Let the given place be Rome, whose latitude is 42 deg. 8 m. north ; and let the given star be the Lucida Pleiadum. Rectify the globe for the latitude of the place; bring the star to the edge of the eastern horizon, and mark the point of the ecliptic rising along with it ; that will be found to be Taurus, 18 deg. opposite to which, on the horizon, will be found May the 8th. The Lucida Pleiadum, therefore rises cosmically May the 8th.

If the globe continues rectified as before, and the Lucida Pleiadum be brought to the edge of the western horizon, the point of the ecliptic, which is the sun's place, then rising on the eastern side of the horizon, will be Scorpio, 29 deg. opposite to which, on the horizon, will be found November the 21st. The Lucida Pleiadum, therefore, sets cosmically November the 21st.

In the same manner, in the latitude of London, Sirius will be found to rise cosmically Aug. the 10th, and to set cosmically Nov. the 10th.

It is of the cosmical setting of the Pleiades, that *Virgil* is to be understood in this line,

Ante tibi Eoæ Atlantides abseondantur,*

and not of their setting in the east, as some have imagined, where stars rise, but never set.

DEFINITION. *When a star rises or sets at sunsetting, it is said to rise or set achronically.*

Hence, likewise, we have the following

PROBLEM XXXV. *The latitude of the place being given, to find the time of the year when a given star will rise or set achronically.*

Let the given place be Athens, whose latitude is 37 degrees north, and let the given star be Arcturus.

Rectify the globe for the latitude of the place, and bringing Arcturus to the eastern side of the horizon, mark the point of the ecliptic then setting on the western side ; that will be found Aries, 12 deg. opposite to which, on the horizon, will be found April the 2d. Therefore Arcturus rises at Athens achronically April the 2d.

* Georg. l. i. v. 221.

It is of this rising of Arcturus that *Hesiod* speaks in his Opera and Dies.*

> When from the solstice sixty wint'ry days
> Their turns have finish'd, mark, with glitt'ring rays,
> From ocean's sacred flood, Arcturus rise,
> Then first to gild the dusky evening skies.

If the globe continues rectified to the latitude of the place, as before, and Arcturus be brought to the western side of the horizon, the point of the ecliptic setting along with it will be Sagittary, 7 degrees opposite to which, on the horizon, will be found November the 29th. At Athens, therefore, Arcturus sets achronically November the 29th.

In the same manner Aldebaran, or the Bull's Eye, will be found to rise achronically May the 22d, and to set achronically December the 19th.

DEFINITION. *When a star becomes visible in a morning, after it hath been so near the sun as to be hid by the splendor of his rays, it is said to rise heliacally.*

But for this there is required some certain depression of the sun below the horizon, more or less, according to the magnitude of the star. A star of the first magnitude is commonly supposed to require that the sun be depressed 12 degrees perpendicularly below the horizon.

This being premised, we have the following

* Lib. ii. ver. 285.

PROBLEM XXXVI. *The latitude of the place being given, to find the time of the year when a given star will rise heliacally.*

Let the given place be Rome, whose latitude is 42 degrees north, and let the given star be the bright star in the Bull's Horn.

Rectify the globe for the latitude of the place, screw on the brass quadrant of altitude in its zenith, and turn it to the western side of the horizon. Bring the star to the eastern side of the horizon, and mark what degree of the ecliptic is cut by 12 degrees, marked on the quadrant of altitude; that will be found to be Capricorn, 3 deg. the point opposite to which is Cancer, 3 deg. and opposite to this will be found on the horizon, June 25th. The bright star, therefore, in the Bull's Horn, in the latitude of Rome, rises heliacally June 25.

These kinds of risings and settings are not only mentioned by the poets, but likewise by the ancient physicians and historians.

Thus *Hippocrates*, in his book De Ære, says, " One ought to observe the heliacal risings and sittings of the stars, especially the *Dog-star* and *Arcturus*; likewise the *cosmical* setting of the *Pleiades.*"

And *Polybius*, speaking of the loss of the Roman fleet, in the first Punic war, says, " It was not so much owing to fortune, as to obstinacy of the consuls, in not hearkening to their pilots, who dissuaded them from putting to sea at that season of

the year, which was between the rising of *Orion* and the *Dog-star*; it being always dangerous, and subject to storms."[*]

DEFINITION. *When a star is first immersed in the evening, or hid by the sun's rays, it is said to set heliacally.*

And this again is said to be, when a star of the first magnitude comes within twelve degrees of the sun, reckoned in the perpendicular.

Hence again we have the following

PROBLEM XXXVII. *The latitude of the place being given, to find the time of the year when a given star sets heliacally.*

Let the given place be Rome, in latitude 42 deg. north, and let the given star be the bright star in the Bull's Horn. Rectify the globe for the latitude of the place, and bring the star to the edge of the western horizon; turn the quadrant of altitude, till 12 deg. cut the ecliptic on the eastern side of the meridian. This will be found to be 7 deg. of Sagittary, the point opposite to which, in the ecliptic, is 7 deg. of Gemini; and opposite to that, on the horizon, is May the 28th, the time of the year when that sets heliacally in the latitude of Rome.

[*] Lib. i. p. 53.

OF THE CORRESPONDENCE OF THE CELESTIAL AND TERRESTRIAL SPHERES.*

That the reader may thoroughly understand what is meant by the correspondence between the two spheres, let him imagine the celestial globe to be delineated upon glass, or any other transparent matter, which shall invest or surround the terrestrial globe, but in such a manner, that either may be turned about upon the poles of the globe, while the other remains fixed; and suppose the first point of Aries, on the investing globe, to be placed on the first point of Aries, on the terrestrial globe (which point is in the meridian of London), then every star in the celestial sphere will be directly over those places to which it is a correspondent. Each star will then have the degree of its right ascension directly upon the corresponding degree of terrestrial longitude; their declination will also be the same with the latitude of the places to which they answer; or, in other words, when the declination of a star is equal to the latitude of a place, such star, within the space of 24 hours, will pass vertically over that place, and all others that have the same latitude.

If we conceive the celestial investing globe to be fixed, and the terrestrial globe to be gradually turned from west to east, it is clear, that as the meridian of London passes from one degree to another

* *Adams's* Treatise on the Globes.

under the investing sphere, every star in the celestial sphere becomes correspondent to another place upon the earth, and so on, until the earth has completed one diurnal revolution; or till all the stars, by their apparent daily motion, have passed over every meridian of the terrestrial globe. From this view of the subject, an amazing variety, uniting in wonderful and astonishing harmony, presents itself to the attentive reader; and future ages will find it difficult to investigate the reasons that should induce the present race of astronomers to neglect a subject so highly interesting to science, even in a practical view, but which in theory would lead them into more sublime speculations, than any that ever yet presented themselves to their minds.

A GENERAL DESCRIPTION OF THE PASSAGE OF THE STAR MARKED γ IN THE HEAD OF THE CONSTELLATION DRACO, OVER THE PARALLEL OF LONDON.

The star γ, in the head of the constellation Draco, having 51 deg. 32 min. north declination, equal to the latitude of London, is the correspondent star thereto. To find the places which it passes over, bring London to the graduated side of the brass meridian, and you will find that the degree of the meridian over London, and the representative of the star, passes over from London, the road to Bristol, crosses the Severn, the Bristol channel, the counties of Cork and Kerry, in Ireland; the north part of the Atlan-

tic ocean, the Streights of Belleisle, New Britain, the north part of the province of Canada, New South Wales, the southern part of Kamschatka; thence over different Tartarian nations, several provinces of Russia, over Poland, part of Germany, the southern part of the United Provinces; when, crossing the sea, it arrives again at the meridian of London.

When the said star, or any other star, is on the meridian of London, or any other meridian, all other stars, according to their declination and right ascension, and difference of right ascension (which answers to terrestrial latitude, longitude, and difference of longitude), will at the same time be on such meridians, and vertical to such places as correspond in latitude, longitude, and difference of longitude, with the declination, &c. of the respective stars.*

From the stars, therefore, thus considered, we attain a copious field of geographical knowledge, and may gain a clear idea of the proportionable distances, and real bearings, of remote empires, kingdoms, and provinces, from our own zenith, at the same instant of time; which may be found in the same manner as we found the place to which the sun was vertical at any proposed time.

Many instances of this mode of attaining geographical knowledge, may be found in my father's treatise on the globes.

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* *Fairman's* Geography.

OF THE USE OF THE CELESTIAL GLOBE, IN PRO-
BLEMS RELATIVE TO THE PLANETS.

The situation of the fixed stars being always the same with respect to one another, they have their proper places assigned to them on the globe.

But to the planets no certain place can be assigned, their situation always varying.

That space in the heavens, within the compass of which the planets appear, is called the zodiac.

The latitude of the planets scarce ever exceeding 8 degrees, the zodiac is said to reach about 8 degrees on each side the ecliptic.

Upon the celestial globe, on each side of the ecliptic, are drawn eight parallel circles, at the distance of one degree from each other, including a space of 16 degrees; these are crossed at right angles, with segments of great circles at every 5th degree of the ecliptic; by these, the place of a planet on the globe, on any given day, may be ascertained with accuracy.

PROBLEM XXXVIII. *To find the place of any planet upon the globe, and by that means to find its place in the heavens! also, to find at what hour any planet will rise or set, or be on the meridian, on any day in the year.*

Rectify the globe to the latitude and sun's place, then find the planet's longitude and latitude in an

ephemeris, and set the graduated edge of the moveable meridian to the given longitude in the ecliptic, and counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south ; and set the centre of the artificial sun to that point, and the centre will represent the place of the planet for that time.

Or fix the quadrant of altitude over the pole of the ecliptic, and holding the globe fast, bring the edge of the quadrant to cut the given degree of longitude on the ecliptic; then seek the given latitude on the quadrant, and the place under it is the point sought.

While the globe moves about its axis, this point moving along with it will represent the planet's motion in the heavens. If the planet be brought to the eastern side of the horizon, the horary index will shew the time of its rising. If the artificial sun is above the horizon, the planet will not be visible : when the planet is under the strong brass meridian, the hour index shews the time it will be on that circle in the heavens : when it is at the western edge, the time of its setting will be obtained.

PROBLEM XXXIX. *To find directly the planets which are above the horizon at sun-set, upon any given day or latitude.*

Find the sun's place for the given day, bring it to the meridian, set the hour index to XII, and elevate the pole for the given latitude : then bring the place

of the sun to the western semicircle of the horizon, and observe what signs are in that part of the eclip- tic above the horizon, then cast your eye upon the ephemeris for that month, and you will at once see what planets possess any of those elevated signs; for such will be visible, and fit for observation on the night of that day.

PROBLEM XL. *To find the right ascension, de- clination, amplitude, azimuth, altitude, hour of the night, &c. of any given planet, for a day of a month and latitude given.*

Rectify the globe for the given latitude and day of the month; then find the planet's place, as be- fore directed, and then the right ascension, declina- tion, amplitude, azimuth, altitude, hour, &c. are all found, as directed in the problems for the sun; there being no difference in the process, no repetition can be necessary.

OF THE USE OF THE CELESTIAL GLOBE, IN PRO- BLEMS RELATIVE TO THE MOON.

From the sun and planets we now proceed to those problems that concern the moon, the brilliant satellite of our earth, which every month enriches it with its presence; by the mildness of its light softening the darkness of night; by its influence affecting the tide; and by the variety of its aspects,

A a

offering to our view some very remarkable pheno-
mena.

> " Soon as the ev'ning shades prevail,
> The moon takes up the wond'rous tale ;
> And nightly to the list'ning earth,
> Repeats the story of her birth :
> Whilst all the stars that round her burn,
> And all the planets in their turn,
> Confirm the tidings as they roll,
> And spread the truth from pole to pole."

As the orbit of the moon is constantly varying in
its position, and the place of the node always chang-
ing, as her motion is even variable in every part of
her orbit, the solutions of the problems which re-
late to her, are not altogether so simple as those
which concern the sun.

The moon increases her longitude in the ecliptic
every day about 13 deg. 10 min. by which means she
crosses the meridian of any place about 50 min. later
than she did the preceding day.

Thus, if on any day at noon her place (longitude)
be in the 12th deg. of Taurus, it will be 13 deg.
10 min. more, or 25 deg. 10 min. in Taurus on the
succeeding noon.

It is new moon when the sun and moon have the
same longitude, or are in or near the same point of
the ecliptic.

When they have opposite longitudes, or are in op-
posite points of the ecliptic, it is full moon.

To ascertain the moon's place with accuracy, we
must recur to an ephemeris ; but, as even in most

ephemerides the moon's place is only shewn at the beginning of each day, or XII o'clock at noon, it becomes necessary to supply, by a table, this deficiency, and assign thereby her place for any intermediate time.

In the nautical ephemeris, published under the authority of the Board of Longitude, we have the moon's place for noon and midnight, with rules for accurately obtaining any intermediate time; but as this ephemeris may not always be at hand, we shall insert, from Mr. *Martin*'s treatise on the globes, a table for finding the hourly motion of the moon. In order, however, to use this table, it will be necessary, first to find the quantity of the moon's diurnal motion in the ecliptic for any given day; for the quantity of the moon's diurnal motion varies from about 11 deg. 46 min. the least, to 15 deg. 16 min. when greatest.

The following tables are calculated from the least of 11 deg. 46 min. to the greatest of 15 deg. 16 min. every column increasing 10 minutes; upon the top of the column is the quantity of the diurnal motion, and on the side of the table are the 24 hours; by which means it will be easy to find what part of the diurnal motion of the moon answers to any given number of hours.

Thus, suppose the diurnal motion to be 12° 32′, look on the top column for the number nearest to it, which you will find to be 12° 36′, in the sixth column; and under it, against 9 hours, you will find 4 deg. 43 min. which is her motion in the ecliptic in

the space of 9 hours for that day. The quantity of the diurnal motion for any day is found by taking the difference between it and the preceding day.

Thus, let the diurnal motion for the 11th of May, 1787, be required.

	signs	deg.	min.
On the 11th of May her place was -	11	2	35
On the 10th of May - - - - - - -	10	19	47
The diurnal motion sought -		12	48

TABLES

FOR FINDING THE HOURLY MOTION OF THE MOON,
AND THEREBY HER TRUE PLACE AT
ANY TIME OF THE DAY.

TABLE I.

	11 46	11 56	12 6	12 16	12 26	12 36	12 46	12 56	13 6	13 16	13 26
	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.
1	0 29	0 30	0 30	0 30	0 31	0 31	0 32	0 32	0 33	0 33	0 34
2	0 59	1 0	1 0	1 1	1 2	1 33	1 4	1 5	1 5	1 6	1 43
3	1 28	1 20	1 31	1 32	1 33	1 35	1 36	1 37	1 38	1 39	1 41
4	1 58	1 59	2 1	2 3	2 4	2 6	2 8	2 9	2 11	2 13	2 14
5	2 27	2 29	2 31	2 34	2 35	2 37	2 40	2 42	2 44	2 46	2 48
6	2 57	2 59	3 1	3 4	3 6	3 9	3 11	3 14	3 16	3 19	3 21
7	3 26	3 29	3 32	3 35	3 38	3 40	3 43	3 46	3 49	3 52	3 55
8	3 55	3 59	4 2	4 6	4 9	4 12	4 15	4 19	4 22	4 25	4 20
9	4 25	4 28	4 32	4 36	4 40	4 43	4 47	4 51	4 55	4 58	5 2
0	4 54	4 58	5 3	5 7	5 11	5 1	5 19	5 23	5 27	5 32	5 56
1	5 24	5 28	5 33	5 37	5 42	5 4	5 51	5 56	6 0	6 3	6 9
2	5 53	5 58	6 3	6 8	6 13	6 18	6 23	6 28	6 33	6 38	6 43
3	6 22	6 28	6 33	6 39	6 44	6 49	6 55	7 0	7 6	7 11	7 17
4	6 52	6 58	7 3	7 9	7 15	7 21	7 27	7 33	7 38	7 44	7 50
5	7 21	7 27	7 34	7 40	7 46	7 52	7 59	8 5	8 11	8 17	8 24
6	7 51	7 57	8 4	8 11	8 17	8 24	8 31	8 37	8 44	8 51	8 57
17	8 20	8 27	8 34	8 41	8 48	8 55	9 3	9 10	9 17	9 24	9 31
18	8 49	8 57	9 4	9 12	9 19	9 27	9 34	9 42	9 49	9 57	10 4
19	9 19	9 26	9 35	9 43	9 51	9 58	10 6	10 14	10 22	10 30	10 38
20	9 48	9 56	10 5	10 13	10 21	10 30	10 38	10 47	10 55	11 3	11 12
21	10 17	10 26	10 36	10 44	10 53	11 1	11 10	11 19	11 27	11 36	11 43
22	10 47	10 56	11 6	11 15	11 21	11 33	11 42	11 51	12 0	12 10	12 19
23	11 17	11 26	11 36	11 46	11 55	12 4	12 14	12 24	12 33	12 43	12 52
24	11 46	11 56	12 6	12 16	12 26	12 36	12 46	12 56	13 6	13 16	13 26

TABLE II.

HOURS.	13 30	13 40	13 50	14 6	14 16	14 26	14 36	14 46	14 56	15 6	15 1
	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.	d. m.
1	0 31	0 34	0 35	0 36	0 36	0 36	0 36	0 37	0 37	0 38	0 3
2	1 8	1 9	1 16	1 10	1 11	1 12	1 13	1 14	1 15	1 15	1 1
3	1 42	1 42	1 46	1 46	1 47	1 48	1 49	1 51	1 51	1 53	·1 5
4	2 16	2 8	2 19	2 21	2 22	2 24	2 26	2 28	2 30	2 31	2 3
5	2 50	2 52	2 54	2 56	2 58	3 0	3 3	3 5	3 7	3 9	3 1
6	3 24	3 26	3 29	3 31	3 34	3 39	3 39	3 41	3 45	3 46	3
7	3 58	4 1	4 4	4 7	4 10	4 10	4 15	4 18	4 21	4 24	4
8	4 32	4 35	4 39	4 42	4 45	4 49	4 52	4 55	4 59	5 2	5
9	5 6	5 10	5 13	5 17	4 21	5 25	5 28	5 32	5 36	5 40	5 4
10	5 40	5 42	5 48	5 52	5 57	6 1	6 5	6 9	6 13	6 17	6 2
11	6 14	6 19	6 23	6 28	6 32	6 37	6 41	6 46	6 51	6 55	7
12	6 48	6 53	6 50	7 3	7 8	7 13	7 28	7 23	7 28	7 33	7 2
13	7 22	7 27	7 33	7 38	7 44	7 49	7 54	8 6	8 5	8 11	8 1
14	7 56	8 0	8 8	8 13	8 19	8 25	8 81	8 37	8 43	8 48	8 5
15	8 30	8 36	8 42	8 49	8 55	9 1	9 7	9 14	9 20	9 26	9 3
16	9 4	9 11	9 17	9 21	9 12	9 37	9 44	9 51	9 57	10 4	10 1
17	9 38	9 45	9 52	9 59	10 20	10 13	10 20	10 28	10 33	10 42	10 4
18	10 12	10 19	10 27	10 34	10 42	10 49	10 57	11 4	11 12	11 19	11 2
19	10 46	10 54	11 5	11 10	11 18	11 26	11 34	11 41	11 49	11 57	12
20	11 29	11 38	11 37	11 24	11 8	12 2	12 10	12 18	12 27	12 35	12 4
21	11 58	12 3	12 11	12 20	12 9	12 38	12 40	12 55	13 4	13 13	13 2
22	12 28	12 37	12 46	12 55	13 5	13 14	13 23	13 33	13 41	13 50	13 5
23	13 2	13 12	13 21	13 31	13 43	13 59	13 59	14 9	14 10	14 28	14 3
24	13 36	13 46	13 56	14 6	14 16	14 36	14 36	14 46	14 56	15 6	15 1

The moon's path may be represented on the globe in a very pleasing manner, by tying a silken line over the surface of the globe exactly on the ecliptic ; then, finding by an ephemeris the place of the nodes for the given time, confine the silk at these two points, and at 90 degrees distance from them elevate the line about 5¼ deg. from the ecliptic, and depress it as much on the other, and it will then represent the lunar orbit for that day.

PROBLEM XLI.   *To find the moon's place in the ecliptic for any given hour of the day.*

You should be provided with an ephemeris,* that will give the moon's latitude and place in the ecliptic ; first note her place in the ecliptic upon the globe, and then counting so many degrees amongst the parallels in the zodiac, either above or below the ecliptic, as her latitude is north or south upon the given day, and that will be the point which represents the true place of the moon for that time, to -which apply the artificial sun or a small patch.

Thus, on the 11th of May, 1787, she was at noon in 2 deg. 35 min. of Pisces, and her latitude was 4 deg. 18 min.; but, as her diurnal motion for that day is 12 48 in nine hours, she will have passed over 4 deg. 47 min. which added to her place at noon, gives 7 h. 22 min. for her place on the 11th of May, at nine at night.

* The Nautical Almanack is the best English ephemeris. *White's* Epemeris is a very useful manual. EDIT.

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PROBLEM XLII. *To find the moon's declination for any given day or hour.*

The place in her orbit being found by Prob. xli, bring it to the brazen meridian ; then the arch of the meridian contained between it and the equinoctial will be the declination sought.

PROBLEM XLIII. *To find the moon's greatest and least meridian altitudes in any given latitude, that of London for example.*

It is evident, this can happen only when the ascending node of the moon is in the vernal equinox ; for then her greatest meridian altitude will be 5 deg. greater than that of the sun, and therefore about 67 deg.; also her least meridian altitude will be 5 deg. less than that of the sun, and therefore only 10 deg. ; there will therefore be 57 deg. difference in the meridian altitude of the moon ; whereas that of the sun is about 47 deg.

N. B. When the same ascending node is in the autumnal equinox, then will her meridian altitude differ by only 37 deg. ; but this phenomenon can separately happen but once in the revolution of a node, or once in the space of 19 years : and it will be a pleasant entertainment to place the silken line to cross the ecliptic in the equinoctial points alternately ; for then the reason will more evidently appear, why you observe the moon some-

mes within 23 deg. of our zenith, and at other times
not more than 10 deg. above the horizon, when she
is full south.

PROBLEM XLIV. *To illustrate by the globe the phe-nomena of the harvest moon.*

About the time of the autumnal equinox, when
the moon is at or near the full, she is observed to
rise almost at the same time for several nights to-gether ; and this phenomenon is called the *harvest
moon.*

This circumstance, with which farmers were
better acquainted than astronomers, till within
these few years, they gratefully ascribed to the good-ness of God, not doubting that he had ordered it on
purpose to give them an immediate supply of moon-light after sun-set, for their greater convenience in
reaping the fruits of the earth.

In this instance of the harvest moon, as in many
others discoverable by astronomy, the wisdom and
beneficence of the Deity is conspicuous, who really
so ordered the course of the moon, as to bestow
more or less light on all parts of the earth, as their
several circumstances and seasons render it more or
less serviceable.*

About the equator, where there is no variety of
seasons, moon-light is not necessary for gathering in
the produce of the ground, and there the moon

* *Ferguson's* Astronomy.

rises about 50 minutes later every day or night than
on the former. At considerable distances from the
equator, where the weather and seasons are more
uncertain, the autumnal full moons rise at sun-set
from the first to the third quarter. At the poles,
where the sun is for half the year absent, the winter
moons shine constantly without setting, from the
first to the third quarter.

But this observation is still further confirmed,
when we consider that this appearance is only pe-
culiar with respect to the full moon, from which
only the farmer can derive any advantage; for, in
every other month, as well as the three autumnal
ones, the moon, for several days together, will
vary the time of its rising very little; but then in
the autumnal months this happens about the time
when the moon is at the full : in the vernal
months, about the time of new moon; in the
winter months, about the time of the first quarter;
and in the summer months, about the time of the last
quarter.

These phenomena depend upon the different an-
gles made by the horizon, and different parts of the
moon's orbit, and that the moon can be full but
once or twice in a year, in those parts of her orbit
which rise with the least angles.

The moon's motion is so nearly in the ecliptic,
that we may consider her at present as moving
in it.

The different parts of the ecliptic, on account
of its obliquity to the earth's axis, make very dif-

ferent angles with the horizon as they rise or set. Those parts, or signs, which rise with the smallest angles, set with the greatest, and *vice versa*. In equal times, whenever this angle is least, a greater portion of the ecliptic rises than when the angle is larger.

This may be seen by elevating the globe to any considerable latitude, and then turning it round its axis in the horizon.

When the moon, therefore, is in those signs which rise or set with the smallest angles, she will rise or set with the least difference of time ; and with the greatest difference in those signs which rise or set with the greatest angles.

Thus in the latitude of London, at the time of the vernal equinox, when the sun is setting in the western part of the horizon, the ecliptic then makes an angle of 62 degrees with the horizon ; but when the sun is in the autumnal equinox, and setting in the same western part of the horizon, the ecliptic makes an angle but of 15 degrees with the horizon ; all which is evident by a bare inspection of the globe only.

Again, according to the greater or less inclination of the ecliptic to the horizon, so a greater or less degree of motion of the globe about its axis will be necessary to cause the same arch of the ecliptic to pass through the horizon ; and consequently the time of its passage will be greater or less in the same proportion ; but this will be best illustrated by an example.

Therefore, suppose the sun in the vernal equinox, rectify the globe for the latitude of London and the place of the sun ; then bring the vernal equinox, or sun's place, to the western edge of the horizon, and the hour index will point precisely to VI ; at which time we will also suppose the moon to be in the autumnal equinox, and consequently at full and rising exactly at the time of sun-set.

But on the following day, the sun, being advanced scarcely one degree in the ecliptic, will set again very nearly at the same time as before ; but the moon will, at a mean rate, in the space of one day pass over 13 deg. in her orbit ; and therefore, when the sun sets in the evening after the equinox, the moon will be below the horizon, and the globe must be turned about till 13 degrees of Libra come up to the edge of the horizon, and then the index will point to 7 h. 16 min. the time of the moon's rising, which is an hour and quarter after sun-set for dark night. The next day following there will be two hours and an half ; and so on successively, with an increase of one hour and a quarter dark night each evening respectively, at this season of the year ; all owing to the very great angle which the ecliptic makes with the horizon at the time of the moon's rising.

On the other hand, suppose the sun in the autumnal equinox, or beginning of Libra, and the moon opposite to it in the vernal equinox, then the globe, rectified as before, being turned about till

he sun's place comes to the western edge of the ho-
rizon, the index will point to VI, for the time of
the setting and the rising of the full moon on that
equinoctial day. On the following day, the sun
will set nearly at the same time ; but the moon being
advanced (in the 24 hours) 13 degrees in the eclip-
tic, the globe must be turned about till that arch
of the ecliptic shall ascend the horizon ; which mo-
tion of the globe will be very little, as the ecliptic
now makes so small an angle with the horizon, as is
evident by the index, which now points to VI h.
17 min. for the time of the moon's rising on the se-
cond day, which is about a quarter of an hour after
sun-set. The third day, the moon will rise within
half an hour ; on the fourth, within three quarters
of an hour, and so on ; so that it will be near a week
before the nights will be an hour without illumina-
tion : and in greater latitudes this difference will be
still greater, as you will easily find by varying the
case, in the practice of this celebrated problem on
the globe.

This phenomenon varies in different years ; the
moon's orbit being inclined to the ecliptic about
five degrees, and the line of the nodes continually
moving retrograde, the inclination of her orbit to
the equator will be greater at some seasons than it is
at others, which prevents her hastening to the north-
ward or descending southward, in each revolution,
with an equal pace.

PROBLEM XLV. *To find at what azimuth the moon is upon at any place when it is flood, or high water; and thence the high tide for any day of the moon's age at the same place.*

Having observed the hour and minute of high water, about the time of new or full moon, rectify the globe to the latitude and sun's place; find the moon's place and latitude in the ephemeris, to which set the artificial moon,* and screw the quadrant of altitude in the zenith; turn the globe till the horary index points to the time of flood, and lay the quadrant over the centre of the artificial moon, and it will cut the horizon in the point of the compass upon which the moon was, and the degrees on the horizon contained between the strong brass meridian and the quadrant, will be the moon's azimuth from the south.

To find the time of high water at the same place.

Rectify the globe to the latitude and zenith, find the moon's place by an ephemeris for the given day of her age, or day of the month, and set the artificial moon to that place in the zodiac: put the quadrant of altitude to the azimuth before found, and turn the globe till the artificial moon is under its graduated edge, and the horary index will point to the time of the day on which it will be high water.

* Or patch representing the moon.

THE USE OF THE CELESTIAL GLOBE IN THE SOLUTION OF PROBLEMS ASCERTAINING THE PLACES AND VISIBLE MOTIONS OR ORBITS OF COMETS.*

There is another class or species of planets, which are called comets. These move round the sun in regular and stated periods of times, in the same manner, and from the same cause, as the rest of the planets do; that is, by a centripetal force, every where decreasing as the squares of the distances increase, which is the general law of the whole planetary system. But this centripetal force in the comets being compounded with the projectile force, in a very different ratio from that which is found in the planets, causes their orbits to be much more elliptical than those of the planets, which are almost circular.

But, whatever may be the form of a comet's orbit in reality, their geocentric motions, or the apparent paths which they describe in the heavens among the fixed stars, will always be circular, and therefore may be shewn upon the surface of a celestial globe, as well as the motions and places of any of the rest of the planets.

To give an instance of the cometary praxis on the globe, we shall choose that comet for the subject of these problems, which made its appearance

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* *Martin's* Description and Use of the Globes.

at Boston in New England, in the months of Oc-
tober and November 1758, in its return to the
sun ; after which it approached so near the sun,
as to set *heliacally*, or to be lost in its beams, for
some time spent in passing the perihelion. Then
afterwards emerging from the solar rays, it ap-
peared retrograde in its course from the sun to-
wards the latter end of March, and so continued
the whole month of April and part of May, in the
West Indies, particularly in Jamaica, whose lati-
tude rendered it visible in those parts, when it
was for the greatest part of the time invisible to
us, by reason of its southern course through the
heavens.

When two observations can be made of a comet,
it will be very easy to assign its course, or mark it
out upon the surface of the celestial globe. These,
with regard to the above-mentioned comet, we have,
and they are sufficient for our purpose in regard to
the solution of cometary problems.

By an observation made at Jamaica on the 31st of
March, 1759, at five o'clock in the morning the co-
met's altitude was found to be 22 deg. 50 min. and
its azimuth 71 deg. south-east. From hence we
shall find its place on the surface of the globe by the
following problem.

PROBLEM XLVI. *To rectify the globe for the latitude of the place of observation in Jamaica, latitude 17 deg. 30 min. and given day of the month, viz. March 31st.*

Elevate the north pole to 17 deg. 30 min. above the horizon, then fix the quadrant of altitude to the same degree in the meridian, or zenith point. Again, the sun's place for the 31st of March is in 10 deg. 34 min. ♈, which bring to the meridian, and set the hour index at XII, and the globe is then rectified for the place and time of observation.

PROBLEM XLVII. *To determine the place of a comet on the surface of the celestial globe from its given altitude, azimuth, hour of the day, and latitude of the place.*

The globe being rectified to the given latitude, and day of the month, turn it about towards the east, till the hour index points to the given time, *viz.* V o'clock in the morning; then bring the quadrant of altitude to intersect the horizon in 71 deg. the given azimuth in the south-east quarter; then, under 22 deg. 50 min. the given altitude, you will find the comet's place, where you may put a small patch to represent it.

B b

PROBLEM XLVIII. *To find the latitude, longitude, declination, and right ascension of the comets.*

In the circles of latitude contained in the zodiac, you will find the latitude of the comet to be about 30 deg. 30 min. from the ecliptic; the same circle of latitude reduces its place to the ecliptic in 26 deg. 30. min. of ♒, which is its longitude sought. Then bring the cometary patch to the brazen meridian, and its declination will be shewn to be 9 deg. 15 min. south. At the same time, its right ascension will be 227 deg. 30 min.

PROBLEM XLIX. *To shew the time of the comet's rising, southing, setting, and amplitude, for the day of the observation at Jamaica.*

Bring the place of the comet into the eastern semicircle of the horizon, (the globe being rectified as directed) the index will point to III hours 15 min. which is the time of its rising in the morning at Jamaica, the amplitude 10 deg. very nearly to the south. The patch being brought to the meridian, the index points to IX o'clock 10 min. for the time of culminating, or being south to them. Lastly, bring the patch to touch the western meridian, and the index will point to III in the afternoon, for the time of the comet's setting, with 10 degrees of southern amplitude, of course.

PROBLEM L. *From the comet's place being given, to find the time of its rising in the horizon of London, on the 31st day of March, 1759.*

For this purpose, you need only rectify the globe for the given latitude of London, and bring the cometary patch to the eastern horizon, and the index points to III hours 45 min. for the time of its rising at London, with about 14 deg. of south amplitude; then turn the patch to the western horizon, and the index points to II hours 25 minutes, the time of its setting.

N. B. From hence it appears, the comet rose soon enough that morning to have been observed at London, had the heavens been clear, and the astronomers been before-hand apprized of such a phenomenon.

PROBLEM LI. *To determine another place of the same comet, from an observation made at London on the 6th day of May, at ten in the evening.*

On the 6th day of May, 1759, at ten at night, the place of the comet was observed, and its distance measured with a micrometer, from two fixed stars marked μ and ν in the constellation called *Hydra*, and its altitude was found to be 16 deg. and its azimuth 37 deg. south west; from whence its place on the surface of the globe is exactly determined as in Problem xlvii, and having stuck a patch thereon, you will have the two places of the comet on the surface of the globe, for the two distant days and places of observation, as required.

PROBLEM LII. *From two given places of a comet, to assign its apparent path among the fixed stars in the heavens.*

The two places of the comet being determined by the observations on the 31st of March, 1758, and the 6th of May following, and denoted by two patches respectively, you must move the globe up and down, in the notches of the horizon, till such time as you bring both the patches to coincide with the horizon ; then will the arch of the horizon between the two patches shew, upon the celestial globe, the apparent place of the comet in the interval between the two observations, and by drawing a line with a black lead pencil along by the frame of the horizon, its path on the surface of the globe will be delineated, as required. And here it may be observed, that its apparent path lies through the following southern constellations, *viz.* the tail of Capricorn, the tail of Piscis Australis, by the head of Indus, the neck and body of Pavo, through the neck of Apus, below Triangulum Australe, above Musca, by the lowermost of the Crosiers, across the hind legs and through the tail of Centaurus, from thence between the two stars in the back of the Hydra before-mentioned; after this, it passed on to Sextans Uraniæ, and then to the ecliptic near Cor Leonis, soon after which it totally disappeared.

PROBLEM LIII. *To estimate the apparent velocity of a comet, two places thereof being given by observation.*

Let one place be ascertained near the beginning of its appearance, and the other towards the end thereof; then bring these two places to the horizon, and count the number of degrees intersected between them, which being the space apparently described in a given time, will be the velocity required. Thus, in the case of the above-mentioned comet, you will find that it described more than 150 deg. in the space of 36 days, which is more than four deg. per day.

PROBLEM LIV. *To represent the general phenomena of the comet for any given latitude.*

Bring the visible path of the comet to coincide with the horizon, by which it was drawn, and then observe what degree of the meridian is in the north point of the horizon, which, in the case of the foregoing comet, will be the 23d deg. This will shew the greatest latitude in which the whole path can be visible in any latitude less than this, as that-of Jamaica; where, for instance, the most southern part of the path will be elevated more than five deg. above the horizon, and the comet visible through the whole time of its apparition. But rectifying the globe for the latitude of London, the path of the said comet will be for the most part invisible, or below the horizon; and therefore it could not have been seen in

our latitude, but at times very near the beginning and end of its appearance; because, by bringing the comet's path on one part to the south point of the horizon, it will immediately appear in what part the comet ceases to be visible; and then bringing the other part of the path to the point, it will appear in what part it will again become visible.

After this manner may the problems relating to any other comets be performed; and thus the paths of the several comets, which have hitherto been observed, may be severally delineated on the celestial globe, and their various phenomena in different latitudes be thereby shewn.

E S S A Y III.

CONTAINING

A DESCRIPTION

OF THE MOST IMPROVED

PLANETARIUM, TELLURIAN, AND LUNARIUM.

I now proceed, in pursuance of my original plan, to describe one of the instruments contrived to facilitate the study of geography and astronomy. It will realize to the eye of the pupil many phenomena, and impress them strongly on his memory. The instrument here described may be considered as one of the best hitherto contrived for explaining the celestial motions. The description of this will, with very few alterations, apply to most other instruments designed for the same purpose. The explanation of the instrument will also enable me to render some articles plainer, and to treat others more fully; while those who have not thoroughly comprehended what has been already said, may gain more perfect ideas of the subject.

It seems highly probable, that the ancients were not unacquainted with planetary machines, and

that the same powers of genius which led them to contemplate and reason upon the motion of the heavenly bodies, induced them to realize their ideas, and form instruments for explaining them; and we may fairly presume, that these were carried to no small degree of perfection, when we consider that of one, *Archimedes* was the maker, and *Cicero* the encomiast.

The instrument now to be described was invented by the celebrated *Huygens*, though since his time it has been ascribed to almost as many inventors as makers; each deviation in form, the mounting it in this mode or the other, the addition of a zodiac, or some such slight changes, have been deemed by many of sufficient importance to give them a claim to the title of inventors:—be it so. Let the friend of science encourage every humble effort to improve it; and let him bestow a name which, though it may in some measure gratify vanity, yet incites to labour, rather than by contempt, check the ardour, or discourage the talents which, when called forth, may be of the greatest service to society.

DESCRIPTION OF THE PLANETARIUM.

Plate 11, *fig.* 1, represents the planetarium.*

* This instrument, with two other parts, the *Tellurian* and *Lunarium* Plate xii, fig. 1 and 2, comprises an Orrery, the most portable and complete of any other made. By the triple division of the

The box A B contains the wheel-work by which the planets are made to move round a brass ball, representing the sun: this motion is communicated to them by turning the handle.

A planetarium may be considered, in some sort, as a diametrical section of our universe, in which the upper and lower hemispheres are suppressed.

The upper plate is to answer for the ecliptic; on this therefore are placed, in two opposite circles, corresponding to each other, the signs of the ecliptic, and the days of the month, by means whereof the planets may be easily set to their mean places in the ecliptic for any day in the year. Through the centre of the plate there passes a strong stem, on which the brass ball ⊙ is placed, which represents the sun; round the stem are the different sockets, which carry the arms, by which the balls representing the planets are supported. The planets are ivory balls, having the hemisphere which is next the sun white, the other black, to exhibit their respective

machine, the motions are more completely and accurately shewn than by the larger kind, where all the planetary motions are attempted to be exhibited in one machine. It requires a considerable bulk, as well as expence, to unite in one machine only, the motions displayed in this, and much more so, when the satellites periodical revolutions are included. The box AB, is supported on a brass pillar and stand not shewn in the figure; and the arms are to be taken off their common central arbor, when either of the other two parts the Tellurian and Lunarium is to be applied. The diameter of the brass box is about 10 inches, and the machine and apparatus packs into a neat portable mahogany case, about 20 inches in height and 12 inches square. EDIT.

phases to each other. The planets may be easily put on or taken off their sockets, as occasion requires. About the primary planets are placed the secondary planets, or moons, which are in this instrument only moveable by hand; but when the instrument is fitted upon a large scale, and in a more expensive form, even these are put in motion by the wheel-work.

The planets are disposed in the following order :— in the centre is the brass ball ☉, to represent the sun; then Mercury ☿, Venus ♀, the Earth ⊕, Mars ♂, Jupiter ♃, and Saturn ♄; then the Georgium Sidus ♅.

When the pupil has been gratified by putting the instrument in motion, and making his own observations on those motions, it will be proper to acquaint him with the names of the different planets, and of their division into primary and secondary, to shew him how they were first distinguished from the fixed stars, and how the length of their periodic revolution was discovered. Here it will be proper to observe, that the annual motion of the earth, or the time it takes to perform its period round the sun, is made the basis to which the others are compared; and this is one of the reasons why the months, and days of our months, are engraved on the circle. Having observed this, the planets may be put in motion, and they will be found to revolve round the representative of the sun in their proportionable times, each planet always completing its revolution in the same space of time, in periods regulated and pro-

portioned to their distance from the sun : the curve which they describe in their revolution, is what is termed their orbit.

GENERAL EXPLANATION OF THE SOLAR SYSTEM BY THE PLANETARIUM.

In the centre of the system is the sun, placed in the heavens by that *Almighty Power* who said, " Let there be light, and there was light," to be the fountain of light and heat to all the planets revolving round him.

—— " His rapid rays,
" Themselves unmeasur'd, measure all our days :
" A thousand worlds confess his quick'ning heat,
" And all he cheers are fruitful, fair, and sweet."

The situation of this glorious body, in the system, is pointed out in this machine by the brass ball in the centre.

Mercury is the nearest planet to the sun, and moves round him in about 88 days. To observe this by the planetarium, observe the parts of the ecliptic where Mercury and Venus are situated, or set them to any two given places therein, and then turn the handle ; and when Mercury is returned to the place from whence he set out, the earth will have gone over 88 days of the ecliptic. In the same manner you will find the periods of the other planets correspond-ing to their respective periods in the heavens.

As Mercury moves round him in rather less than three months, that consequently is the length of his

year; the year in each planet being the space of time which it occupies in going round the sun. Mercury is seldom seen, on account of his being so near to the sun as to be generally concealed by his rays; and the time of his rotation on his axis, or the length of his days and nights, has not yet been discovered.

Venus, the next planet to Mercury, distinguished in the heavens by her superior lustre and brightness, completes her annual or yearly revolution round the sun in about 225 days; and her diurnal or daily rotation upon her own axis, in about $23\frac{1}{2}$ hours. When this planet appears to the west of the sun, she rises before him in the morning, and is called the morning star; and when she appears to the east of the sun, she shines in the evening after he sets, and is then called the evening star; being in each situation, alternately, for about $7\frac{1}{2}$ months.

The next planet above Venus is the *Earth*, whose annual revolution is performed in 365 days, 5 hours, and 49 minutes, or rather more than 12 months (the brazen ecliptic is however only divided into 365 days), and its diurnal rotation in about 24 hours. Every fourth year, one day is added at the end of February, to recover the time which the earth spends in her annual course above the 365 days, which compose a common year. This fourth year, therefore, consists of 366 days, and is called bissextile, and also leap-year.

Next above the earth's orbit is that of *Mars*, who completes his revolution round the sun in somewhat

less than two of our years, and his rotation upon his axis is rather more than 24½ hours.

Jupiter, the largest of all the planets, holds the next place to Mars in distance from the sun. He performs his annual revolution in rather less than 12 years, and his diurnal rotation in about ten hours. Jupiter, as well as Venus, is sometimes called a morning, and sometimes an evening star.

Next to the orbit of Jupiter is that of *Saturn*, who completes his annual revolution round the sun in about 29½ years. The time of his diurnal rotation is unknown.

Saturn was generally considered as the remotest planet of our system, till, on the 13th of Mach, 1781, Dr. *Herschel* discovered another, still further, distant from the sun, round which it revolves in an orbit nearly circular, in about 82 years. To this planet Dr. *Herschel* has given the name of the *Georgium Sidus*.

Besides these seven primary planets, there are fourteen others, called secondary planets, or satellites, which move round their primaries in the same manner as these move round the sun.

The first of these is the moon, represented by the small ball annexed to the earth. While it accompanies the earth in its annual progress through its orbit, it is continually revolving round it ; as you will see in that part of the instrument that is particularly designed to illustrate the phenomena of the moon.

Jupiter has four satellites, Saturn seven, and the Georgium Sidus six : they are all invisible to the

naked eye, and are only to be seen by the assistance of telescopes. Saturn, besides his seven satellites, has a bright shining ring, which encompasses him: it is at such a distance from his body, that the fixed stars may frequently be seen between the inner edge of the ring and the planet itself. Dr. *Herschel* has lately discovered that this ring is divided into two parts, an inner and an outer ring, which are separated from each other by a space of one thousand miles.

To explain, by the planetarium, why the sun, being a fixed body, appears to pass through all the signs of the zodiac in twelve months, or one year. It will shew that this phenomenon is occasioned by the annual motion of the earth.

As the general phenomena of the planetary system will be best understood by an induction of particulars, I should advise the tutor to remove all the planets but those whose motion he is going to explain; for instance, let him now leave only the earth and sun; place the earth over Libra, and it is plain that the sun will then be transferred, by the eye of the spectator to Aries, in which sign it will appear at the latter end of March: move the earth on in its orbit to Capricornus, and the sun will appear at Cancer in June, seeming to have moved from ♈ to ♋, though it has not stirred, the real motion of the earth having caused the spectator to transfer the sun to all the intermediate points in the heavens,

and thus given it apparent motion. Continue to move the earth till it arrives at Aries, and the sun will be seen in Libra, in the month of September: moving the earth on to Cancer, the visual ray of the spectator refers the sun to Capricorn, as it appears in the month of December. Lastly, continue moving the earth, and it will arrive at Aries, where we set out. Thus we have shewn that it is the motion of the earth which causes the sun to appear in all the different signs of the zodiac. Custom, indeed, has taught us to say the sun is in Aries, when it is between us and Aries, and so of any other sign ; whereas it would have been more proper to say, that the earth is in Libra.

To shew why, at different times of the year, we see the heavens decorated with an entire different collection of stars.

This phenomenon is occasioned by the earth's progressive or annual motion ; while the earth is traversing his course under the vast concave of fixed stars, we are gradually carried under the different constellations. From hence it is evident, that at night, when the earth is turned from the sun, we shall, in succession, have the opportunity of viewing, from time to time, all the stars in the zodiac, and consequently a different constellation will present itself every month.

Thus, the Pleiades are not visible in the summer ; but in the winter the earth is got between the sun

and them.   These stars are observable at night, be-
cause they are not intercepted from our sight by the
sun's rays;   and in this manner they appear during
the whole winter, only they seem to get more wes-
terly every night, as the earth moves gradually by
them to the east.   To make this still more clear,
place the earth in the planetarium between the sun
and any of the signs, that side towards the sun will
be day, and that towards the sign night : it follows,
that at night we are turned towards the stars, which
in that sign (suppose, as before, the Pleiades in Tau-
rus) will then be conspicuous to us ; but as the spring
approaches, the earth withdraws itself from between
the sun and the Pleiades, till at length the earth, by
its progressive motion, gets the sun between it and
the stars, which then lie hid behind the solar rays :
after the same manner, while the earth performs his
annual tract, the sun, which always seems to move
the contrary way, darkens, by his splendor, the other
constellations successively ; but the stars opposite to
those hid by the sun, are at night presented to our
view.

GENERAL PHENOMENA OF THE PLANETS.

Let the tutor now place the Earth, Mars, and Ve-
nus, on the planetarium ; and as each planet moves
with a different degree of velocity, they are continu-
ally changing their relative positions. Thus, on turn-
ing the handle of the machine, he will find, first,
that the Earth moves twice as fast as Mars, making

two revolutions while he makes one; and Venus, on the other hand, moves much faster than the earth. Secondly, that in each revolution of the earth these planets continually change their relative positions, corresponding sometimes with the same point of the ecliptic, but much oftener with different points.

To explain the conjunction, opposition, elongation, and other phenomena of the inferior planets.

I may now proceed to make some observations on the motions of Venus, as observed in the planetarium. If considered as viewed from the sun, we shall find that Venus would appear at one time nearer to the earth than at another; that sometimes she would appear in the same part of the heavens, and at others in opposite parts thereof.

As the planets, when seen from the sun, change their position with respect to the earth, so do they also, when seen from the earth, change their positions with respect to the sun, being sometimes nearer to, at others farther from, and at times in conjunction with him.

But the conjunctions of Venus or Mercury, seen from the earth, not only happen when they are seen together from the sun, but also when they appear to be in opposition to the solar spectator. To illustrate this, bring the earth and Venus to the first point of Capricorn; then by applying a string from the sun over Venus and the earth, you will find them to be in conjunction, or on the same point of the ecliptic.

C c

Whereas, if you turn the handle till the sun is between Venus and the earth, a spectator in the sun will see Venus and the earth in opposition; but an inhabitant of the earth will see Venus not in opposition to the sun, but in conjunction with him.

In the first conjunction Venus is between the sun and earth; this is called the inferior conjunction. In the second, the sun is situated between the earth and Venus; this is called the superior conjunction.

After either of these conjunctions, Venus will be seen to recede daily from the sun, but never departing beyond certain bounds, never appearing opposite to the sun; and when she is seen at the greatest distance from him, a line joining her centre with the centre of the earth, will be a tangent to the orbit of Venus.

To illustrate this, take off the sun from its support, and the ball of Venus from its supporting stem; place the wire, *plate* 11, *fig.* 2, so that the part P may be on the stem that supports the earth, and a similar socket, *fig.* 3, on the pin which supports the ball of Venus; the wire F is to lie in a notch at the top of the socket, which has been put upon the supporting stem of Venus; then will the wire represent a visual ray going from an inhabitant of the earth to Venus. By turning the handle, you will now find that the planet never departs further than certain limits from the sun, which are called its greatest elongations, when the wire becomes its tangents to the orbit; after which, it approaches the sun till

it arrives at either the inferior or superior conjunc-
tion.

It will also be evident from the instrument, that
Venus, from her superior conjunction, when she is
furthest from the earth, to the time of her inferior
conjunction, when she is nearest, sets later than the
sun, is seen after sun-set, and is, as it were, the
fore-runner of night and darkness. But from the
inferior conjunction, till she comes to the superior
one, she is always seen westward of the sun, and
must consequently set before him in the evening, and
rise before him in the morning, foretelling that light
and day are at hand.

Bring Venus and the earth to the beginning of
Aries, when they will be in conjunction ; and turn
the handle for nearly 225 days, and as Venus moves
faster than the earth, she will be come to Aries, and
have finished her course, but will not have over-
taken the earth, who has moved on in the mean time;
and Venus must go on for some time, in order to
overtake her. Therfore, if Venus should be this day
in conjunction with the sun, in the inferior part of
her orbit, she will not come again to the same con-
junction till after 1 year, 7 months, and 12 days.

It is also plain, by inspection of the planetarium,
that though Venus does always keep nearly at the
same distance from the sun, yet she is continually
changing her distance from the earth ; her distance
is greatest when she is in her superior, and least
when she is in her inferior conjunction.

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To explain the phases, the retrograde, direct, and sta-tionary situations of the planets.

As Venus is an opake globe, and only shines by the light she receives from the sun, that face which is turned towards the sun will always be bright, while the opposite one will be in darkness; consequently, if the situation of the earth be such, that the dark side of Venus be turned towards us, she will then be invisible, except she appears like a spot on the disc of the sun. If her whole illuminated face is turned towards the earth, as it is in her superior conjunction, she appears of a circular form; and according to the different positions of the earth and Venus, she will have different forms, and appear with different phases, undergoing the same changes of form as the moon. These different phases are seen very plain in this instrument, as the side of the planet, which is opposite to the sun, is blackened; so that in any position, a line drawn from the earth to the planet, will represent that part of her disc which is visible to us.

The irregularities in the apparent motions of the planets, is a subject that this instrument will fully elucidate; and the pupil will find that they are only apparent, taking their rise from the situation and motion of the observer. To illustrate this, let us suppose the above mentioned wire, when connected with Venus and the earth, to be the visual ray of an observer on the earth, it will then point out how the

motions of Venus appear in the heavens, and the path she appears to us to describe among the fixed stars.

Let Venus be placed near her superior conjunction, and the instrument in motion, the wire will mark out the apparent motion of Venus in the ecliptic. Thus Venus w ll appear to move eastward in the ecliptic, till the wire becomes a tangent to the orbit of Venus, in which situation she will appear to us to be stationary, or not to advance at all among the fixed stars; a circumstance which is exceeding visible and clear upon the planetarium.

Continue turning, till Venus be in her superior conjunction, and you will find by the wire, or visual ray, that she now appears to move backward in the ecliptic, or from east to west, till she is arrived to that part where the visual ray again becomes a tangent to her orbit. In which position, Venus will again appear stationary for some time; after which she will commence anew her direct motion.

Hence, when Venus is in the superior part of her orbit, she is always seen to move directly, according to the order of the signs; but when she is in the inferior part, she appears to move in a contrary direction.

What has been said concerning the motions of Venus, is applicable to those of Mercury; but the conjunctions of Mercury with the sun, as well as the times of his being direct, stationary, or retrograde, are more frequent than those of Venus.

Of the superior planets, as seen from the earth.

If the tutor wishes to extend his observations on the instrument to Mars, he will find by the visual ray, that Mars, when in conjunction, and when in opposition, will appear in the same point of the ecliptic, whether it is seen from the sun or the earth ; and in this situation only is its real and apparent place the same, because then only the ray proceeds as if it came from the centre of the universe.

He will observe, that the direct motion of the superior planets is swifter the nearer it is to the conjunction, and slower when it is nearer to quadrature with the sun ; but that the retrograde motion of a superior planet is swifter the nearer it is to opposition, and slower the nearer it is to quadrature ; but at the time of change from direct to retrograde, its motion becomes insensible.

To prove, by the planetarium, the truth of the Copernican, and absurdity of the Ptolemaic system.

Of all the prejudices which philosophy contradicts, there is none so general as that the earth keeps its place unmoved. This opinion seems to be universal, till it is corrected by instruction, or by philosophical speculation. Those who have any tincture of education, are not now in danger of being held by it ; but yet they find at first a reluctance to believe that there

are antipodes, that the earth is spherical, and turns round its axis every day, and round the sun every year. They can recollect the time when reason struggled with prejudice upon these points, and prevailed at length, but not without some efforts.*

The planetarium gives ocular demonstration of the motion of the earth about the sun, by shewing that it is thus only that the celestial phenomena can be explained, and making the absurdity of the Ptolemaic system evident to the senses of young people. For this purpose take off the brass ball which represents the sun, and put on the small ivory ball, which accompanies the instrument in its place, to represent the earth, and place a small brass ball for the sun, on that arm which carries the earth.

The instrument in this state will give an idea of the Ptolemaic system, with the earth immoveable in the centre, and the heavenly bodies revolving about in the following order: Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. Now, in this disposition of the planets, several circumstances are to be observed, that are contrary to the real appearances of the celestial motions, and which therefore prove the falsity of this system.

It will appear from the instrument, that on this hypothesis Mercury and Venus could never be seen to go behind the sun, from the earth, because the orbits of both of them are contained between the sun and the earth; but these planets are seen to go as

* *Reid's* Essays on the Intellectual Powers of Man.

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often behind the sun as before it; we may, therefore, from hence conclude, that this system is erroneous.

It is also apparent in the planetarium, that on this scheme these planets might be seen in conjunction with, or in opposition to the sun, or at any distance from it. But this is contrary to experience, for they are never seen in opposition to the sun, or on the meridian of London; for instance, at midnight, nor ever recede from it beyond certain limits.

Again, on the Ptolemaic system all the planets would be at an equal distance from the earth, in all parts of their orbits, and would therefore necessarily appear always of the same magnitude, and moving with equal and uniform velocities in one direction; circumstances which are known to be repugnant to observation and experience.

To rectify the planetarium, or place the planets in their true situations, as seen from the sun.

The situations of the planets in the heavens are accurately calculated by astronomers, and published in almanacks appropriated to the purpose, as the Nautical Almanack, *White*'s Ephemeris, &c. An ephemeris is a diary or daily register of the motions and places of the heavenly bodies, shewing the situation of each planet at 12 o'clock each day. These situations it exhibits, both as seen from the sun, and from the earth; but as for the

former, or the heliocentric, is the only one of any use for this purpose, we shall here insert, and explain, so much of that part of Mr. *White*'s ephemeris, as will enable the pupil to rectify his planetarium.

Days.	Day increas.	Length of day.	Helioc. long. ♄	Helioc. long. ♃	Helioc. long. ♂	Helioc. long. ⊕	Helioc. long. ♀	Helioc. long. ☿
1	7 4	14 48	27 ♓ 35	2 ♍ 14	27 ♍ 16	11 ♏ 14	8 ♐ 35	1 ♉ 18
7	7 24	15 8	27 47	2 42	29 57	17 2	18 7	26 ♊ 53
13	7 44	15 28	27 59	3 0	2 ♎ 39	21 52	7 37	3 ♌ 4
19	8 0	15 44	28 11	3 37	5 20	28 36	7 ♑ 7	4 ♍ 15
25	8 10	16 0	28 23	4 5	8 3	4 ♐ 22	16 36	0 ♎ 0

In the foregoing table for May 1790, you have the heliocentric places calculated to every six days of the month, which is sufficiently accurate for general purposes. Thus on the 19th, you have Saturn in 28° 11′ of Pisces, Jupiter 3° 37′ of Virgo, Mars in 5° 20′ of Libra, the Earth 28° 36′ of Virgo, Venus 7° 7′ of Capricorn, and Mercury 4° 13′ of Virgo; to which places on the ecliptic of the planetarium the several planets are to be set, and they will then exhibit their real situations, both with respect to the sun and the earth, for that day.

To use the instrument as a tellurian, plate 12, *fig.* 1.

The sun, the earth, and the moon, are bodies, which from our connexion with them, are so in-

teresting to us, that it is necessary to enter into a minute detail of their respective phenomena. To render this instrument a tellurian, all the planets are first to be taken off, the piece of wheel-work, A B, is to be placed on in their stead, in such a manner that the wheel c may fall into the teeth that are cut upon the edge of the ecliptic. The milled nut, D, is then to be screwed on, to keep the wheel-work firmly in its place. It is best to place this wheel-work in such a manner, that the index E may point to the 21st of June, and then to move the support of the globe so that the north pole may be turned towards the sun.

The instrument will then shew, in an accurate and clear manner, all the phenomena arising from the annual and diurnal motion of the earth ; as the globe is of three inches diameter, all the continents, seas, kingdoms, &c. may be distinctly seen ; the equator, the ecliptic, tropics, and other circles, are very visible ; so that the problems relative to peculiar places may be satisfactorily solved. The axis of the earth is inclined to the ecliptic in an angle of $66\frac{1}{2}$ degrees, and preserves its parallelism during the whole of its revolution. About the globe there is a circle, to represent the terminator, or boundary between light and darkness, dividing the enlightened from the dark hemisphere. At N O is an hour circle, to determine the time of sun-rising or setting.

The brass index G represents a central solar ray ; it serves to shew when it is noon, or when the sun

s upon the meridian at any given place; it also shews what sign and degree of the ecliptic on the globe the sun describes on any day, and the parallel it describes.

The plane of the terminator, H I, passes through the centre of the earth, and is perpendicular to the central solar ray. The index E points out the sun's place in the ecliptic instrument for any given day in the year.

To explain the changes of seasons by the tellurian.

Before I shew how the seasons are explained by the instrument, it is necessary to assume two propositions : 1. That a globular luminous body, sending out parallel rays of light, will only enlighten one half of another globe, and that of course will be the hemisphere turned towards the luminous body. 2. That the earth moves round the sun in such a manner, that in all parts of its orbit its axis is parallel to itself, and has a certain inclination to the plane of the orbit. These being understood, the first thing to be done is to rectify the tellurian ; or, in other words, to put the globe into a position similar to that of the earth, for any given day. Thus, to rectify the tellurian for the 21st of June, turn the handle till the annual index comes to the given day; then move the globe by the arm K L, so that the north pole may be turned towards the sun ; and adjust the terminator, so that it may just touch the edge of the arctic circle,

The globe is then in the situation of the earth for the longest day in our northern hemisphere, the annual index pointing to the first point of Cancer and the 21st of June ; bring the meridian of London to coincide with the central solar ray, and move the hour circle, NO, till the index L points to XII ; we then have the situation of London with respect to the longest day.

Now, on gently turning the handle of the machine, the point representing London will, by the rotation of the earth, be carried away towards the east, while the sun seems to move westward ; and when London has arrived at the eastern part of the terminator, the index will point on the hour circle the time of sun-setting for that day ; continue to turn on, and London will move in the shaded part of the earth, on the other side of the terminator ; when the index is again at XII, it is midnight at London ; by moving on, London will emerge from the western side of the terminator, and the index will point out the time of sun-rising, the sun at that instant appearing to rise above the horizon in the east to an inhabitant of London.

It will be evident by the instrument, while in this position, that the central solar ray, during the whole revolution of the earth on its axis, only points to the tropic of Cancer, and that the sun is vertical to no other part of the earth, but those who are under this tropic.

By observing how the terminator cuts the several

parallels of the globe, we shall find that all those be-
tween the northern and southern polar circles, except
the equator, are divided unequally into diurnal
and noctural arches, the former being greatest on
the north side of the equator, and the latter on the
south side of it.

In this position, the northern polar circle is
wholly on that side the terminator which is nearest
the sun, and therefore altogether in the enlight-
ened hemisphere, and the inhabitants thereof en-
joy a continual day. In the same manner, the in-
habitants of the southern polar circle continue in
the dark at this time, notwithstanding the diurnal
revolution of the earth ; it is the annual motion
only which can relieve them from this situation of
perpetual darkness, and bring to them the blessings
of day, and the enjoyments of summer ; while in
this state, the inhabitants of north latitude are
nearest to the central solar ray, and consequently
to the sun's perpendicular beams, and of course a
greater number of his rays will fall upon any given
place, than at any other time ; the sun's rays do now
also pass through a less quantity of the atmosphere,
which, together with the length of the day and the
shortness of the night, are the reasons of the increase
of heat in summer, together with all its other delight-
ful effects.

While the earth continues to turn round on its
own axis once a day, it is continually advancing
from west to east, according to the order of the
signs, as is seen by the progress of the annual

index E, which points successively to all the signs and degrees of the ecliptic ; the sun in the mean time seems to describe the ecliptic also, going from west to east, at the distance of six signs from the earth ; that is, when the earth really sets out from the first point of Capricorn, the sun seems to set out from the first point of Cancer, as is plain from the index.

But as, during the annual revolution of the earth, the axis always remains parallel to itself, the situation of this axis, with respect to the sun, must be continually changing.

As the earth moves on in the ecliptic, the northern polar circle gets gradually under the terminator, so that when the earth has arrived at the first point of Aries, and the annual index is at the first point of Libra on the 22d of September, this circle is divided into two equal parts by the terminator, as is also every other parallel circle, and consequently the diurnal and nocturnal arches are equal ; this is called the time of equinox, the days and nights are then equal all over the earth, being each of them 12 hours long, as will be seen by the horary index L. The central solar ray G, having successively pointed to all the parallels that may be supposed to be between the equator and the tropic of Cancer, is at this period perpendicular to the inhabitants that live at the equator.

By continuing to turn the handle, the earth advances in the ecliptic, and terminator shews how the days are continually decreasing, and the diurnal

arches shortening, till by degrees the whole space contained by the northern polar circle is on that side of the terminator which is opposite to the sun, which happens when the earth is got to the first point of Cancer, and the annual index is at the first point of Capricorn, on the 21st of December. In this state of the globe, the northern polar circle, and all the country within that space, have no day at all; whilst the inhabitants that live within the southern polar circle, being on that side of the terminator which is next the sun, enjoy perpetual day. By this, and the former situation of the earth, the pupil will observe that there are nations to whom a great portion of the year is darkness, who are condemned to pass weeks and months without the benign influence of the solar rays. The central solar ray is now perpendicular to the tropic of Capricorn; the length of the days is now inversely what it was when the sun entered Cancer, the days being now at their shortest and the nights longest in the northern hemisphere; the length of each is pointed out by the horary index.

The earth being again carried on till it enters Libra, and the sun Aries, we shall again have all the phenomena of the equinoctial seasons. The terminator will divide all the parallels into two equal parts; the poles will again be in the plane of the terminator, and consequently, as the globe revolves, every place from pole to pole will describe an equal arch in the enlightened and obscure he-

mispheres, entering into and going out of each ex-
actly at six o'clock, as shewn by the hour index.

As the earth advances, more of the nothern
polar circle comes into the illuminated hemisphere,
and consequently the days increase with us,
while those on the other side of the equator decrease,
till the earth arrives at the first point of Capricorn,
the place from which we first began to make our
observations.

*To explain the phenomena that take place in a parallel,
direct, and right sphere.*

Take off the globe and its terminator, and put
on in its place the globe which accompanies the
instrument, and which is furnished with a meri-
dian, horizon, and quadrant of altitude ; the edge
of the horizon is graduated from the east and
west to the north and south points, and within
these divisions are the points of the compass to
the under side of this horizon ; but at 18 degrees
from it another circle is affixed, to represent the
twilight circle ; the meridian is graduated like the
meridian of a globe ; the quadrant of altitude is di-
vided into degrees, beginning at the zenith, and
finishing at the horizon.*

* We now more properly apply the moveable horizon, &c. to
all the 3-inch globes of these sort of orreries, so that the trouble of
changing the globe is done way. EDIT.

This globe, if the horizon be differently set with respect to the solar ray, will exhibit the various phenomena arising from the situation of the horizon with respect to the sun, either in a right, a parallel, or an oblique sphere ; or, having set the horizon to any place, you will see by the central solar ray how long the sun is above or below the horizon of that place, and at what point of the compass he rises, his meridian altitude, and many other curious particulars, of which we shall give a few examples.

Set the horizon to coincide with the equator, and place the earth in the first point of Libra ; then will the globe be in the position of a parallel sphere, and of the inhabitants of the poles at that season of the year, which inhabitants are represented by the pin at the upper part of the quadrant of altitude : the handle being turned round gently, the earth will revolve upon its axis, and the solar ray will coincide with the horizon, without deviating in the least to the north or south; shewing, that on the 21st of March the sun does not appear to rise or set to the terrestrial poles, but passes round through all the points of the compass, the plane of the horizon bisecting the sun's disc.

Now place the horizon so that it may coincide with the poles, and the pin representing an inhabitant, be over the equator ; the globe in this position is said to be in that of a right sphere ; the equator and all the parallels of latitude are at right angles, or perpendicular to the horizon ; by

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turning the handle till the earth has completed a year, or one revolution about the sun, we shall perceive all the solar phenomena as they happen to an inhabitant of the equator; which are, 1. That the sun rises at six and sets at six throughout the year, so that the days and nights there are perpetually equal. 2. That on the 21st of March and 22d of September, the sun is in the zenith, or exactly over the heads of the inhabitants. 3. That one half of the year, between March and September, the sun is every day full north; and the other half, between September and March, is full south of the equator, his meridian altitude being never less than $66\frac{1}{2}$ degrees.

If the pin representing an inhabitant be now removed out of the equator, and set upon any place between it and the poles, the horizon will not then pass through either of the poles, nor coincide with the equator, but cut it obliquely, one half being above, the other half below the horizon; the globe in this state is said to be in that of an oblique sphere, of which there are as many varieties, as there are places between the equator and either pole. But one example will be sufficient; for whatever appearance happens to one place, the same, as to kind, happens to every other place, differing only in degree, as the latitudes differ. Bring the pin, therefore, over London, then will the horizon represent the horizon of London, and in one revolution of the earth round the sun, we shall have all the solar appearances through the four seasons

clearly exhibited, as they really are in nature; that is, the earth standing at the first degree of Libra, and the sun then entering into Aries, the meridian turned to the solar ray, and the hour index set to XII, you will then have the globe standing in the same position towards the sun, as our earth does at noon on the 21st of March. If the handle be turned round, when the solar ray comes to the western edge of the horizon, the hour index will point to VI, which shews the time of sun-setting; London then passes into, and continues in darkness, till the hour index having passed over XII hours, comes again to VI, at which time the solar ray gains the eastern edge of the horizon, thereby defining the time of sun-rising; six hours afterwards the meridian again comes to the solar ray, and the hour index points to XII, thereby evidently demonstrating the equality of the day and night, when the sun is in the equinoctial. You may then also observe, that the sun rises due east, and sets due west.

Continuing to move the handle, you will find that the solar ray declines from the equator towards the north, and every day at noon rises higher upon the graduations of the meridian than it did before, continually approaching to London, the days at the same time growing longer and longer, and the sun rising and setting more and more towards the north, till the 21st of June, when the earth gets in the first degree of Capricorn, and the sun appears in the tropic of Cancer, rising about 40 min. past III in the morning, and setting about 20 min. past

VIII in the evening ; and after continuing about seven hours in the nether hemisphere, appears rising in the north east, as before. From the 21st of June to the 22d of September, the sun recedes to the south, and the days gradually decrease to the autumnal equinox, when they again become equal.

During the three succeeding months, the sun continues to decline towards the south pole, till the 21st of December, when the sun enters the tropic of Capricorn, rising to the south-east point of the compass about 20 min. past VIII in the morning, and setting about 40 min. past III in the evening, at the south-west point upon the horizon ; after which, the sun continues in the dark hemisphere for 17 hours, and then appears again in the south-east as before. From this chill solstice the sun returns towards the north, and the days continually increase in length till the vernal equinox, when all things are restored to the same order as at the beginning.

Thus all the varieties of the seasons, the time of sun-rising and setting, and at what point of the compass, as also the meridian altitude and declination every day of the year, and duration of twilight, and to what place the sun is at any time vertical, are fully exemplified by this globe and its apparatus.

Before we quit the phenomena particularly arising from the motion and position of the earth, let the globe, with the meridian and horizon, be removed,

and the ivory ball which fits upon a pin be placed thereon, to represent the earth.

As the axis of this globe stands perpendicular to the plane of the ecliptic, you will find that the solar ray continually points to the equator of this little ball, and will never deviate to the north or south ; though by turning the handle, the ball is made to complete a revolution round the sun. This shews, that the earth in this position would have the days and nights equal in every part of the globe, all the year long ; there would have been no difference in the climates of the earth ; no distinctions of seasons; an eternal summer, or never ceasing winter, would have been our portion ; an unvaried sameness, that would have limited inquiry, and satiated curiosity ; and that the variety of the seasons is owing to its axis being inclined to the plane of its orbit.

An explanation of the causes of the vicissitudes of the seasons, so naturally introduces the following reflections of Mr. *Cowper*, in his Winter's Walk, that I hope they will not be deemed impertinent, either by the tutor or his pupil.

What prodigies can power divine perform
More grand than it produces year by year,
And all in sight of inattentive man?
Familiar with th' effect we slight the cause.
And, in the constancy of nature's course,
The regular return of genial months,
And renovation of a faded world,
See nought to wonder at. Should God again,
As once in Gibeon, interrupt the race
Of the undeviating and punctual sun,

How would the world admire! but speaks it less
An agency divine, to make him know
His moment when to sink, and when to rise,
Age after age, than to arrest his course?
All we behold is miracle; but seen
So duly, all is miracle in vain.
Where now the vital energy that mov'd,
While summer was, the pure and subtle lymph
Through th' imperceptible meand'ring veins
Of leaf and flower? It sleeps, and th' icy touch
Of unprolific winter has impress'd
A cold stagnation on th' intestine tide;
But let the months go round, a few short months,
And all shall be restor'd. These naked shoots,
Barren as lances, among which the wind
Makes wintry music, sighing as it goes,
Shall put their graceful foliage on again;
And more aspiring, and with ampler spread,
Shall boast new charms, and more than they have lost.

*   *   *   *   *   *   *

And all this uniform, uncolour'd scene
Shall be dismantled of its fleecy load,
And flush into variety again,
From dearth to plenty, and from death to life,
Is nature's progress when she lectures man
In heavenly truth; evincing, as she makes
The grand transition, that there lives and works
A soul in all things, and that soul is God.
The beauties of the wilderness are his,
That makes so gay the solitary place,
Where no eye sees them. And the fairer forms,
That cultivation glories in, are his.
He sets the bright procession on its way,
And marshals all the order of the year.

*   *   *   *   *   *

He feeds the secret fire
By which the mighty process is maintain'd:

Who sleeps not, is not weary; in whose sight
Slow circling ages are as transient days;
Whose work is without labour; whose designs
No flaw deforms, no difficulty thwarts;
And whose beneficence no change exhausts.

OF THE LUNARIUM. *Plate* 12, *fig.* 2.

Having thus illustrated the phenomena, which arise particularly from the inclination of the earth's axis to the plane of the ecliptic, from its rotation round its axis, and revolution round the sun; I now proceed to explain, by this instrument, the phenomena of the moon. But in order to this, it will be necessary to speak first of the instrument, which is put in motion, like the preceding one, by the teeth of the fixed wheel; it is also to be placed upon the same socket as the tellurian, and confined down by the same milled nut.

The sloping ring D Q represents the plane of the moon's orbit, or path, round the earth; so that the moon in her revolution round the earth does not move parallel to the plane of the ecliptic, but on this inclined plane; the two points of this plane, that are connected by the brass wire, are the nodes, one of which is marked ♌, for the ascending node, the other ♋, for the descending node. The moon is, therefore, sometimes on the north, and sometimes on the south side of the ecliptic, which deviations from the ecliptic are called her north or south latitude; her greatest deviation, which is when she

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is at her highest and lowest points, called her limits, is 5 deg. 18 min.; this, with all the other intermediate degrees of latitude, are engraved on this ring, beginning at the nodes, and numbered both ways from them. At each side of the nodes, and at about 18 deg. distant from them, we find this mark ☉, and at about 12 deg. this ☽, to indicate that when the full moon has got as far from the nodes as the mark ☽, there can be no eclipse of the moon, nor any eclipse of the sun; when the new moon has passed the mark ☉, these points are generally termed the limits of eclipses. The nodes of the moon do not remain fixed at the same point of the ecliptic, but have a motion contrary to the order of the signs.

T X is a small circle parallel to the ecliptic; it is divided into 12 signs, and each sign into 30 deg.; this circle is moveable in its socket, and is to be set by hand, so that the same sign may be opposite to the sun, that is marked out by the annual index. These signs always keep parallel to themselves, as they go round the sun; but the inclined plane with its nodes go backwards, so that each node recedes through all the above signs in about 19 years. R S is a circle, on which are divided the days of the moon's age; X Y is an ellipses, to represent the moon's elliptical orbit, the direct motion of the apogee, or the line of the apsides, with the situation of the elliptical orbit of the moon, and place of the apogee in the ecliptic at all times.

To rectify the lunarium.

Set the annual index on the large ecliptic, to the first of Capricorn; then turn the plate, with the moon's signs upon it, until the beginning of Capricorn points directly at the sun; turn the handle till the annual index comes to the first of January; then find the place of the north node in an ephemeris, to which place among the moon's signs, set the north node of her inclined orbit, by turning it till it is in its proper place in the circle of signs; set the moon to the day of her age.

GENERAL PHENOMENA OF THE MOON.

Having rectified the lunarium for use, on putting it into motion it will be evident,

1. That the moon, by the mechanism of the instrument, always moves in an orbit inclined to that of the ecliptic, and consequently in an orbit analogous to that in which the moon moves in the heavens.

2. That she moves from west to east.

3. That the white or illuminated face of the moon is always turned towards the sun.

4. That the nodes have a revolution contrary to the order of the signs, that is, from Aries to Pisces; that this revolution is performed in about 19 years, as in nature.

5. That the moon's rotation upon her axis is effected and completed in about $27\frac{1}{2}$ days, whereas it is $29\frac{1}{2}$ days from one conjunction with the sun to the next.

6. That every part of the moon is turned to the sun, in the space of her monthly or periodic revolution.

To be more particular. On turning the handle, you will observe another motion of the earth, which has not yet been spoken of, namely, its monthly motion about the common centre of gravity between the earth and moon, which centre of gravity is represented by the pin Z. From hence we learn, that it is not the centre of the earth which describes what is called the annual orbit, but the centre of gravity between the earth and moon, and that the earth has an irregular, vermicular, or spiral motion about this centre, so that it is every month at one time nearer to, at another further from the sun. It is evident from the instrument, that the moon does not regard the centre of the earth, but the centre of gravity, as the centre of her proper motion ; that the centre of the earth is furthest from the sun at new moon, and nearest at the full moon ; that in the quadratures the monthly parallax of the earth is so sensible, as to require a particular equation in astronomical tables. These particulars were first applied to the orrery, by the late learned and ingenious Mr. *Benjamin Martin.*

To explain the phases of the Moon.

The moon assumes different phases to us, 1, on account of her globular figure; 2, on account of the motion in her orbit, between the earth and the sun, for whenever the moon is between the earth and the sun, we call it new moon, the enlightened part being then turned from us; but when the earth is between the sun and the moon, we then call it full moon, the whole of the enlightened part being then turned towards us.

The phases of the moon are clearly exhibited in this instrument; for we here see, that half which is opposite to the sun is always dark, while that is next to the sun is white, to represent the illuminated part. Thus, when it is new moon, you will see the whole white part next the sun, and the dark part turned towards the earth, shewing thereby its disappearance, or the time of its conjunction and change: on turning the handle, a small portion of the white part will begin to be seen from the earth, which portion will increase towards the end of the seventh day, when you will perceive that half of the light, and half of the dark side, is turned towards the earth, thus illustrating the appearance of the moon at the first quarter. From hence the light side will continually shew itself more and more in a gibbous form, till at the end of fourteen days the whole white side will be turned towards the earth,

and the dark side from it, the earth now standing in a line between the sun and moon; and thus the instrument explains the opposition, or full moon. On turning the handle again, some of the shaded part will begin to turn towards the earth, and the white side to turn away from it, decreasing in a gibbous form till the last quarter, when the moon will appear again as a crescent, which she preserves till she has attained another conjunction.

In this lunarium the moon has always the same face or side to the earth, as is evident from the spots delineated on the surface of the ivory ball, revolving about its axis, in the course of one revolution round the earth; in consequence of which the light and dark parts of the moon appear permanent to us, and the phases are shewn as they appear in the heavens.

The tutor will be enabled, by this instrument, to explain some other circumstances to his pupil; namely, that as the earth turns round its axis once in 24 hours, it must in that time exhibit every part of its surface to the inhabitants of the moon, and therefore its luminous and opake parts will be seen by them in constant rotation. As that half of the earth which is opposed to the sun is always dark, the earth will exhibit the same phases to the lunarians that we do to them, only in a contrary order, that when the moon is new to us, we shall be full to them, and *vice versa*. But as one hemispere only of the moon is ever turned towards us, it is only those that are in this hemisphere who can see us; our earth will appear to them always in one place, or fixed in the

same part of the heavens : the lunarians in the op-
posite hemisphere never see our earth, nor do we ever
view that part of the moon which they inhabit. The
moon's apparent diurnal motion in the heavens is pro-
duced by the daily revolution of our earth.

If we consider the moon with respect to the sun,
the instrument shews plainly that one half of her
globe is always enlightened by the sun ; that every
part of the lunar ball is turned to the sun, in the
space of her monthly or periodic revolution ; and that
therefore the length of the day and night in the moon
is always the same, and equal to $14\frac{3}{4}$ of our day.
When the sun sets to the lunarians in that hemishere
next the earth, the terrestrial moon rises to them,
and they can therefore never have any dark night ;
while those in the other hemisphere can have no
light by night, but what the stars afford.

Of the periodical and synodical month.

The difference between the periodical month, in
which the moon exactly describes the ecliptic, and
the synodical, or time between any two new moons,
is here rendered very evident. To shew this dif-
ference, observe at any new moon her place in the
ecliptic, then turn the handle, and when the moon
has got to the same point in the ecliptic, you will
see that the dial shews $27\frac{1}{3}$ days, and the moon has
finished her periodic revolution. But the earth, at
the same time, having advanced in its annual path
about 27 degrees of the ecliptic, the moon will not

have got round in a direct line with the sun, but will require 28 days and 4 hours more, to bring it into conjunction with the sun again.

Of eclipses of the sun and moon.

There is nothing in astronomy more worthy of our contemplation, nor any thing more sublime in natural knowledge, than rightly to comprehend those sudden obscurations of the heavenly bodies that are termed eclipses, and the accuracy with which they are now foretold. " One of the chief advantages derived by the present generation, from the improvement and diffusion of philosophy, is delivery from unnecessary terror, and exemption from false alarms. The unusual appearances, whether regular or accidental, which once spread consternation over ages of ignorance, are now the recreations of inquisitive security. The sun is no more lamented when it is eclipsed, than when it sets; and meteors play their corruscations without prognostic or prediction."

I have already observed, that the sun is the only real luminary in the solar system, and that none of the other planets emit any light but what they have received from the sun; that the hemisphere which is turned towards the sun is illuminated by his rays, while the other side is involved in darkness, and projects a shadow, which arises from the luminous body.

When the shadow of the earth falls upon the moon, it causes an eclipse of the moon ; when the shadow of the moon falls upon the earth, it causes an eclipse of the sun.

An eclipse of the moon, therefore, never happens but when the earth's opake body interposes between the sun and the moon, that is, at the full moon ; and an eclipse of the sun never happens but when the moon comes in a line between the earth and the sun, that is, at the new moon.

From what we have already seen by the instrument, it appears, that the moon is once every month in conjunction, and once in opposition ; from hence it would appear, that there ought to be two eclipses, one of the sun, the other of the moon, every month ; but this is not the case, and for two reasons ; first, because the orbit of the moon is inclined in an angle of about 5 degrees to the plane of the ecliptic ; and secondly, because the nodes of this orbit have a progressive motion, which causes them to change their place every lunation. Hence it often happens, that at the times of opposition or conjunction, the moon has so much latitude, or, what is the same thing, is so much below or above the plane of the ecliptic, that the light of the sun will, in the first case, reach the moon, without any obstacle, and in the other the earth ; but as the nodes are not fixed, but run successively through all the signs of the ecliptic, the moon is often, both at the times of conjunction and opposition, in or very near the plane of the ecliptic ; in these cases an eclipse happens

either of the sun or moon, according to her situation. The whole of this is rendered clear by the lunarium, where the wire projecting from the earth, shews when the moon is above, below, or even with the earth, at the times of conjunction and opposition, and thus when there will be, or not, any eclipses.

The distance of the moon from the earth varies sensibly with respect to the sun; it does not move in a circular, but in an elliptic orbit round us, the earth being at one of the foci of this curve.* The longer axis of the lunar orbit is not always directed to the same point of the heavens, but has a movement of its own, which is not to be confounded with that of the nodes; for the motion of the last is contrary to the order of signs, but that of the line of apsides is in the same direction, and returns to the same point in the heavens in about nine years. This motion is illustrated in the lunarium by means of the brass ellipses X Y, which is carried round the earth in little less than nine years; thus shewing the situation of the elliptical orbit of the moon, and the place of the apogee in the ecliptic.

Those who wish to extend the application of the instrument further, may have an apparatus applied to it for explaining the Jovian and Saturnian systems, illustrating the motion of their satellites, and of the ring of Saturn. But as this application would ex-

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* That point of her orbit wherein she is nearest the earth, is called her *perigee*; the opposite point, in which she is farthest off, is called her *apogee*. These two points are called her *apsides*, the apogee is the higher, the perigee the lower apsis.

tend the price of the instrument beyond the reach of most purchasers, I have thought it would be unnecessary to describe them; the more so, as the phenomena they are intended to explain are accurately and clearly described in several introductory works of astronomy.

Having surveyed and endeavoured to illustrate the general phenomena of the heavens, let us turn the mental eye towards our Lord, who hath made all things in heaven and earth, and whose tender care is over all.

" Innumerable worlds stood forth at thy command, and by thy word they are filled with glorious works.

" Who can comprehend the boundless universe? or number the stars of heaven?

" Amidst them thou hast provided a dwelling for man, that he might praise thy name.

" The sun shineth, and is very glorious, and we rejoice in the light thereof.

" We admire its brightness, and perceive its greatness; and our earth vanishes in comparison with it.

" Many worlds are nourished by it, and its glory is great. By its influence the earth is clothed with plenty, and the habitation of man rendered exceeding beautiful.

" Yet what is this amidst thy works? is it not as a point, and as nothing in the firmament of heaven?

E e

" What then is man, that thou art mindful of him, or the son of man, that thou visitest him ?

" Thy power is circumscribed by no bounds, both great and small are alike unto thee.

" From the sun in the firmament of heaven, to the sand on the sea shore, all is the operation of thy hand.

" From the cherubim and seraphim which stand before thee, to the worm in the bowels of the earth, all living creatures receive of thee what is good and expedient for them."*

Praise then the Lord, O my soul, praise his name for ever and ever.

* See " Hymns to the Supreme Being, in imitation of the Eastern Songs." London, 1780.

ESSAY IV.

AN

INTRODUCTION

TO

PRACTICAL ASTRONOMY.

————————

THERE is no part of mathematical science more truly calculated to interest and surprize mankind, than the measurement of the relative positions and distances of inaccessible objects.

To determine the distance of a ship seen on a remote spot of the unvaried face of the ocean, to ascertain the height of the clouds and meteors which float in the invisible fluid above our heads, or to shew with certainty the dimensions of the sun, and other bodies, in the heavens, are among the numerous problems which, to the vulgar, appear far beyond the reach of human art, but which are nevertheless truly resolved by the incontrovertible principles of the mathematics.

These principles, simple in themselves, and easy to be understood, are applied to the construction of a variety of instruments ; and the following pages

contain an account of their use in the *quadrant* and the *equatorial.*

The position of any object, with regard to a spectator, can be considered in no more than two ways; namely, as to its distance, or the length of a line supposed to be drawn from the eye to the object ; and as to its direction, or the situation of that line with respect to any other lines of direction ; or, in other words, whether it lies to the right or left, above or below those lines. The first of these two modes bears relation to a line absolutely considered, and the second to an angle. It is evident, that the distance can be directly come at by no other means than by measuring it, or successively applying some known measure along the line in question ; and therefore, that in many cases the distance cannot be directly found ; but the position of the line, or the angle it forms, with some other assumed line, may be readily ascertained, provided this last line do likewise terminate in the eye of the spectator. Now the whole artifice in measuring inaccessible distances consists in finding their lengths, from the consideration of angles, observed about some other line, whose length can be submitted to actual mensuration. How this is done, I shall proceed to shew.

Every one knows the form of a common pair of compasses. If the legs of this instrument were mathematical lines, they would form an angle greater or less, in proportion to the space the points would have passed through in their opening. Suppose an arc of a circle to be placed in such a manner, as to be passed over by these points, then the angles

will be in proportion to the parts of the arc passed over; and if the whole circle be divided into any number of equal parts, as for example 360, the number of these comprehended between the points of the compasses will denote the magnitude of the angle. This is sufficiently clear; but there is another circumstance which beginners are not always sufficiently aware of, and which therefore requires to be well attended to: it is, that the angle will be neither enlarged nor diminished by any change in the the length of the legs, provided their position remains unaltered; because it is the inclination of the legs, (and not their length) or the space between them, which constitutes the angle.— So that if a pair of compasses, with very long legs, were opened to the same angle as another smaller pair, the intervals between their respective points would be very different; but the number of degrees on the circles, supposed to be applied to each, would be equal, because the degrees themselves on the smaller circle would be exactly proportioned to the shortness of the legs. This property renders the admeasurement of angles very easy, because the diameter of the measuring circle may be varied at pleasure, as convenience requires.

In practice, however, the magnitude of instruments is limited on each side. If they are made very large, they are difficult to manage; and their weight, bearing a high proportion to their strength, renders them liable to change their figure, by bending, when their position is altered: but, on the contrary, if

they are very small, the errors of construction and graduation amount to more considerable parts of the divisions on the limbs of the instrument.

GENERAL PRINCIPLES OF CALCULATION.

Before we proceed any further, I shall slightly notice the general principles of the calculations we are going to use.

Plane trigonometry is the art of measuring and computing the sides of plane triangles, or of such whose sides are right lines.

In most cases of practice, it is required to find lines or angles whose actual admeasurement is difficult or impracticable. These mathematicians teach us to discover by the relation they bear to other given lines or angles, and proper methods of calculation.

Finding the comparison of one right line with another right line more easy than the comparison of a right line with a curve, they measure the quantities of the angles not by the arc itself, which is described on the angular point, but by certain lines described about that point.

If any three parts of a triangle are known, the remaining unknown parts may be found either by construction or by calculation.

If two angles of a triangle are known in degrees and minutes, the third is found by subtracting their sum from 180 degrees; but if the triangle be right-

angled, either angle in degrees, taken from 90 deg. gives the other angle.

Before the required side of a triangle can be found by calculation, its opposite angle must be given or found.

The required part of a triangle must be the last of four proportionals, written in order one under the other, whereof the three first terms are given or known.

Against the three first terms of the proportion, are to be written the corresponding numbers taken from tables, which have been constructed to facilitate calculation.

These tables are called *logarithms*; and are so contrived, that *multiplication* is performed by *addition*, and *division* by *subtraction*.

If the value, then, of the first term of your proportion be taken from the sum of the second and third, you obtain the value of the fourth, or quantity required; because the addition and subtraction of logarithms corresponds with the multiplication and division of natural numbers.

To avoid even the subtraction of the first term, when radius is not one of the proportionals, some chuse to add the arithmetical complement.

To find the arithmetical complement of a logarithm, begin at the left hand, and write down what each figure wants of 9, and what the last figure wants of 10. The number thus found is to be added to the second and third values; the sum, rejecting the borrowed index, is the tabular number expressing the

quantity required: thus the arithmetical complement of 2.6963564 is 7.3036436.

To find the logarithm of a given number. Here you must remember that the integral part of a logarithm is called its *index*, because it denotes the number of figures in the natural number answering to the logarithm. The decimal part of every logarithm belongs equally to a whole number, a mixed number, or a decimal number; that is, they are expressed by the same figures, in the same order, but the index varies according to the value of the expression. The index of a logarithm is always an unit less than the number of figures in the integer number, of which it is the logarithm.

Hence the following general rule for finding the index of a logarithm. To the left of the logarithm, write that figure or figures which expresses the distance from unity, of the highest place digit in the given number, reckoning the unit's place 0, the next place 1, the next to that 2, the next to that 3, &c.

By attending to the following example, it will be easy for you to find the logarithm of a given number, and the number corresponding to a given logarithm.

Thus let the number be 7854. One column gives the decimal part; the next the logarithm completed with the indexes.

Number.	Decim. Part.	Complete Log.
7854	0.895091	3.895091
785.4	0.895091	2.895091
78.54	0.895091	1.895091
7.854	0.895091	0.895091
0.7854	0.895091	$\bar{1}$.895091
0.07854	0.895091	$\bar{2}$.895091

Tables of logarithms are also constructed for sines, tangents, &c. of an arc: these are to be taken out from the tables, according to their respective value.

Spherical trigonometry is the science of calculating the triangles formed on the surface of a globe, by three arches of great circles: the smaller circles of a sphere are not noticed in the calculations of spherical trigonometry. This science is too intricate to be any way explained in this Essay; we must therefore content ourselves with only giving the proportions necessary to answer our purpose.

OF THE QUADRANT, AND ITS USES.

Every circle being supposed to be divided into 360 equal parts or degrees, it is evident that 90 degrees, or one-fourth part of a circle, will be sufficient to measure all angles formed between a line perpendicular to the horizon, and other lines which are not directed to points below the level. *Plate* 14, *fig.* 1, is a drawing of a very simple and useful instrument of this kind. A B C is a quadrant mounted upon an axis and pedestal: by means of the axis, it

may be immediately placed in any vertical position, and the pedestal being moveable in the axis of the circle E F, serves to place it in the direction of any azimuth, or towards any point of the compass. The limb A B, is divided into degrees and halves, numbered from A; and upon the radius B C, are fixed two sights, of which B is perforated with a small hole, and is provided with a dark glass to defend the eye from the sun's light; and the other sight Z has a larger hole furnished with cross wires, and also a smaller, which is of use to take the sun's altitude by the projection of the bright image of that luminary upon the opposite sight. From the centre C, hangs a plumb-line, C P. The horizontal circle F E, is divided into four quadrants of 90 degrees; and an arm E, connected with the pedestal, moves along the limb, and consequently shews the position of the plane of the quadrant, as will hereafter be more minutely explained. Lastly, the screws G, H, I, render it very easy to set the whole instrument steadily and accurately in its proper position, notwithstanding any irregularity in the table or stand it may be placed upon.

The rationale of this instrument is very clear and obvious. It is used to measure the angular distance of any body, or appearance, either from the zenith or point immediately above our heads, or from the horizon or level. The plumb-line C P, if continued upwards from C, would be directed to the zenith Z; and the line C L, supposed to be drawn from the centre of the quadrant to an object L, will form an

angle L C Z, which is the zenith distance, and is equal to the angle B C P, formed between the opposite parts of the same lines. We see, therefore, that the degrees on the arc, comprehended on the limb of the quadrant, between the plumb-line and the extremities next the eye, measure the angle of zenith distance.

Again, the line C K, forming a right angle with the perpendicular C Z, is level or horizontal; the angle L C K must therefore be the altitude or elevation of L above the horizon; and this last angle must be equal to the angle measured between the plumb-line and the end A farthest from the eye; because both these are equal to the quantity which would be left, after taking the zenith distance from a right angle, or the whole quadrant.

The determination of the altitude or zenith distance of an object is not sufficient to ascertain its place, because the object may be placed in any direction with respect to azimuth, or the points of the compass, without increase or diminution of its altitude. Hence it is, that an horizontal graduated circle is a necessary addition to a quadrant, which is not intended to be always used in the same plane. The bearing or position of an object relative to the cardinal points; together with the altitude, is sufficient to ascertain the place of any object or phenomenon.

After this short account of the general principles of the quadrant, I shall proceed to shew some of the leading problems resolved by it.

PROBLEM I. *To adjust the quadrant for obser-vation.*

The quadrant is adjusted for observation when its plane continues perpéndicular to the horizon in all positions of the line of sight. To effect this, bring the index to 90° on the horizontal circle, and turn one or both of the screws which are fixed opposite 60°, till the plumb-line lightly touches the plane of the quadrant; then turn the index to 0°, and make the same adjustment by means of the screw at 0°, and the quadrant is ready for observation.

Or otherwise; set the index at 0°, and observe the degree marked by the plumb-line on the limb; then turn the index to the other 0°, which is dia-metrically opposite, and observe the degree marked by the plumb-line : if it be the same as before, there will be no occasion to alter the screws at 60°; but if otherwise, one or both of those screws must be turned till the plumb-line intersects the middle deg. or part, between the two. After this operation, the degree marked by the plumb-line must be observed, as be-fore, by setting the index at both the 90°, and the adjustment of the plumb-line to the middle distance must be made by the screw at 0°, taking care not to touch the other screws.

The latter method of adjustment, being more ac-curate in practice, may be used after the former.

The larger or more expensive instruments have apparatus for setting the axis of motion at right

angles to the planes of the horizontal circle and quadrant, the line of sight or collimation parallel to the radius passing through 90°, &c. &c. In small instruments, these adjustments are made by the workman.

INTRODUCTORY PROBLEMS.

PROBLEM II. *To find the distance of an object on the earth by observations made from two stations on the same level.*

OBSERVATIONS. Choose two stations, between which the ground is level, and place a visible mark on each. The distance between them ought not to be less than the seventh or eighth part of the estimated distance of the objects, and neither station ought to be considerably nearer the object than the other. Measure the distance between the stations, by means of measuring poles, a chain, or a piece of stretched cord. From one station direct the quadrant to the object, by looking through the hole in one sight and moving the upright axis about, till the object is seen through the hole in the other, exactly at the intersection of the cross wires. Observe the degrees and parts shewn by the index on the horizontal circle, then direct the quadrant in the same manner to the mark of the other station, and observe the degrees and parts shewn by the index. The number of degrees and parts intercepted between this and the former position of the index is the an-

gle at the first station. The same operations re-
peated at the second station will give the angle at
that station.

Thus, let F, *plate* 15, *fig*. 1, be the object, A, B,
the two stations 880 feet distant from each other; the
angle observed at A found to be 83° 45', that observed
at B 85° 15'.

Solution. Take the sum of the two observed
angles from 180°, and the remainder will be the
angle under which the two station marks would be
seen from the object. Let F be the object, A and B
the two stations, the angle at A found by observation
to be 83° 45', that at B 85° 15', the sum of these two
angles is 169°, which taken from 180° gives 11° for
the value of angle F.

Then as the sine of angle F.

  at the object   -   -   11° 00'   9.2805988
Is to the sine of Angle A at

  one station A   -   -   83° 45'   9.9974110
So is the distance A B be-

  tween the stations   -   880   2.9444827
To the distance of the ob-

  ject B F, from the other
  _____

  station   -   -   4584.5 feet   3.6612949

Solution of the problem by protraction. From a
scale of equal parts, lay down a right line to re-
present the measured base. By means of the pro-
tractor, or by the line of chords, draw a line from
each extremity of the base, forming angles equal to
those actually observed ; continue these lines till they
intersect.

The interval between the point of intersection at one extremity of the base being taken between the compasses, and applied to the line of equal parts, will shew the distance between the object and the station represented by that extremity.

This problem may, in cases of small distance, be conveniently applied to a base line measured within a room, and the observation taken out at the windows.

PROBLEM III. *To find the height of a spire, a mountain, or any other elevation.*

Case 1. When the distance, DE, *plate* 15, *fig.* 2, of the point F immediately beneath the object can be measured.*

Observe the angle of altitude CDE with the quadrant, by viewing the summit through the sights, and noting the degrees and parts indicated by the intersection of the plumb-line; measure also the horizontal distance; let the angle CDE be 47° 30′, the line DE 100 feet.

Then as radius - - -	10.0000000
To the tangent of ∠CDE 47° 30′	10.0379475
So is the measured distance DE 100	2.0000000
To the height required, 109.5 -	2.0379475

* As the point cannot conveniently be taken from the ground, you must add the height of the eye at the observation to the height found.

Or by construction. Draw a right line equal to the measured base, taken from a scale of equal parts.

Erect a perpendicular from one extremity, and from the other draw a line inclined towards the perpendicular, and forming an angle with the base equal to the observed angle.

The interval between the intersection of this last line and the perpendicular, and the lower extremity of the perpendicular itself, being taken in the compasses, and applied to the line of equal parts, will shew the height required.

Case 2. When the distance of the point A immediately beneath the summit cannot be measured.

Find the distance by Prob. ii, and the height by Case 1, of this problem.

Or, otherwise; measure a base line DC, *plate* 15, *fig.* 3, directly towards the object, and take the altitude from each end of the base.

Let DC, the base, be 100 feet, the angle observed at C 32°, the angle at D 58°; subtract the lesser altitude from the greater, and the difference is the angle B 26°.

Then as the sine of this difference 26°   9.6418420
Is to the sine of the lesser altitude 32°   9.7242097
So is the base line 100   -   -   2.0000000
To the direct distance between the   _____
     summit and nearer end of the base
line   -   -   -   -   -   2.0823677
                                                      _____

And,

As radius or angle A 90°   -   10.

Is to the sine of the greater altitude

58°   -   -   -   -   9.9284205

So is the distance last found   -   2.0823677

_____

To the height required 102.51 feet   2.0107822

Or by construction. Set off the base line, and from its extremities draw lines inclined to the base in the respective angles observed, but in such a manner, as that the less angle may be formed by the base itself, and the greatest by the prolongation of the base.

These lines will intersect.

From the point of intersection, let fall a perpendicular on the prolongation of the base, and it will give the height required.

The first method of solving this case is in general the best in practice. It is for the most part much more easy to find a base sufficiently long and level between two stations, nearly equi-distant from the eminence, as the first requires, than in a direction towards it, because the ground usually rises irregularly towards mountains. And in the latter case also, if the difference between the two altitudes be not very considerable, the result will be rendered erroneous by a very small inaccuracy of observation.

PROBLEM IV. *To plot a field by a base line measured within the field.*

Set up marks in the corner of a field, and measure a line in the field in such a direction, as that it may be set as far as possible from pointing towards any of the angles.

Direct the sights from one end of the base to each of the angles successively, and also to the other extremity of the base, carefully noting the degrees and parts of the horizontal circle marked out by the index. Repeat the like operations at the other end of the base line.

Construction. Draw a faint line upon paper upon which set off from a scale of equal parts the measured base. From is extremities draw lines, forming the respective angles observed. The intersections of those lines will shew the corners or angles of the field, and must be joined by right lines.

This problem being nothing more than a determination of the position of the angular points with respect to the base line by Prob. ii, will be more accurate in practice, the more nearly the conditions there expressed are adhered to. If a base line cannot be had in view of all the angles, and in a convenient position, two or more base lines may be measured, and connected together by the observation of the requisite angles ; or the three sides of a triangle may be measured in the field; according

to the discretion of the ingenious learner, and the bearings of the corners of the field taken from such extremities of any of these measured lines, as are best adapted to the purpose.

As this method is far from being laborious, the student will do well to measure the field twice, but from a different base each time.

It may be proper to observe, for the use of such as are unacquainted with surveying of land, that the English acre is 4840 square yards, and that land is most conveniently measured by the Gunter's chain, of 22 yards in length, divided into 100 links; because the square chain, or 22 multiplied by 22, equal to 484, is exactly the tenth part of an acre. If the plot of a field measured in chains and links be therefore made upon paper, and divided into a number of triangles by drawing right lines within it, the base and perpendicular of each triangle may be measured from the scale of equal parts, and half their product will be the area of the triangle in square chains; the sum of all the areas of the triangles will be the area of the field; which divided by 10, will shew the number of acres; the remaining decimal fraction multiplied by 4, gives the roods; and the decimal part of this last product multiplied by 40, gives the perches.

In the following example is a more ready method of obtaining the contents.

Example. Let A B C D E F, *plate* 15, *fig.* 4, be the

F f 2

field, in which I assumed two stations, P, Q, at the distance of 10 chains from each other.

From P, I observed the following angles: Q P A to be 21° 20'; A B P, 49° 10'; B P C, 57° 12'; C P D, 29° 40'; D P E, 64° 25'; E P F, 79° 16'.

From the station Q, I observed the following angles: P Q D, 10° 40'; D Q C, 18° 30'; C Q B, 42° 00'; B Q A, 67° 05'. A Q F is equal to A Q O added to E Q O; that is, 137°; F Q E, 62° 52'.

Solution. Construct the figure as directed, and divide it into two trapeziums, D C B A, and D E F A; then apply the perpendiculars, H B, L D, I F, and the diagonals B D, A E, and the side A D, to a scale of equal parts, and you will obtain the area near the truth.* But it may be obtained accurately by

Trigonometry.

1. In the triangle A Q B, you will find Q A 10.428, Q B 15.198, and the angle A Q B 67° 5'.

2. In the triangle B P Q, you will find Q B 15.198, B P 15.259, the angle B P Q 38° 20'.

3. In the triangle Q P C, we have P C 12.404, P B 15.259, angle B P C 57° 12'.

4. In the triangle Q P D, we find P D 8.941, P C 12.404, C P B 29° 40'.

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* The angles are in some instances in this example assumed too oblique to be ascertained with accuracy in practice, but answer fully the purpose of illustration.

5. In the triangle Q P E, we have P E 10.950, P D 8.941, angle D P E 64° 25′.

6. In the triangle P Q F, we obtain P F equal 16.820, Q F 14.471, angle P F Q 36° 18′.

7. In the triangle E P F, P E is 10.950, P F 16.820, angle E P F 79° 16′.

8. In the triangle A Q F, Q F is 14.471, A Q 10.428, angle A Q F 137°.

Now writers on mensuration have shewn, that if you add the logarithms of the two sides of a triangle and the included angle together, the sum, rejecting radius will be the logarithm of double the area of that triangle. By this method we find,

1. the double area of △ A Q B				to be			145.984
2.	-	-	-	-	B P Q	—	143.844
3.	-	-	-	-	B P C	—	159.143
4.	-	-	-	-	C P D	—	54.895
5.	-	-	-	-	D P E	—	88.304
6.	-	-	-	-	P F Q	—	144.105
7.	-	-	-	-	E P F	—	180.964
8.	-	-	-	-	A Q F	—	102.916

Divide by 2) 1020.155

510.077

The young student in trigonometry will find the solution of this problem no contemptible exercise ; he may likewise, if he has a sufficient degree of patience and industry, find every line drawn in the figure.

F f 3

PROBLEM V. *To plot a field, by measuring the sides and angles.*

Set up marks at each of the angles, and at every one of these marks direct the quadrant to the two adjacent marks on each side. The number of degrees and parts between the two positions of the index on the horizontal circle, will shew the angle at the station where the observation is made. Measure the distance to the next station, and observe the angle there in the same manner. And thus proceed completely round the field.

Construction. From the scale of equal parts draw a line equal to the first measured side, and from its extremities draw two lines, forming angles equal to those actually observed.

Make these last lines equal to the sides they represent, and from their extremities draw two other lines at angles respectively found by observation.

Proceed thus till the whole field is plotted.

When all the angles of a field are thus measured, their sum, if the operation has been truly made, will be equal to twice as many right angles, deducting four, as there are angles in all, provided they be all inward angles. But if any of them be outward angles, their respective supplements to 360° must be taken in making up the sum instead of the angles themselves. When the sum proves either greater or less than just the figure, it will

not answer on paper ; and as observations made with small instruments cannot be expected to be free from perceptible errors, it will be expedient to correct the angles by adding or subtracting such defect or excess to or from all the angles, in proportion to their magnitude, or more readily in equal proportions among them.

This way of measuring is much used in America, by the measuring wheel and mariner's compass, and is applicable to extensive woody or mountainous tracts of land, where great accuracy is not required. It may also be used in conjunction with other methods, for delineating a sea-coast, &c.

The following example will shew how you may obtain the contents of the field.

Example. In surveying the field A B C D E, *plate* 15, *fig.* 5, I observed at A the angle FAE to be 51° 13′, at B the angle CBG was 69° 30′, at C the angle ACB was 39° 7′, and the angle ACD 78° 35′ ; at D the angle EDH was 88° 40′, and at E the angle CEA 54° 20′ ; the side AB measured 1940 lines, BC 1555, CD 2125, DE 2741, and EA 1624. We have now to find the area of the field.

Subtract the angle CBG 69° 30′ from 180° and you have the angle CBA 110° 30′ ; to which if you add the angle ACB 39° 7′, and subtract this sum from 180, you obtain the angle CAB 30° 23′. We find by trigonometry AC to be 288 links. The sum of the angles EAF and CAB, taken from 180°, gives the angle EAC 98° 24′. Lastly, subtract

F f 4

the angle H D E from 180, and you get angle E D C 91° 20'.

Then, by the preceding problem, in the triangle ABC we obtain from the two sides A B, BC, and the included angle ABC, the double

area   -   -   -   -   28256 8

In the triangle E A C, from the sides A C,

A E, and the angle E A C   -   -   4625146

In the triangle E D C from the sides D E,

DC, and angle E D C   -   -   5823047

_____

2)13273851

_____

Area 66.39625

Answer, 66 acres, 1 rood, 19 perches.

If the angles had been measured with a mariner's compass, they must have been arranged in a traverse table similar to plane sailing in navigation, and the content found by the method shewn in my *Geometrical and Graphical Essays*, 8vo.

PROBLEM VI. *To find the altitude and height of fire-balls, and other meteors, in the atmosphere.*

Though the extreme velocity and transient nature of fiery meteors in the atmosphere, in a great measure prevents the making of such observations as might tend to ascertain their distance, yet they form a subject of inquiry so curious and interesting, as renders such as can be made of great value. An observer, who perceives an appearance of this

kind, ought carefully to note the buildings, trees, stars, &c. near which it passes; and, as soon afterwards as convenient, take their altitude and bearings. If two such observations be taken by persons at different places, sufficiently distant from each other, the distance on the earth may be considered as the base, and from this and the two observed angles the height of the meteor may be found by Problem ii.

By observations of this kind it has been found, that the larger fire-balls are elevated about 60 miles above the earth's surface, and that some of them are near 5 miles in diameter.

PROBLEM VII. *To find the height of a cloud by observation of a flash of lightning.*

If the altitude of that part of a cloud, from which a flash of lightning has issued, be immediately taken with the quadrant, and the number of seconds of time elapsed between the instant of the flash, and the first arrival of the thunder, be reckoned, these data will be sufficient to determine the height of the thunder-cloud. For sound is admitted to pass through 1142 feet in a second; but light has such an extreme velocity, that it passes through thirty-five thousand miles in a second, and may therefore be reckoned instantaneous in all observations upon the earth. Hence it follows, that the number of seconds observed, mul-

tiplied by 1142, will give the distance of the cloud in feet; and

As radius

Is to the sine of the observed angle;

So is the distance of the cloud

To its height.

Example. Suppose the angle of elevation C A B, *plate* 15, *fig.* 6, from which a flash of lightning issued, was 53° 8', and that between the flash and the report of the thunder 5 seconds were counted; then 1142 feet multiplied by 5 gives 5710 feet for the distance of the cloud.

And as radius or sine of 90° 10.0000000

Is to the sine of the observed angle

 53° 8' - - - 9.9031084

So is the distance of the cloud 5710 3.7566361

To its height 4568 feet - 3.6597445

Or by construction. From a point in any right line, draw another right line, forming the observed angle. Set off on this left line, from the angular point, the distance of the cloud, taken from a scale of equal parts. From the extreme of the last-mentioned line let fall a perpendicular on the other line; and this perpendicular will be the height required.

If the flash of lightning strike directly down, the height of the cloud will also be the length of the flash. But this is not often the case.

PROBLEM VIII. *To determine the height of a cloud by observations on its altitude and velocity.*

When the sky abounds with detached clouds, moving with considerable velocity, it is easy to determine the degree of swiftness, by observing the progress of their shadows which pass along the ground. For this purpose nothing more is necessary, than to note the instants of time when one of these shadows passes over two objects; such as hedges, trees, &c. lying in its direction; and to measure the interval passed over during the intermediate time. When this velocity is thus found, place the plane of the quadrant in the direction of the wind, and setting the sights to a considerable altitude, to be written down, take notice of some remarkable edge of a cloud, which passes across the wire in the aperture of the farthest sight, giving notice at the same instant to an assistant to note the time. Then move the quadrant on its axis twenty or thirty degrees, and give the like notice to the assistant when the same part of the cloud passes the wire; write down this last altitude. The perpendicular height of the cloud will be found by the following proportions.

As the number of seconds observed when the
　　shadow of the former cloud was seen on the
　　ground
Is to the number of seconds elapsed between the two
　　observations with the quadrant;

So is the distance measured on the ground

To the distance passed through by the cloud (whose altitude was taken) during the time of observation.

Then,

As the sine of the difference between the two altitudes

Is to the sine of the less altitude ;

So is the distance passed over by the cloud,

To its distance from the observer, when the greater altitude was taken.

And lastly,

As radius

Is to the sine of the greater altitude ;

So is the distance last found

To the perpendicular height of the cloud.

Example. The shadow of a cloud was observed to pass over 1230 yards in 50 seconds; its altitude at that instant was 41 degrees ; three minutes after, its altitude was 11 degrees 37 minutes: to find its height.

Now the spaces described by bodies moving with equal velocity, are as the times of description ; therefore, by the first part of the rule, as 50 seconds to 180 seconds so is 1230 yards to 4428 yards, the distance passed over by the shadow during the observation.

But the progressive motion of the shadow from B to C, *plate* 15, *fig.* 7, during the elapsed time between the observations, is the same as if the observer had moved in the same time from B to-

wards A ; or the effect would be exactly the same
if an observer at A took the less altitude, while
another at B took the greater altitude at the same
instant. Hence the second part of the rule is
evident; for A D E is the complement of the less
angle, and B D E that of the greater. The dif-
ference of these complements is equal to the angle
A D B; but the difference of the complements
must be equal to the difference of the altitudes;
therefore, by the second part of the rule,

As the sine A D B of the difference be-
 tween the two altitudes 29° 38′ 9.6907721
Is to the sine of the less altitude D A B
 11° 37′ - - - - 9.3039794
So is the distance A B passed over by
 the cloud 4428 yards - - 3.6462076
          ———————
          12.9501870
          9.6907721
          ———————

To its distance at the time of the
 greater altitude B D 1817.2 yds. 3.2594042

  Lastly, by the last part of the rule, see likewise the
rule to Problem viii.

As radius sine of 90 - - 10.
Is to sine of greater altitude 41 9.8190429
So is the distance B D 1817.2 - 3.2594049
          ———————
To the perpendicular height D E
 1192.2 yards - - 3.0763478

PRINCIPLES AND PROBLEMS PREPARATORY TO THE APPLICATION OF THE INSTRUMENTS TO PRACTICAL ASTRONOMY.

By practical astronomy, is understood the knowledge of observing the celestial bodies, with respect to their position and time of the year, and of deducing from these observations certain conclusions, useful in calculating the time when any proposed proposition of these bodies shall happen.

OF TERRESTRIAL LATITUDE.

The latitude of any place is equal to the elevation of the pole of the equator above that place.

The distance between the zenith and the horizon, and that between the pole, is equal, for each of them are 90 degrees. If, therefore, we take away the distance of the zenith from the pole, which is common to both, the remainder, that is, the elevation of the pole, or latitude of the place, is equal to the distance from the zenith to the equator.

The distance from the zenith to the pole is equal to the complement of the latitude to 90 degrees.

The inclination of the equator to the horizon, is also equal to the complement of the latitude to 90 degrees.*

* In *plate* 3, *fig.* 5, P represents the pole, E Q the equator, H O the horizon, P H the elevation of the pole, Z the zenith,

All those stars that are not further from the pole than the latitude, are called *circumpolar stars*.

If the greatest and less altitudes of a circumpolar star be determined by observation, half the sum gives you the *latitude* of the place.

The · complement of the meridian altitude of a star is its *zenith distance*; and this is called north or south, according as the star is north or south at the time of observation.

The latitude of a place is equal to a star's meridian zenith distance added to the declination, if the star passes between the zenith and the equator. In all other cases, the latitude is the difference between the meridian zenith distance and the declination of the star.

The greatest declination of the sun, is equal to the inclination of the ecliptic to the equator.

H Z O, or the visible part of the heavens, contains twice 90, or 180 degrees; it being 90 degrees from Z to H, and 90 degrees from Z to O: but it is also 90 from the pole P to E the equator. If you take away P E, there remains 90 degrees for the other two arcs. In other words, the elevation of the pole and the elevation of the equator are together equal to 90 degrees; *i. e.* in technical terms, the elevation of the pole is the complement of the elevation of the equator to 90 degrees. Hence one being known and subtracted from 90, gives the other.

Hence also it is clear, that the elevation of the equator is equal to the distance of the pole from the zenith, both being equal to the distance of the pole from 90 degrees.

Hence also the distance of the equator from the zenith is equal to the elevation of the pole, or latitude of the place; for H Z is equal to 90, and P E is equal to 90: take away P Z, common to both, and the remainders, P H, Z E, must be equal.

The inclination of the equator to the ecliptic is equal to half the difference between the sun's meridian altitudes on the longest and shortest days.

The latitude of the place and the zenith distance of a star being given, to find the declination of the star.

1. When the latitude of the place and zenith distance are of different kinds, that is, one north and the other south, their *difference* is the declination; but it is of the same name with the latitude, when that is the greater of the two; otherwise it is of the contrary kind.

2. When the latitude and zenith distance are of the same kind, that is, both north or both south, their *sum* is the declination, and it is of the same kind with the latitude.

OF CELESTIAL LONGITUDE, LATITUDE, &c.

It has been already observed, that in order to measure and estimate the motion of the sun and stars, it was necessary to fix on some point in the heavens, to which their motions might be referred. The vernal equinoctial point is that point from which astronomers reckon what is called *longitude* in the celestial sphere. The ecliptic is divided into twelve signs, of 30 degrees each, with whose names and characters you are acquainted. Astronomers

begin at the first point of Aries, and reckon from west to east.

Celestial longitude is, therefore, the number of degrees on the ecliptic contained between the first point of Aries and any celestial object, or between the first point of Aries and a circle passing through the object perpendicular to the ecliptic. Thus if ♈ C, *plate* 15, *fig.* 8, represents the ecliptic, and ♈ the first point of Aries, and any star be at S on the ecliptic, or at *s* on a circle p *s* S, perpendicular to the ecliptic, then will the arch ♈ S be the longitude of the stars *s*, S.

The *latitude of a celestial object* is its distance from the ecliptic, reckoned on a circle perpendicular thereto. Thus a star at s, *plate* 15, *fig.* 8, will have for latitude the arc S*s*; but placed at S on the ecliptic, it will have no latitude.

As the diurnal motion is in the direction of the equator, astronomers, to facilitate both observation and calculation, found it necessary to determine the situation of celestial bodies with respect to this circle, which is effected by determining their right ascension and declination. Right ascension and declination are, with respect to the equator, what longitude and latitude are, with respect to the ecliptic. Thus if ♈ Q represent the equator, and ♈ the first point of Aries, then will ♈ E be the right ascension of a star situated at E on the equator, or at e in a circle e E perpendicular thereto: the star at E will have no declination, but that at e is measured by the arch e E.

G g

GENERAL OBSERVATIONS.

To fix your attention with greater certainty to the objects of research, it may be proper to observe, that as practical astronomy consists in determining the position of celestial objects for a given instant, it may be reduced to three things :

1. The knowledge of the obliquity of the ecliptic.

2. The measure of time.

3. The right ascensions and declinations of the stars, &c.

OF THE OBLIQUITY OF THE ECLIPTIC.

The obliquity of the ecliptic is a very important element of astronomy, because it enters into the calculation of all spheric triangles where the ecliptic and equator are concerned.

The obliquity of the ecliptic being equal to the sun's greatest declination, *i. e.* when in the tropics, the obliquity may be ascertained by observing the meridian height of the sun's centre on one of the solstitial days; and this quantity taken from the height of the equator, at the place of observation, gives the declination of the tropic. Or, more accurately, observe the sun's meridian altitude in each tropic : this will give their distance, half of which is the distance of each tropic from the equator,

that is, the obliquity of the ecliptic. From good observations, made in 1772, this obliquity was found to be 23° 28'.

OF THE MEASURE OF TIME.

All astronomical observations depend on, or have a reference to time. To measure this with accuracy, is one of the primary objects of an astronomer.

As the diurnal revolution of the earth is found to be uniform, they have taken this for the measure of time, comparing it with the sun. Astronomers consider *noon* as the beginning of the diurnal revolution ; or, in other words, an *astronomical day* commences at the instant the centre of the sun is in the plane of our meridian, and finishes when it has returned thereto, after one entire revolution.

The *astronomical* day begins, therefore, twelve hours later than the *civil* day of the same denomination, and is counted up to twenty-four hours, or the succeeding noon, when the next day begins. Thus the day of the month, and the hour of the day, are the same in this method as in the civil account at noon, and from noon till midnight : but from midnight till noon they differ ; for in the civil account a fresh day begins at midnight, and the hours also begin again, but in the astronomical method the day is still continued beyond the midnight. Hence five o'clock in the morn-

ing of April the 10th, is called by astronomers April 9, 17 hours.

As the earth revolves uniformly on its axis, if it had no real annual motion, and consequently the sun no apparent annual motion, or if this motion was uniform, the days would be all necessarily of one length, and that would be about 23 hours 56 minutes, for in that time a diurnal revolution of the earth is completed, as appears by an easy observation : for any fixed star that is on the meridian at a given hour of the night, will, after 23 hours 56 minutes, be on the meridian again the night following. This interval of time is called a *siderial day.*

But accurate observations have shewn, that the *solar days* are not equal to each other, and that the time which elapses between the sun's being on the meridian of any place, and its return thereto again, is considerably longer sometimes than at others.

Hence astronomers have been obliged to distinguish two sorts of time ; one they call *apparent*, the other *mean* time.

Apparent time, called by foreign writers *true time*, is that determined immediately from the sun, by observing when his centre transits the meridian, which is at the instant of apparent noon, when a new astronomical day commences.

Mean time is that which would be observed every day, if the apparent diurnal motion of the sun was regular ; or that shewn by good clocks or watches,

which go uniformly. The mean day of 24 hours, pointed out by these, must necessarily be always of the same length.

The inequality in the length of the natural days is termed the *equation of time.* Now as astronomical tables can only be calculated to mean or uniform time, the proper results from an observation cannot be obtained, till the observed or apparent time is reduced to mean time ; for which purpose proper tables are calculated, called tables of the *equation of time.*

These are inserted on the second page of every month in the Nautical Almanack, for the noon of each day at Greenwich. It is marked *subtractive,* when the sun comes to the meridian sooner, and *additive,* when it comes to the meridian later than the time of mean noon ; that is, the quantity given by the table is to be subtracted from apparent, in order to obtain mean time, in the first case, and added to it in the second.

OF CORRESPONDING OR EQUAL ALTITUDES.

At equal distances from the meridian, a star has equal altitudes. If, therefore, equal altitudes of an heavenly body be taken on different sides of the meridian, the middle point of time between the observations will give the time when the body is upon the meridian, if it has not changed its declination. By this means the time when any body comes to the

meridian may be ascertained; and when applied to the sun, or a fixed star, the rate at which a clock (adjusted to the mean solar or siderial time) gains or loses may be determined with accuracy.

The method of ascertaining time by equal altitudes is universally used by practical astronomers, because it depends neither on an accurate knowledge of the latitude, nor on that of the declination; for these elements are only necessary in taking out the equation of declination, and any probable error therein will not sensibly affect that equation; neither does it depend on the exact quantity of the altitude, provided only it be the same in both observations.

OF THE RIGHT ASCENSION AND DECLINATION OF THE STARS.

The *declination* of stars, &c. is easily found by observing their *meridian altitudes*; and their *right ascension* is also easily attained by knowing how *to measure time*.

For as all stars in the same circle of declination have the same right ascension, it follows, 1st, That all stars passing at the same time through the same meridian, have then the same right ascension. 2dly, The right ascension of stars passing the meridian at different times, differ in proportion to the intervals of the times of their passage.

Example. The stars make a revolution in 23ʰ 56′ 4″ mean time. If, therefore, by a clock regulated to

mean time, and an instrument fixed in the plane of the meridian, or by corresponding altitudes, or otherwise, a star be observed to pass the meridian one hour after the other; say as $23^h 56' 4''$, the time of one revolution, is to $360°$ of the equator passed over the meridian in the same time, so is one hour, the difference between the transit of the stars, to $15° 2' 28''$, difference between their right ascensions; then the right ascension of one being known, the other is also known.

Whence it follows, that to determine the right ascension of any star, or even of all the stars, it is sufficient to know the right ascension of one star only, and to have a clock which shews an equal interval of time for the diurnal revolution of the several different fixed stars.

PROBLEM IX. *To reduce the degrees of the equator into time, and time into degrees of the equator.*

1. To reduce degrees into time, multiply by 4; observing that minutes, when multiplied by 4, produce seconds, and degrees produce minutes.

Reduce $23° 56'$ into time.

$$23° 56'$$
$$4$$
$$\overline{\hspace{2cm}}$$
$$1 \quad 33' \quad 44''$$

Reduce 69° 20′ 45″ into time.

4
_____

4ʰ 37′ 23″ 00ᵗʰⁱʳᵈˢ

2. To reduce time into degrees, multiply by 10 in a similar manner, and increase the produce one half, or divide the time by 4.

Reduce 1ʰ 33′ 44″ into degrees.

1ʰ 33′ 44″

10
_____

15 37 20
Half 7 48 40
_____

Degrees 23 26 0

Reduce 4ʰ 37′ 23″ to degrees.

10
_____

46 13 50
Half 23 6 55
_____

Degrees 69 20 45

OF REDUCTION FROM ONE MERIDIAN TO ANOTHER.

As all the heavenly bodies rise, culminate, and set, sooner to those who are towards the east, and later to those who are towards the west, and as all

tables and calculations in England for astronomy and navigation are adapted to the meridian of Greenwich, it is necessary for those who may be under any other meridian, to be able to find the time at Greenwich corresponding to that pointed out by their own clocks and watches.

Without this reduction no calculations can be made from such tables, or from the various articles contained in the Nautical Almanack, relating to the longitude, right ascension and declination of the sun, the equation of time, moon's motion, &c. so as to adjust them to any other meridian than that for which they were made.

To find the time at Greenwich corresponding with any given time under another meridian.

1. Find the difference of longitude between the two meridians, or how much the given place or meridian is to the east or west of Greenwich, and reduce this difference to time, by the foregoing rule.

2. If the given place be east of Greenwich, subtract the difference of meridians from your time; if it be west, add the difference to your time. The result will give the time it then is at Greenwich.

N. B. The time being given at Greenwich, the corresponding time under any other meridian is found by reversing this rule.

Example. What is the time at Greenwich, when it is 8ʰ 17′ 19″ at Jerusalem, 35° 30′ east of Greenwich, or in time 2ʰ 21′ 20″? *Answer,* 5ʰ 55′ 59″

Required the time at Greenwich, when it is 23ʰ 32′ 17″ at Boston, on the 12th of June; Boston being 4ʰ 42′ 29″ west? *Answer*, 28ʰ 14′ 46″, or 4ʰ 14′ 46″ P. M. on the 13th of June.

What is the time at Jerusalem, when it is 21ʰ 49′ 17″, on the 9th of September, at Greenwich? *Answer*, 24ʰ 10′ 37″ or 0ʰ 10′ 37″ on the 10th of September.

Again, required the time at Boston, when it is 3ʰ 37′ 0″ on the 1st of May at Greenwich? *Answer*, 22ʰ 54′ 31″ of the last day of the preceding month, or 10ʰ 54′ 31″ of civil time, on the morning of the 1st of May.

N. B. To know the time at Paris, Genoa, &c. when it is any given time where you are, take the difference between your meridian and that of Paris, &c. and then proceed as in the foregoing rule.

To find any of the motions of the sun or planets, the equation of time, right ascension, declination, semidiameter, and parallax of the moon; also the moon's distance from the stars, for any given time, under any other meridian.

Rule.   1st, Find by the preceding problem, the time at Greenwich which corresponds to the time under the given meridian. 2dly, Take the daily, the half daily, &c. (according to the interval for which you are to calculate) variation from the Nautical Ephemeris, and by even proportions find the time

that corresponds to the interval between this time, and that given in the Ephemeris. 3dly, Add or subtract this variation according as the motion is increasing or decreasing.

Example. What is the sun's declination at Greenwich, March 27, 1790, at 9ʰ. The reason why Greenwich is mentioned, and not any other place, is, because the time at whatever place you may want the declination, is supposed to be already reduced to that of Greenwich, as the first step to be attended to in all such problems.

March 28. Declination at noon 3° 10′ 47″ N.
March 27.   Ditto   Ditto   2 47 23
                                             _____

Variation of declination in 24
    hours   -   -   -   0 23 24
                                             _____
Variation in 9 hours, by proport. 0   8 46
Which, added to declination - 2 47 23
                                             _____
Gives the required declination - 2 56   9

Example. Required the sun's declination 1790, August 24, 2ʰ 57′ at Greenwich?

August 24. Declination at noon   10° 58′ 59″
August 25.   Ditto   Ditto   10 38 16
                                             _____

Variation in 24 hours   -   -   0 20 43
Variation in 2 hours 57 minutes   0   2 36
Which subtracted from   -   -   10 58 59
Gives the declination required - 10 56 23

PROBLEM X. *To find at what time, by a clock keeping mean time, any fixed star will be on the meridian on any given day.*

The right ascension of the stars being reckoned on the equator, they pass the meridian successively in times proportional to their respective distances therefrom. The distance of a star from the meridian is, therefore, nothing more than its difference in right ascension from the sun reduced to time; from whence it is plain, that to find the time when any star comes to the meridian, you must subtract the right ascension of the sun at noon from that of the star; the difference is the time required.

This simple calculation would be sufficient in general for finding the time when a star transits the meridian, if it always preserved the same difference in right ascension from the sun : but the sun, by its diurnal acceleration, approaches the star insensibly; and will consequently pass the meridian sooner, by a quantity proportional to this acceleration, and its distance from the sun. It is therefore necessary to subtract from the quantity first found another small quantity, that may be ascertained. Hence the following

Rule. Take the difference between the sun's and planet's motion, in right ascension in 24 hours, if the planet is progressive; or their sum, if retrograde : then say,

As 24 hours, diminished by this sum or difference, when the planet's motion is greater than the sun's, or increased by it, when the sun's motion is the greater,

Is to 24 hours,

So is the difference between the sun's* and planet's right ascension at noon to the time required.

For a star.

Take the increase of the sun's right ascension in 24 hours, and add to it 24 hours; then say,

As this sum

Is to 24 hours,

So is the difference between the sun's* and star's right ascension

To the time required.

Examples.

On July 1st, 1767, the sun's right ascension, when on the meridian of Greenwich, was $6^h 40' 25''$; and on July 2d, it was $6^h 44' 33''$: also the moon's right ascension was $159° 2'$; and on July 2d, it was

---

* In the latter part of both these rules, the sun's right ascension is to be taken from the planet's or star's right ascension; and if their right ascensions should be less than the sun's, they must be increased by 24 hours, before you subtract.

169° 39'. Required the time of the moon's passage over the meridian ?

<div align="center">

Sun's ⊙'s R. A. July 1, 6ʰ 40' 25"

2, 6 44 33

———————

Daily increase 0 4 8

Moon's ☽'s R. A. 159° 2' - 10ʰ 36' 8"

169 39 - 11 18 36

———————

Daily increase 0 42 28

Moon's motion in 24 hours   42' 28"

Sun's -   -   -   -   4 8

———————

Difference 38 20

Sun's R. A. at noon - 6ʰ 40' 25"

Moon's R. A. at noon 10 36 8

———————

Difference 3 55 43

</div>

As 24^h 38′ 20″=23^h 21′ 40″ : 24 :: 3^h 55′ 43″

$$\begin{array}{cc}
60 & 60 \\
\hline
1401 & 235 \\
60 & 60 \\
\hline
84100 & 14143 \\
& 24 \\
\hline
& 56572 \\
& 28286 \\
\hline
\end{array}$$

$$84100 \overline{)\begin{array}{l}339432 \\ 336400\end{array}} \left(4^b \; 2' \; 9'' \right.$$

3032
60

$$84100 \overline{)\begin{array}{l}181920 \\ 168200\end{array}} \left(\overset{\cdot}{2} \right.$$

13720
60

$$84100 \overline{)\begin{array}{l}823200 \\ 7569\end{array}} \left(9 \right.$$

66300

Answer, 4^b 2′ 9″, the time required.

At what time will the star Arcturus come to the meridian of Greenwich on the 1st of Sep. 1787?

Sun's R. A. 1 Sep. 10ʰ 41′ 59″　Star's R. A. 14ʰ 6′ 6″

　-　　-　　2　　　10　45　37　　　-　-　-　10　41　59

Increase in 24ʰ　0　3　38　　　Diff.　3　24　1

As 24ʰ 3′ 38″ : 24ʰ :: 3ʰ 24′ 1″ : 3ˣ 23′ 31″, the time required.

PROBLEM XI. *To find the altitude of the sun, or any other celestial body.*

This consists in the simple application of the quadrant to a celestial body, in the same manner as I have already shewn with respect to terrestrial objects.

The quadrant being adjusted as it should be in all cases previous to its use, the celestial body must be viewed through the sights, and the plumb-line will shew its altitude on the graduated limb of the instrument.

If the observation be made on the sun, the dark glass must be used to defend the eye, or the luminous spot formed by the small hole must be made to fall on the centre of the cross immediately beneath the eye-hole.

The sun having no visible point to mark out its centre, you must take the altitude either of the upper or lower limb. If the lower limb be observed, you

must add the sun's semidiameter thereto, in order to find the altitude of the sun's centre. If the altitude of the upper limb be observed, the semidiameter must be subtracted. The mean semidiameter of the sun is 16 minutes, which for common observation may be taken as a constant quantity, for the greatest deviations from this quantity scarcely exceed a quarter of a minute. When greater accuracy is aimed at, the semidiameter may be taken from the Nautical Almanack. The observed altitude of the sun's lower limb being 18° 41', add thereto 16 min. for the sun's semidiameter, and you obtain 18° 57', the central altitude.

The apparent altitudes of all the heavenly bodies are increased by refraction, except when they are situated in the zenith. An observed angle of a star, or any other object in the heavens, must be diminished a small quantity, to be taken from the table of refractions.

Where greater exactness is required, a small quantity is to be added to the error occasioned by parallax, or the difference between the altitude of an object as seen from the centre and the surface of the earth. That from the centre is the true altitude, and the greatest, except at the zenith, where parallax vanishes; consequently the apparent altitude of the sun is to be augmented by a small quantity taken from the table of the sun's parallax.

June 6, 1788, the apparent altitude of the sun's lower limb was observed to be 62° 19'; required the

H h

true altitude of the sun's centre, as seen from the centre of the earth.

Observed altitude -	62° 19'
Semidiameter - - -	16
	62 35
Subtract from refraction -	30
	62 34 30
Add for parallax - -	4
True central altitude -	62 34 34

If it is a fixed star that has been observed, there is no correction for semidiameter or parallax; you have only to subtract for refraction, in order to obtain the true altitude.

Thus, let the observed altitude of

Arcturus be - -	38° 40'
Subtract for refraction - -	1 10
True altitude - - -	38 38 50

PROBLEM XII. *To find the latitude of the place of observation.*

When the sun or a star is nearly on the meridian, or a few minutes before twelve at noon, take its altitude, and repeat this observation at short intervals of time, till it is found neither to increase nor diminish.

This last or greatest altitude, is the meridian altitude. When the sun is the object, you must obtain the true central altitude, by correcting for semidiameter and refraction, as shewn in the preceding problem.

Having obtained the meridian altitude, the first object for consideration is, whether the latitude be north or south, and whether the declination of the object be north or south. If the latitude and declination be both north or both south, they are said to be of the same name; but if one be north and the other south, they are said to be of different denominations. This being determined, to find the latitude,

1. Take the given altitude from 90° to find the zenith distance. 2. If the zenith distance and declination be of one name, subtract one from the other, and the difference is the latitude; but if they have contrary names, their sum gives the latitude.

The latitude is always of the same name with the declination, unless when the declination has been subtracted from the zenith distance.

Example.

Aug. 17, 1776, Cambridge. The
    apparent altitude of the sun's
    lower limb   -   -   -   53° 46′ 8″ S.
Sun's semidiameter   -   -   -   16

Apparent altitude of the sun's centre 54 2 8
Subtract for refraction   -   -   41

Real altitude of the sun's centre - 54 1 27
This sum, taken from 90°, gives
    the zenith distance of the sun's
    centre   -   -   -   35 58 33
Add for the sun's declination - - 16 13 57

    The sum is the latitude of
        Cambridge   -   -   52 12 30

N. B. The sun's declination, as found in the tables, is to be reduced by the rules given p. 474, to the meridian of observation.

Nov. 6, 1792, Long. 158° W. the meridian altitude of the sun's lower limb was observed to be 87° 37′ N. required the latitude ?

Observed altitude   -   -   87° 37′ N.
Sun's semidiameter   -   -   16

Altitude of the sun's centre   -   87 53
This from 90, gives the zenith distance 2 7
Declination reduced   -   - 16 25 S.

Latitude required   -   -   18 32 S.

Dec. 1, 1793. The observed meridian altitude of Sirius was 59° 50′ S. required the latitude?

Observed altitude	-		59° 50′ S.
Zenith distance	-	-	30 10 N.
Declination of Sirius	-		16 27 S.
Latitude required	-	-	13 43 N.

PROBLEM XIII. *To find the time by equal or corres-
ponding altitudes.*

This problem is of extensive use, for the basis of all astronomical observation is the determination of the exact time of any appearance in the heavens; which cannot be attained, unless you are assured of the going of your watch or clock. I have before shewn you, that a mean solar day is always considered as of the same determinate length; but the length of an apparent day is variable, being sometimes longer, sometimes shorter, than a mean day. The instant, therefore, of apparent noon will sometimes follow, at others precede, that of mean noon. The interval between apparent and mean time, is called the equation of time.

To find, then, the time of apparent noon, observe the sun's altitude in the morning, and also the time by a clock or watch. Leave the quadrant in the same situation, taking care that its position be not altered by any accident; and in the afternoon, direct it to the sun, by moving the index of the horizontal

circle only, and observe the time when the sun's altitude corresponds with that to which the quadrant was set in the morning. Add the times of observation together; the middle instant between these times of observation is that of apparent noon: this being corrected, by adding or substracting the equation of time, gives the time of true noon. If it be precisely XII, the clock is right; but if it differ, the clock is faster or slower, by the quantity of the difference greater or less than XII.

Thus, suppose the time in the morning to be - - - 21° 35' 8"
That in the afternoon - 2 55 43

24 30 51
The time of noon by watch - 12 15 25
Equation of time - - 13 3

Mean noon by watch - 12 2 22

The watch is therefore 2 min. 22 sec. too fast.

To be more particular and accurate. In our latitude, the altitudes should be taken when the sun is at least two hours distant from the meridian. The best time is when the sun is on or near the prime vertical, or east and west point of the compass; because his motion perpendicular to the horizon is greater at that time.

About this time, in the forenoon, take several altitudes of the sun, writing down the degrees and minutes shewn on the arch, and also the exact time

shewn by the clock at each observation : the obser-vations to be written one below the other, in the order they were made ; the time of each observation being previously increased by 12 hours.

In the afternoon set the index to the same de-gree and minute as the last observation, note ex-actly the time shewn by the clock when the sun is come down to the same altitude, and write down the time opposite to the last morning altitude ; proceed in the same manner to note the time of all the alti-tudes corresponding to those taken in the morning, writing down each of them opposite to that morn-ing one with which it corresponds.

Half the sum of any pair of corresponding alti-tudes, will be the time of noon by the watch un-corrected. Find the mean of all the times of noon thus deduced from each corresponding pair of obser-vations ; which correct for the change in the sun's declination, and you obtain the exact time shewn by the clock at solar noon. This, corrected by the equation of time, gives the time of mean noon ; and the watch is too fast or too slow, according as the time of noon thus found is more or less than 12 hours.

Example 1. Equal altitudes taken June, 1782.

Morning.	Afternoon.
20^h 55' 46''	3^h 8' 44''
20 57 41	3 6 48
20 59 27	3 4 58

H h 4

1st pair 20ʰ 55ᵐ 46ˢ   2d pair 20ʰ 57ᵐ 41ˢ   3d pair 20ʰ 59ᵐ 27ˢ
            3 8 44   3 6 48   3 4 58

    Sum 24 4 30   24 4 29   24 4 25
    ½ sum 12 2 15   12 2 14½   12 2 12½

As the seconds differ, add them together, and divide the sum by 3 (the number of pairs) which gives you a mean

$$15$$
$$14\tfrac{1}{2}$$
$$12\tfrac{1}{2}$$

$$3)\,42$$

$$14$$

Therefore the mean of the observed
   time is - - - 12ʰ 2′ 14″
Equation for six hours difference in
   declination - - - 8

Time per watch of mean noon - 12 2 14 8
Equation of time - - 1 55 1

Time per watch of mean noon - 12 0 19 7

The watch is 19 seconds 7 thirds too fast for mean time.

Example 2. Jan. 29, 1786.

Morning.	Afternoon.
21ʰ 35′ 8″	2ʰ 55′ 43″
21 36 8	2 54 42
21 38 9	2 52 41 2
21 39 12½	2 51 38

	h. m. s.	h. m. s.	h. m. s.	h. m. s. th
1st pr.	21 35 8	2d 21 36 8	3d 21 38 9	4th 21 39 12 5
	2 55 43	2 54 42	2 52 41 2	2 51 38
Sum	24 30 51	24 30 50	24 30 50 2	24 30 50 5
½ sum	12 15 25 5	12 15 25	15 15 25 1	12 15 25 2

The difference here is only among the thirds, which added together are 8''', divided by 4 we have 2. Therefore

The mean of the observed time is	$12^h\ 15'\ 25''\ 2^m$	
Equation for declination - -	20 2	
Time of apparent noon by watch -	12 15 5 0	
Equation of time - -	0 13 29 8	
Time by watch of mean noon -	12 1 35 2	
Watch too fast for mean time -	1 35 2	

PROBLEM XIV. *To find the error of a clock or watch, by corresponding or equal altitudes of a fixed star.*

Rule 1. Add half the elapsed time between the observations, to the time when the first altitude was taken, and you have the time of the star's transit over the meridian per watch.

Rule 2. Subtract the sun's right ascension from the star's, increased by 24 hours, if necessary. Take the increase of the sun's right ascension in 24 hours, and add to it 24 hours; then say,

As this sum

Is to 24 hours,

So is the difference between the sun and star's
   right ascension

To the true time of the star's transit.

   If the watch be regulated to solar time, the dif-
ference between the true time of the star's transit
and the time shewn by the watch, will be the error.

   If your meridian be different from that of Green-
wich, say.

As 24 hours

Are to the daily difference of the sun's right ascen-
   sion ;

So is the longitude, in time,

To a proportional part, which must be added to the
   true time of the star's transit, if the longitude be
   east, but subtracted if west.

   If the watch be regulated to mean solar time, that
is, if it divides the time equally, apply the equation
of time as directed in page 2 of the Nautical Alma-
nack, to the true apparent time of the star's tran-
sit, before you subtract.

Example.

On the 6th of November, 1787, at 11^h 10' 9" P. M.
and at 16^h 4' 15" solar time, the star Aldebaran had
equal altitudes at Greenwich. Was the watch too
fast or too slow ?

$$
\begin{array}{r r r}
16^h & 4' & 15'' \\
11 & 10 & 9 \\
\hline
2\,)\,4 & 54 & 6 \\
\hline
\end{array}
$$

Half elapsed time 2 27 3
Time 1st altitude 11 10 9
_____

Star's transit per watch 13 37 12
_____

Star's R. A. - - 4 23 50
                    24
_____

                 - 28 23 50
Sun's R. A. -   14 46 15
_____

Difference - 13 37 35
_____

Sun's R. A. Nov. 6.   14 46 15
- - - - 7.   14 50 15
_____

Increase in 24 hours   0 4 0

As 24^h 4' : 24^h :: 13^h 37' 35" : 13^h 35' 19" true time.
Time per watch 13 37 12
_____

Watch too fast 0 1 53

On July 13, 1792, in longitude 23° 26' E. the following equal altitudes of Altair were observed.— Required the errors of the watch?

Time per Watch.	Altitude.	Time per Watch.
8^h 17′ 0′ -	27° 23′ -	14^h 35′ 57″
8 19 16 -	27 40 -	14 33 42
8 20 12 -	27 55 -	14 32 44
8 21 54 -	28 12 -	14 31 5
8 23 16 -	28 30 -	14 29 41
8 25 55 -	28 52 -	14 27 1

Sum   50 7 33   -   87 10 10

Mean 8 21 15 5   -   14 31 41 6

Mean time of 1st observation   8 21 15 5
Mean time of 2d observation   14 31 41 6

2) 6 10 26 1 dif.

Half elapsed time   -   3 5 13

Star's R. A.   -   -   19 40 40
Sun's R. A.   -   -   8 13 41

Difference   -   -   11 26 59

Sun's R. A. at noon, 23d July   8 13 41
Ditto   -   24th July   8 17 39

Increase in 24 hours   -   -   0 3 58

<div style="text-align:right">True time of star's
transit.</div>

24^h 3′ 58″ : 24 :: 11^h 26′ 59 : 11h 25′ 5″
24^h : 3′ 58″ :: 1^h 33′ 44″ pro. part. 0 0 16

True time of star's transit corrected
     for longitude - - - 11 25 21
Time per watch - - - - 11 26 28
_____
Watch too fast for apparent time - 0 1 7

Secondly, Suppose the watch had been regulated to mean solar time; then

True apparent time of star's transit,
     as above - - - 11 25 21
Equation of time - - - 0 6 3
_____
True mean solar time - - 11 31 24
Time per watch - - 11 26 28
_____
Watch too slow for mean time - 0 4 56

PROBLEM XV. *To draw a meridian line, or to find the cardinal points of the compass, by equal altitudes of the sun, or a star.*

If equal altitudes of the sun be taken, as directed in problem xiii, and the place of the index on the horizon circle be carefully noted at each time of observation, the middle degree or part between each, will be the place where the index will stand, when the sights of the quadrant are directed to the south, or north, according as the sun is to the southward or northward of the place of observation at noon. Set the index to this middle point, and direct the sights of the quadrant to some remote and fixed ob-

ject on the earth. This object will be a south meridian mark, and will serve to set the quadrant at any future time. Then take up the instrument, and after setting the index to 0, place it again on the table, or support, and move the whole instrument, not by any of its parts, but entirely about upon the table, till the sights are truly directed to the meridian mark. Adjust the horizontal circle by Prob. i, and the index will then serve to shew the true bearing of any object; because the diameter joining the two zeros, or 00s, answers to the meridian line.

If the table or support be immoveable, it will be proper to make three marks or indentations, to receive the points of the screws; by which means the horizontal circle may be instantly, at any time, set in its proper position, with respect to the cardinal points of the horizon.

It often happens, that there is not any window in a house, from which the sun can be seen morning and evening. In this case the meridian may be determined by observations of equal altitudes of the pole star, or any other near the pole.

PROBLEM XVI. *To find the time by the sun's transit over the meridian.*

Adjust the quadrant to the cardinal points by the last problem, a short time before noon. Set the index to 0, and elevate the quadrant, so that the shadow of the sight with the cross wire may fall upon

the other. As the instant of apparent noon approaches, the bright spot formed by the sun's light through the lower hole in the former sight, will be seen approaching the mark on the latter. If the observer chuses to look at the sun, he must now put up the dark glass, and apply to the observations. The instants when the first limb, or edge of the sun, appears to touch the perpendicular wire, and also when the latter limb appears to leave it, must be noted by the clock or watch. The middle time is the apparent noon. Or if he chuses to observe by the bright spot only, the instant when the spot is seen upon the mark is the apparent noon ; and this, corrected by the equation of time, will shew how much the clock is fast or slow.

PROBLEM XVII. *To find the time by an observation of the sun's altitude and azimuth.*

Adjust the instrument to the cardinal points, and observe the sun's altitude. Take notice likewise of the angle of azimuth from the meridian, as shewn by the index.
Then,
As the sine complement of the sun's declination
Is to the sine complement of the altitude ;
So is the sine of the azimuth
To the sine of the sun's horary angle.
Which last being reduced into time, by allowing fifteen degrees to one hour, and in proportion for the

other parts, gives the apparent time, if afternoon ; but if before noon, it must be deducted from 12 hours, to give the time. This apparent time must be corrected by the equation of time.

Example. Suppose, that on the 21st of June, the sun's altitude was observed to be 46° 25′, and his azimuth 112° 59′, the declination being 23° 29′.

As the cosine of the sun's declination

23° 29′ - -	9.9624527

Is to the cosine of the altitude

46° 25′ - - -	9.8384769

So is the sine of the azimuth 112° 59′,

or 67° 1′ - -	9.9640797
	19.8025566
	9.9624527

To the sine of the horary angle 43°

47′ 13″ - - -	9.8401039

As 15° to 1^h, so is 43° 47′ 13″ to 2^h 55′ 8″, the apparent or true time past noon, to 9^h 4′ 52″ before noon ; but neither of these times will agree with a watch which measures time equally.

The equation of time for noon at Greenwich is 1′ 15.9″, the daily difference 13″; therefore, as 24^h is to 13″, so is 2^h 55′ 8″ to 1.5″; consequently 1.5″ added to 1′ 15.9″, or 1′ 17.4″, is the equation of time to be added to the given hour : but 2$_h$ 55′ 8″ added to 1′ 17″, gives 2^h 56′ 25″, the time past noon per watch.

It may be necessary to remark, that whenever you apply the equation of time to that immediately de-

duced from calculation, you must add or subtract as the Nautical Ephemeris directs; and if the time is not very near noon, you must make a proportion as above; but if you apply the equation of time to the time per watch, you must subtract where the ephemeris directs you to add, and *vice versa.**

* The preceding examples will be sufficient to instruct the learner in the nature and uses of the astronomical instrument called the Astronomical Quadrant. The one herein described is the ordinary sort as adapted to the use of schools or teachers. For more accurate purposes, or for correct observations in the observatory, they are made of larger dimensions, and contain a variety of essential additions, for accurate adjustment, and nicety of observation, so as to read the observed angle off as minute, as 30, 10, or 5 seconds of a degree. The late ingenious Mr. *Ramsden* constructed the principle of a vertical circle, so as either to move in the meridian or to turn out of it occasionally, to take equal altitudes, &c. &c. which, from its construction, rendered it far superior to the quadrant in point of correctness, and more permanent in its figure and adjustment. In lieu of such an instrument as this, it may be right to inform the learner, that a good portable sextant, with silver arch that admits the angle to be read off to 30″, or less, assisted by a quicksilver artificial horizon with a parallel glass roof, form the best apparatus for taking altitudes, and angular distances of the celestial bodies, in order to determine the time, or the latitude and longitude of the place wherein the observation is made, in a manner similar to the directions herein given. EDIT.

OF THE

EQUATORIAL,

OR

UNIVERSAL SUN-DIAL,

AND ITS USES.

THE *plumb-line*, or direction in which gravity acts, being the only line we can at all times have immediate recourse to, for determining the position of objects, is the chief particular to which the circles in the instrument last described are adapted; and accordingly their planes are placed the one parallel, and the other perpendicular to that line. But as there are few places on the earth, whose vertical or horizontal circles correspond with those in which the celestial motions are performed, it was found necessary, at a very early period, to construct instruments adapted not only to the measurement of altitudes and azimuths, but also to follow the heavenly bodies in their respective paths, and determine their right ascensions and declinations, more immediately than can be done by the quadrant and horizontal circle. The equatorial is the most approved modern instrument for this purpose.

It consists of the following parts :

An horizontal circle E F, *plate* 14, *fig.* 2, divided, like that of the former instrument, into four quadrants of 90° each. But instead of a moveable index, there is a fixed nonius plate at N, and the circle itself may be turned on its axis.

In the centre of the horizontal circle is fixed a strong upright pillar, which supports the centre of a vertical semicircle A B, divided into two quadrants of 90° each. This is called the semicircle of altitude, and supplies the place of the quadrant in the former instrument; but it is more extensively useful, because one quadrant serves to measure altitudes, and the other depressions. It has no plumb-line, but a nonius plate at K.

At right angles to the plane of this semicircle, the equatorial circle M N is firmly fixed. It represents the equator, and is divided into twice twelve hours, every hour being divided into twelve parts, of five minutes each.

Upon the equatorial circle moves another circle, with a chamfered edge, carrying a nonius, by which the divisions on the equatorial may be read off to single minutes; and at right angles to this moveable circle, is fixed the semicircle of declination D, divided into two quadrants of 90° each.

The piece which carries the sights O P is fixed to an index moveable on the semicircle of declination, and carrying a nonius at Q. The sight O, to which

the eye is to be applied, has two small holes, and a dark glass for covering either occasionally ; and the sight P has two pieces screwed on, the lower having a small hole to admit the solar ray, and the upper carries two cross wires.

Lastly, there are two spirit levels fixed on the horizontal circle at right angles to each other.

The following are among the many problems which may be solved with peculiar facility, by means of this useful instrument.

PROBLEM XVIII. *To adjust the equatorial for observation.*

Set the instrument on a firm support. First, to adjust the levels, and the horizontal, or azimuth circle. Turn the horizontal circle, till the beginning O of the division coincides with the middle stroke of the nonius, or near it. In this situation, one of the levels will be found to lie either in a right line joining the two foot-screw which are nearest the nonius, or else parallel to such a right line. By means of the two last-mentioned screws, cause the bubble in the level to become stationary in the middle of the glass ; then turn the horizontal circle half round, by bringing the other O to the nonius ; and if the bubble remains in the middle, as before, the level is well adjusted ; if it does not, correct the position of the level, by turning one or both of the screws which pass through its ends (by

means of a turn-screw), till the bubble has moved half the distance it ought to come to reach the middle; and cause it to move the other half, by turning the foot-screws already mentioned. Return the horizontal circle to its first position, and if the adjustments have been well made, the bubble will remain in the middle; if otherwise, the process of altering the level and the foot-screws, with the reversing, must be repeated till it bears this proof of its accuracy. Then turn the horizontal circle till 90° stands opposite to the nonius; and by the foot-screw immediately opposite the other 90° (without touching the others), cause the bubble of the same level to stand in the middle of the glass. Lastly, by its own proper screws set the other level (not yet attended to) so that its bubble may occupy the middle of its glass.

Secondly, to adjust the line of sight. Set the nonius on the declination semicircle at O, the nonius on the horary circle at VI, and the nonius on the semicircle of altitude at 90°. Look through the sights towards some part of the horizon, where there is a diversity of remote objects. Level the horizontal circle, and then observe what object appears on the centre of the cross wires. Reverse the semicircle of altitude, so that the other 90° may apply to the nonius; taking care, at the same time, that the other three noniuses continue at the same parts of their respective graduations as before. If the remote object continues to be seen on the centre of the cross wires, the line of sight is truly adjusted;

Ii 3

but if not, unscrew the two screws which carry the
frame of the cross wires, and move the frame till the
intersection appears to lie on a new object, half way
between the object first observed, and that to which
the wires are applied in the last position. Return
the semicircle of altitude to its original position : if
the intersection of the wires be then found to be on
the object to which they were last directed, the line
of sight is truly adjusted; but if not, the frame must
be again altered as before : and the same general
operation must be repeated, till the cross wires in
both positions apply to the same object.

Besides this adjustment of the centre of intersec-
tion, it is necessary that one of the wires should be
in the plane of the declination semicircle, and the
other at right angles to that plane. As the wires
are fixed at right angles to each other, the adjustment
of one of them will be sufficient. For this pur-
pose, observe any small object on one of the wires;
if it be the vertical wire, move the index of the se-
micircle of declination ; or, if the other, move the
last mentioned semicircle on the axis of the equa-
torial circle. In either case, the object will coincide
with the wire during its motion, if the position be
right ; if not, alter that position, taking care not to
displace the centre from its adjustment.

To adjust the piece which carries the hole for
forming the solar spot, direct the sights to the sun,
so that the centre of the luminous circle, formed by
the aperture which carries the cross wires, may fall

precisely on the upper sight-hole. Then move the frame, with the small perforation, till the solar spot falls exactly on the lower sight-hole.

Thirdly, to find the correction to be applied to observations by the semicircle of altitude. Set the nonius on the declination semicircle to O, and the nonius on the horary circle to XII; direct the sights to any fixed and distant object, by moving the horizontal circle and semicircle of altitude, and nothing else; note the degree and minute of altitude or depression; reverse the declination semicircle, by directing the nonius on the horary circle to the opposite XII; direct the sights again to the same object, by means of the horizontal circle and semicircle of altitude, as before. If its altitude or depression be the same as was observed in the other position, no correction will be required; but if otherwise, half the difference of the two angles is the correction to be added to all observations or rectifications made with that quadrant, or half of the semicircle, which shew the least angle; or to be subtracted from all observations or rectifications made with the other quadrant, or half.

When the level and cross wires are once truly set, they will preserve their adjustment a long time, if not deranged by violence; and the correction to be applied to the semicircle of altitude is a constant quantity.

PROBLEM XIX. *To measure angles either of azimuth, altitude, or depression.*

Set the middle mark of the nonius on the declination at O, and fix it by means of the milled screw behind. Set the horary circle at XII on the equator, and the instrument (previously adjusted) is ready for observation. Then if the sights be directed successively to any two objects, the degrees and minutes contained between the two positions of the nonius, on the limb of the horizontal circle, will shew the horizontal angle in the same manner as has been described at Prob. ii of the quadrant. And likewise, if the sights be directed to any object, by moving the horizontal circle and semicircle of altitude, the degree and minute marked by the nonius on the last-mentioned semicircle will be the angle of altitude, if on the quadrant or part next the eye; or of depression, if on the remoter quadrant.

Remark. It is proper in this place to describe the nature and use of the admirable contrivance commonly called a *nonius*. It depends on the simple circumstance, that if any line be divided into equal parts, the length of each part will be greater, the fewer the divisions; and contrariwise, it will be less in proportion as those divisions are more numerous. Thus it may be observed, that the distance between the two extreme strokes on the nonius, in the equatorial before us, is exactly equal to eleven degrees on the limb, but that it is divided into

twellve equal parts. Each of these last parts will therefore be shorter than the degree in the proportion of 11 to 12 ; that is to say, it will be one-twelfth part, or five minutes, shorter. Consequently, if the middle stroke be set precisely opposite to any degree, the relative position of the nonius and the limb must be altered five minutes of a degree, before either of the two adjacent strokes next the middle, on the nonius, can be brought to coincide with the nearest stroke of a degree ; and so likewise the second strokes on the nonius will require a change of ten minutes, the third of fifteen, and so forth to thirty, when the middle line of the nonius will be seen to be equidistant between two of the strokes on the limb ; after which, the lines on the opposite side of the nonius will coincide in succession with the strokes on the limb.

It is clear from this, that whenever the middle stroke of the nonius does not stand precisely opposite to any degree, the odd minutes, or distance between it and the degree immediately preceding, may be known by the number of the stroke on the nonius which coincides with any of the strokes on the limb. It must be observed, however, that as the degrees in several quadrants are reckoned in opposite directions, so likewise the nonius has two sets of numbers : for the use of which it need only be remembered, that they always begin from the middle, and go to 30 minutes, and thence from the opposite 30 minutes in the same direction to the middle ; and

that they must always be reckoned in the opposite
direction to the degrees on the limb.*

PROBLEM XX. *To find the distance of an object on the
earth, by observations made at two stations.*

This may be done by measuring a base line and
the horizontal angles, and proceeding as directed
at Problem ii. But as the equatorial measures an-
gles of depression as well as elevation, the stations
may not only be on the same level, but may be ver-
tically the one above the other. For example, if the
altitude of any object be taken from a lower win-
dow of any building, and its depression from a win-
dow immediately above, and the distance of the
two stations of the instrument be accurately mea-
sured. Then,

As the sine of the sum of the angles of altitude and
depression, (or of the difference, if both be altitude
or both depression)

Is to the sine of the angle at the upper station ;

So is the distance between the stations

To the distance of the object from the lower
station.

---

* In this instrument they must be read in the opposite direc-
tion ; but when the nonius plate has its divisions fewer than the
number of parts on the limb to which it is equal, they coincide
successively in the same direction as that of the motion of the
index.

Example 1. From a window near the bottom of a house, the angle of elevation, BCA, *plate* 15, *fig.* 9, of an object, B, was found to be 40°; eighteen feet above the foregoing position, the angle BDE was observed to be 37° 30'. Then,

As sine of the difference of the two an-
   gles 2° 30'   -   -   -   8.6396796
Is to the sine angle BDC, equal angle
   BDE, plus 90 - 127.30   -   9.8994667
So is DC 18 feet   -   -   1.2552725

                     11.1547392
                      8.6396796

To BC, the required distance 327.38
   feet   -   -   -   2.5150596

Example 2. From C, *plate* 15, *fig.* 10, a window near the bottom of the house, the angle BCA of elevation of B was found to be 15° from D; 18 yards higher the angle of depression EDB was 10 degrees.
   Then,
As sine of sum of the angles 25°   -   9.6259483
To sine angle BDC 80°   -   -   9.9933515
So is DC 18 yards   -   -   1.2552725

                     11.2486240
                     9.6259483

To CB 41.944 yards   -   -   1.6226757

PROBLEM XXI. *To measure heights and distances.*

As the semicircle of altitude answers every purpose of the quadrant, in the instrument before described, and the horizontal circle is common to both, it will be easy for the intelligent learner to perform the Problems iii, iv, vii, viii, and ix, by the equatorial, from the instructions given under each respectively.

PROBLEM XXII. *To plot a piece of land.*

The Problems v, and vi, with all others which are solved by the mensuration of horizontal angles, may likewise be performed with facility by the equatorial.

PROBLEMS XXIII, XXIV, XXV, *and* XXVI.

Under this title it may be observed, that the Problems xi, xii, xiii, xiv, xv, xvi, and xvii, for finding the latitude, the time by equal altitudes, the position of the cardinal points, and the time by the sun's transit over the meridian, or by its altitude and azimuth, may be performed with equal ease and greater accuracy by the horizontal circle and semicircle of altitude in the instrument before us, as by the quadrant treated of under those problems.

I shall now proceed to some of the problems, to which the equatorial is more peculiarly adapted.

PROBLEM XXVII. *To find the latitude of the place by the sun, or any known fixed star.*

The instrument being adjusted according to the directions already given, set the semicircle of altitude to 90, and when the sun is coming near the meridian, elevate the sights till the centre of the sun is exactly in the centre of the cross wires; then follow the sun, by moving both the equatorial and declination circles, if necessary, till he is at his greatest altitude: the nonius of the declination will then give you his meridian altitude, from which subtract his declination, if it be north, or add it, if it be south; the remainder, if north, and the sum, if south, is the height of the equator, that is, the complement of the latitude; from which subtract the error in altitude occasioned by refraction, and the remainder subtracted from 90° gives your latitude.

Thus April 7, observed meridian altitude of the sun's lower limb   -   44° 51′ 23″
Semidiameter of the sun   -   16

Altitude of the sun's centre   -   45   7   23
Sun's declination north   -   -   6   57   37

Height of the equator, or co-lati-
     tude   -   -   -   38° 9′ 46″
Subtract for refraction   -   -   5 54

Co-latitude corrected   -   -   38 3 52
Which subtracted from 90° gives the
     latitude   -   -   -   51 56 8

The latitude may be obtained in the same manner
by a fixed star, whose declination is known.

PROBLEM XXVIII. *To find the meridian line
and the time, from one observation of the sun, when
its declination and the latitude of the place are
known.*

This problem requires that both the azimuth and
altitude of the sun should alter quickly; and this is,
generally speaking, the case more eminently, the
farther that luminary is from the meridian. There-
fore,

At the distance of three or four hours, either
before or after noon, adjust the horizontal circle;
set the semicircle of altitude, so that its nonius
may stand at the co-latitude; lay the plane of the
last-mentioned semicircle in the meridian, by esti-
mation, its O being directed towards the depressed
pole; place the nonius of the declination semi-
circle to the declination, whether north or south.
Then direct the line of sight towards the sun,

partly by moving the declination semicircle on the axis of the equatorial circle, and partly by moving the horizontal circle on its own axis. There is but one position of these which will admit of the solar spot falling directly on the mark on the opposite sight. When this position is obtained, the nonius on the equatorial, or horary circle, shews the apparent time, and the circle of altitude is in the plane of the meridian.

PROBLEM XXIX. *To find the time, when the latitude, the sun's declination, and the meridian, are known.*

The meridian being found by equal altitudes of the sun, or a star, which is the best method, and settled by a meridian mark, or by indentation, to set the screws in, place the equatorial accordingly, and adjust it by the levels. Set the semicircle of altitude to the co-latitude of the place, and the index of the line of sight to the declination of the sun. Turn this last semicircle, till the sights are accurately directed to the sun. The nonius will shew the time on the horary circle.

This problem is more accurate than the foregoing, and may be applied at all times when the sun is visible.

PROBLEM XXX. *To find the meridian line, when the time, the sun's declination, and the latitude of the place, are known.*

Adjust the instrument. Set the semicircle of altitude to the co-latitude, and the nonius of the declination semicircle to the declination, and set the nonius of the horary circle to the apparent time. Turn the horizontal circle till the sights are directed to the sun. The semicircle of altitude is then in the plane of the meridian.

This problem gives the position of the meridian more accurately than Problem xxviii. It is much more ready, where the time can be had, than the method of equal altitudes, and it is near enough to the truth of small instruments. The nearer the observation is made to the time of noon, the better; because the sun then changes its azimuth the quickest.

PROBLEM XXXI. *To find the declination of the sun, or any celestial object, when the latitude of the place, and position of the meridian are known.*

Rectify the instrument for the co-latitude, as in the foregoing problem, and place the semicircle of altitude in the meridian. Then direct the sights to the object, partly by moving the declination semicircle on the axis of the equatorial circle, and partly by moving the nonius of the semi-

circle last-mentioned. This nonius will then shew the declination.

PROBLEM XXXII. *To find the right ascension of any celestial object, when the time, the latitude, and the position of the meridian, are known.*

Rectify the instrument for the co-latitude, and place the semicircle of altitude in the meridian. Move the declination and equatorial circles till the cross hairs nearly coincide with the object, then place the sight a little to the westward thereof, and observe by your clock the time when the object passes the vertical wire.

By the clock you have obtained the sun's time, by the nonius of the equatorial you have the hour of the object.

Take the difference between the sun's time and the star's time; and if the time of the star be less than that of the sun, add that difference to the sun's right ascension at the time of observation;* the sum (rejecting 24 hours, if it exceeds that number) is the right ascension of the object.

But if the star's time exceeds that of the sun, the difference must be taken from the sun's right ascension; the remainder (adding 24 hours to the sun's right ascension, if necessary) is the right ascension of the star.

* To be found by the Nautical Almanack.

K k

January 1, 1778.

Observed time of the star by the equatorial - -	2ʰ	18ᵐ	3ˢ P. M.
Sun's time by the clock -	9	44	40 P. M.

Difference between two -	7	26	37
Sun's right ascension -	20	57	9
(which is to be added to the foregoing difference, as the star's time is less than the sun's) - - -	28	23	46
From which rejecting twenty-four hours, you obtain the star's right ascension -	4	23	46

August 31, 1778.

Observed a star, the time by the equatorial was 10ʰ A. M. *i. e.* astronomically -	22	00	00
Sun's time by the clock 5ʰ 55ᵐ 4ˢ which astronomically is -	17	55	4

Difference between the two to	4	4	56
As the star's time exceeds that of the sun, this difference is to be subtracted from the sun's right ascension - -	10	38	58
The remainder is the right ascension of the star -	6	34	2

PROBLEM XXXIII. *To direct the line of sight to any star or planet.*

Adjust the instrument ; that is, place it so that the circles of altitude and declination may be in the plane of the meridian ; set the semicircle of altitude to the co-latitude, and the circle of declination of the given body.

Take the difference between the right ascension of the sun and given body, and if the right ascension of the body be greater than that of the sun, subtract the difference ; if not, add to the time of observation. The remainder in one case, or the sum in the other, will be the hour and minute to which the nonius on the horary circle is to be set; which being done, the sight will point to the star or planet sought.

If the time be too small to admit of having the difference taken from it, borrow 24 hours, and reckon the remainder from XII at noon.

PROBLEM XXXIV. *To find the longitude.**

Adjust the instrument to the co-latitude and meridian, and take the time of the transit of the moon's limb, and also of a proper star, as near as possible to the moon's parallel, and the longitude may be determined by the following rule.

Rule. Find from the Nautical Ephemeris, the in-

* *Vince's* Practical Astronomy, p. 90 and 169.

crease of the moon's right ascension in 12 hours; observe, as before directed, the interval of time between the passage of a given fixed star, and of the moon's enlightened limb, over the meridian at each place, and the difference of these intervals will shew the increase of the moon's right ascension in the time of the star's passage from one meridian to the other. But as the increase of the moon's R. A. in 12 hours is to 180°, so is the above difference of intervals, to the difference of longitude.

Example, on Nov. 30, 1792.

13ʰ 12' 57.62" meridian transit of the
      moon's 2d limb } at Greenwich, by the clock.

13 13 29.08 meridian transit of α ♍

   31.46 difference of R. A. at Greenwich.

13 14 8.05 meridian transit of the
      moon's 2d limb } at York, by the clock.

13 14 30.13 meridian transit of α ♍

   22.08 diff. of R. A. at York. } The clocks being supposed to be going nearly siderial time, no correction is necessary.
   31.46 ditto at Greenwich.

   9.38 increase of moon's right ascension between Greenwich and York by observation, which reduced into degrees gives 141". Now the increase

of the moon's right ascension in twelve hours was 23340"; hence as 23340" to 180°, so is 141" to 1° 5' 14", the difference of longitude between Greenwich and York.

Those stars that are nearest in right ascension and declination to the moon, are best suited for this purpose.

FINIS.

A

LIST OF THE PRICES

At which the Instruments described in this Work,

ARE MADE AND SOLD BY

W. AND S. JONES,

HOLBORN, LONDON.

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PLATE XI and XII.

The complete *Planetarium*, *Tellurian*, and *Lunarium*, all in brass; the box, A B C, *plate* 11, *fig*. 1, mounted on a pedestal with claw feet, and the instrument with all its appendages packed in a portable mahogany case. 36 15

N. B. This instrument, by being divided into three parts, admit the various phenomena to be exhibited in a complete and perspi cuous manner.

PLATE XIV.

Fig. 1.   The simple *Astronomical Quadrant* or *Angular Instrument*, all in brass, of about $4\frac{1}{2}$ inches radius, in a case 1 15 0

Ditto, with rack-work motions, telescopic sight, reflect ing eye-piece to observe to the zenith, horizontal spirit levels, *&c*. packed in a pocket mahogany case...... 4 4 0

For the representations and descriptions of portable, more simple, and less expensive *Orreries*, see the pamphlet entitled, The *Description and Use of a New Portable Orrery*, by *W. Jones*; The Fifth Edition, 1799, price 2*s*. and sold as above.

Fig. 2, The *Portable Equatorial* or *Universal Sun-dial*, all in brass, the radius of the circles about $3\frac{1}{2}$ inches in diameter, in a case 8 8 0

PLATE XVI.

The *Globes*, as represented in the plate, are, according to the mode of mounting by *G. Adams*, the father of our late author, and according to the dimensions of 12 or 18 inches, and the quality of the frames, the pair, from 5*l*. 5*s*. to 15 15 0

For more accurate, and the NEW BRITISH GLOBES, see the Adver tisement prefixed to the Table of Contents of this Work.

PLATE II. *Vol.IV.*

Fig. 1

Ja.^s Lodge sc.

P
R
T
I
L A
Z
N
D
S

Ja.^s Lodge sc.

1799.

PLATE III. *VOL. IV.*

B

b

c

C

d

D

N

A

PLATE IIII.VOL.IV.

R

D
F

C
T

Fig. 3.

N
E
n. m

N
D
n
m

N
C
n
m

N
B
n
m

N
A
m

S

1799.

PLATE V. *Vol.*

B
T   N

NORTH
AMERICA

Equator

Ecliptic   SOUTH
AMERICA

S
T

Fig. 2.

September
Aries
P   e

E   C

e   m

August
Pisces
P   e

E   C

d   m

July
Aquarius
P   e

E   C

P   e

E   C

m
d

S

Capricornus

June

P   e

E   C

m
d

Sagitarius
May

e   e

E   C

m
d

Scorpio
April

Libra
March

C

PLATE VII. *VOL. IV.*

T

R

N

M

L

ig.3.

E

F
G

K

P

PLATE VIII.*Vol. IV.*

Fig. 2.

H

G

P

Fig. 5.

PLATE IX. *VOL. IV.*

F

D

E

a

b

b

d

Fig. 3.

L

c

d   b

I

B

a

PLATE X. *Vol. IV.*

Q   N   P   E

G

D

F

C

G

PLATE XI. *VOL. IV.*

Fig. 3.

2

4

PLATE XII. *VOL. IV.*

Fig. 1.

PLATE XIII.

Fig. 6.

Fig. 8.

PLATE XIV. *VOL. IV.*

Fig. 1.

B

90

80

70

60

50

40

30

G

E

70 60 50 45 30 20

PLATE XV.

Fig: 5.

C

B   G

Fig: 10.

E

B

A

Fig: 7.

D   G

E   C

C

B

Plate XVI.