

## **The young gentleman and lady's astronomy / [James Ferguson].**

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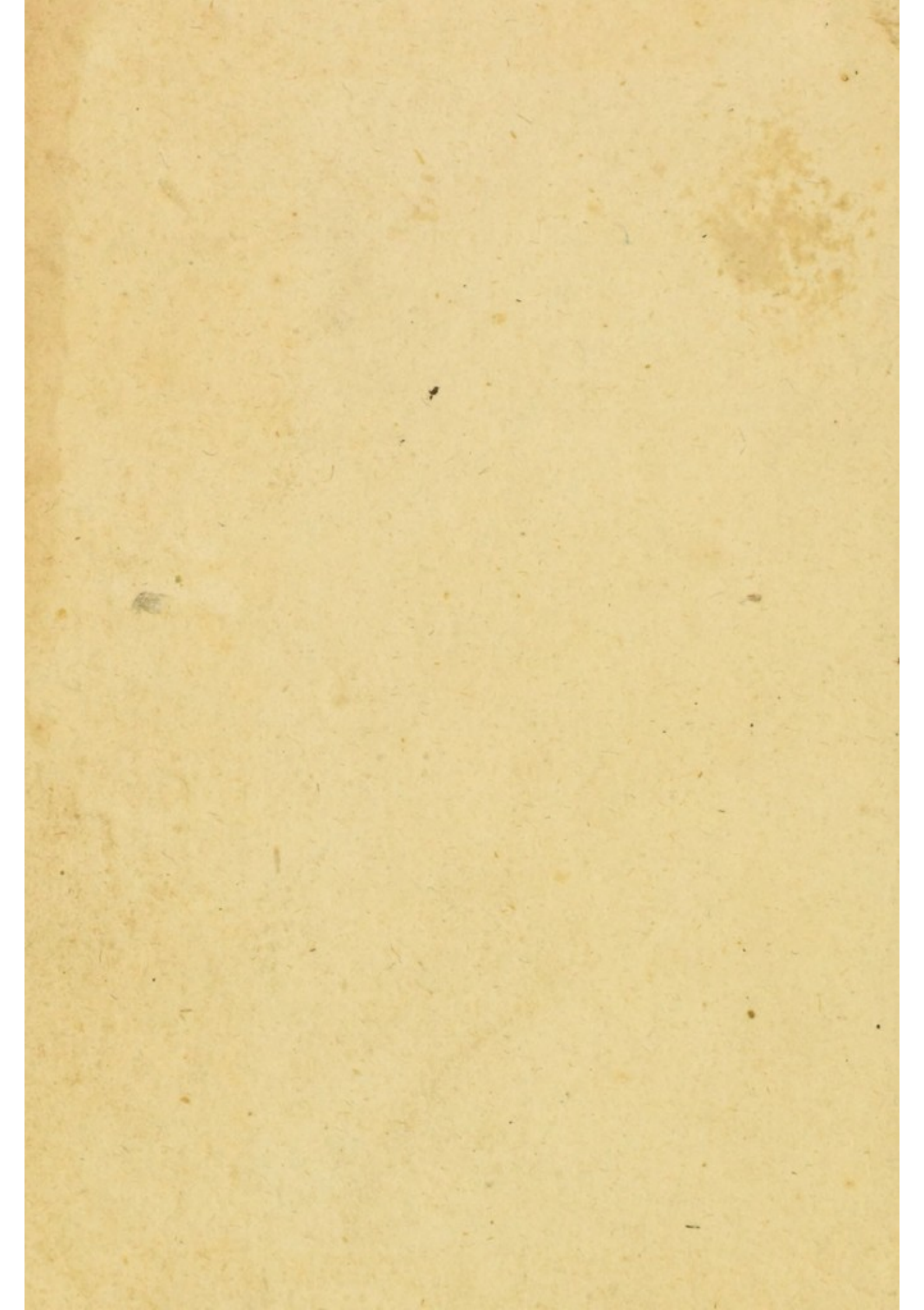
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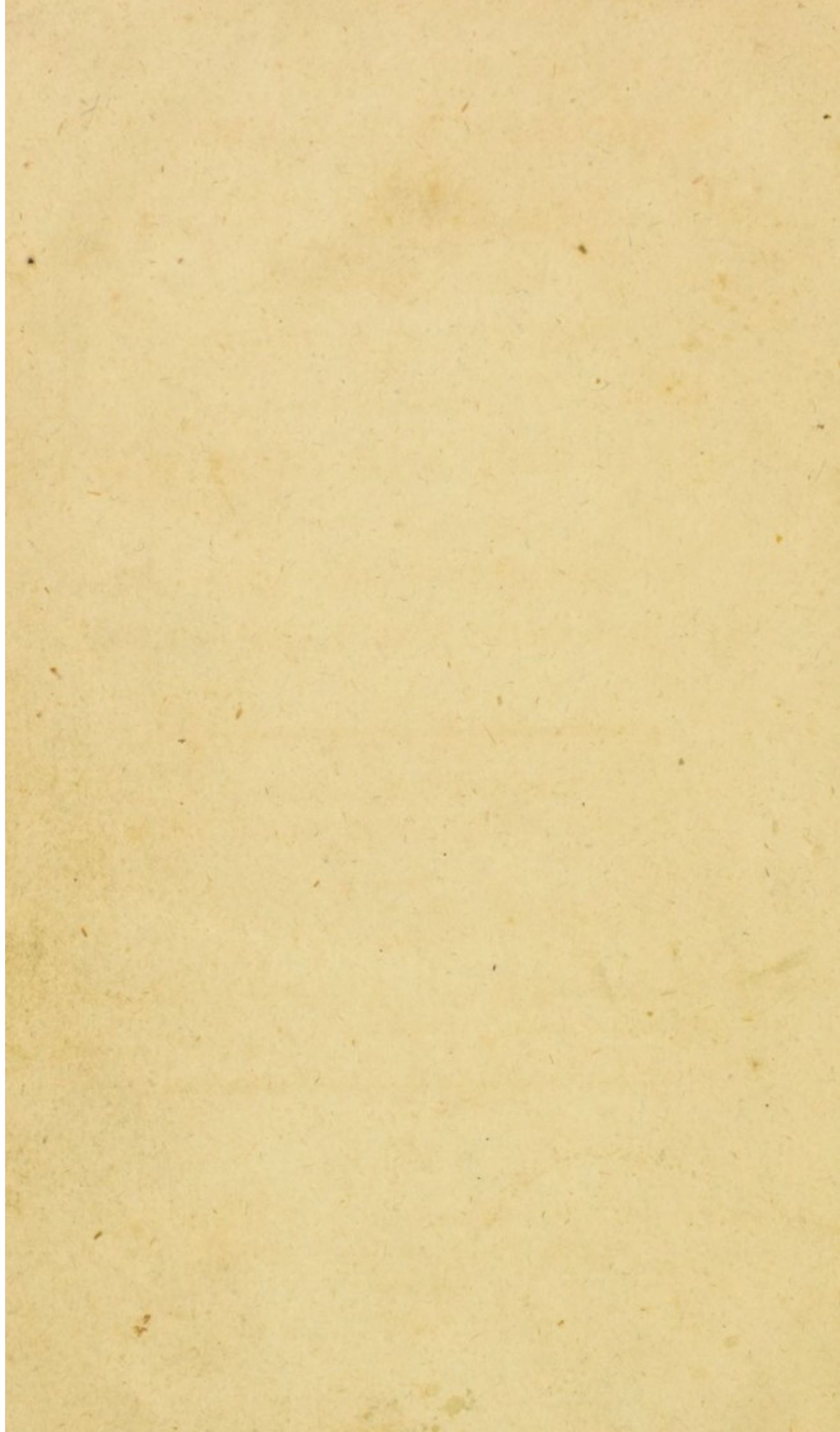


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THE YOUNG  
GENTLEMAN AND LADY'S  
ASTRONOMY,  
FAMILIARLY EXPLAINED  
IN TEN DIALOGUES  
BETWEEN  
NEANDER AND EUDOSIA.  
TO WHICH IS ADDED  
THE DESCRIPTION AND USE OF THE  
GLOBES AND ARMILLARY SPHERE.

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THE EIGHTH EDITION,  
ILLUSTRATED WITH COPPER-PLATES.

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BY JAMES FERGUSON, F. R. S.

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*The works of the LORD are great, sought out of all them that  
have pleasure therein. Psalm cxi. v. 2.*

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DUBLIN:  
PRINTED FOR GILBERT AND HODGES, DAME STREET,  
AND R. CROSS, BRIDGE STREET,

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1808.

ASTRONOMY  
AS TEN DILOGUES  
BETWEEN  
ALEXANDER AND TUDOR  
ON THE DESCRIPTION AND USE OF THE  
GLOBES AND ARMILLARY SPHERE



THE EIGHTH EDITION  
ILLUSTRATED WITH COPPER-PLATES

BY JAMES FERGUSON, F.R.S.

The Author of the 'History of the Earth and Planets' and 'The History of the Moon'.

LONDON:  
PRINTED FOR GILBERT AND RODGER, ST. MARK'S STREET,  
AND A. CROSS, BELGIE CHURCH.

# ADVERTISEMENT.

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THE design of the following Treatise is to shew, that Young Gentlemen and Ladies may acquire a competent knowledge of Astronomy, without any previous knowledge of Geometry or Mathematics. How far the Author has succeeded in this, is left to the judgment and decision of his impartial Readers; to whom, if his labours be agreeable and instructive, the purpose for which he wrote will be fully answered.

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THE  
YOUNG GENTLEMAN AND LADY'S  
ASTRONOMY.

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DIALOGUE I.

ON THE MOTION, FIGURE, AND DIMENSIONS OF  
THE EARTH.

*Neander.*

GOOD morrow, sifter; this is an early visit.—I have thought, for these few days since I came home, that you are anxious about something or other. Pray may I ask what it is?

*Eudoria.* Indeed, brother, I am,—but am almost afraid to tell you what it is.

B

N. Then

N. Then you must think me much changed since I went to CAMBRIDGE. You know I always loved and esteemed you on account of the goodness of your heart, which shone forth with the greatest lustre in the whole of your deportment.—I am still the same as before, excepting the improvement I have made at that famous university; where, not only the sublime sciences are taught by the greatest masters, but the truths of the Christian religion proved in the lectures which I have constantly attended.—You know that you and I used to converse familiarly before I went thither: let us do so still.

E. Dear brother, I cannot express how much you oblige me by this behaviour.—I was afraid before to tell you my mind; but now I will, especially as you are to be here for some considerable time before you set out upon your travels. What I want to learn of you cannot be done, I believe, without taking up a great deal of your time; and perhaps you may think me too vain, in wanting to know what the bulk of mankind think our sex have no business with.

N. Pray,

*N.* Pray, EUDOSIA, what is that?

*E.* It is nothing less than to be in some measure acquainted with the sublime science of Astronomy; for I have been told that, of all others, it is the best for enlarging our minds, and filling them with the most noble ideas of the GREAT CREATOR and his works; and consequently of drawing us nearer to Him, with an humble sense of our own meanness, and of every thing that the greatest art of man can perform.

*N.* Indeed, sister, whoever told you so, told you a great truth; and I am very glad to find you have an inclination to learn the most sublime science that ever was taught by mankind.

*E.* But shall I not be laughed at for attempting to learn what men say is fit only for men to know?

*N.* Never, by any man who thinks right; and I hope you are above minding what those say who think wrong.

*E.* Now, let me speak freely.—I have been told Astronomers pretend that the sun stands still, and that the earth turns round. What do you say to this?—I know you

honour the Bible, and it asserts the contrary. Now, I see so many things in that Book which appear to me to be above all the powers of human composition, and carry such evident marks of divinity with them, as are sufficient to convince me that they could proceed from none but GOD: and therefore, I had much rather baulk all my inclinations to learning, than learn any thing that would prejudice my mind against the Bible.

N. Dear sister, I admire the goodness of your heart.—You may depend upon it, that the study of astronomy will never have the least tendency towards prejudicing your mind against the Scriptures.—You know that we cannot take every thing there in the strict literal sense. If we did, we should believe that Our Saviour was actually a vine at one time, a door at another, and at a third time a lamb. The Scriptures were given us to teach us what we should believe, and how we should behave, in order to attain and secure to ourselves the favour of our Maker here, and our perpetual felicity hereafter; which are things infinitely more interesting to us than all  
other

other knowledge and wealth in the world.—They speak according to the common apprehensions of mankind, in those points which are merely speculative, and have no direct tendency to influence our morals; and, as they never were intended to instruct us in experimental philosophy, or astronomy, or in any thing else that we could acquire by our own industry without them, nothing that regards these sciences can either be deduced or inferred from them.—One might with as good reason take up a law-book and expect to find a system of geography in it, as take up the Bible with a view to find a system of astronomy therein.

E. What you have said is rational and just; and now, if you please, I should be glad to enter upon our intended subject.—If the sun does not move, pray, to what is he fixed? and what hinders him from falling down to the earth, when he is so high above it, especially at noon in summer?

N. *High* and *low* are only relative terms; for, when the sun is at his lowest depression with respect to us, he is directly overhead

head to some other part of the earth; for the earth is round like a globe, and on whatever part of its surface a person stands upright, he thinks himself to be on the uppermost side; and wonders how any one can stand directly opposite to him, on the undermost side of the earth; or rather, how he can hang to it, with his head downward, and not fall off to the lower sky.

*E.* That is what I have often wondered at, when I have heard it affirmed that the earth is habitable on all sides: or that where towns cannot be built, ships may sail. How comes it to pass, that the weight of a ship causeth it not to fall off from the lower seas; or that these ships and seas do not fall off to the lower sky altogether?

*N.* What we call *weight* is caused by *attraction*.—The earth attracts all bodies on or near its surface towards its center, equally on all sides, every particle of matter alike; and therefore those bodies which contain the greatest number of particles of matter acquire from this attraction the greatest and most forcible pressure; and consequently have (what we call) the  
greatest

greatest weight.—The earth may be compared to a great round loadstone rolled in filings of iron, which attracts equally on all sides; so that they cannot fall off even from its undermost side: nay, it will take them up from a table, if they be within the sphere of its attraction.—By and by you shall be satisfied with respect to your query about the sun.

*E.* So far I understand you very well; but still it seems odd to me that people should stand opposite to us on the earth with their heads downward.

*N.* I believe it does; but you know, that either the sun must go round the earth to give us days and nights, or the earth must turn round like a globe on its axis to do so: and will not either of these motions answer the intended purpose?

*E.* Undoubtedly it will.

*N.* Now, as I have no mind to deceive you, and shall in due time prove every thing that I advance, even to your own satisfaction; I do say, that the sun does not move round the earth every twenty-four hours, but that the earth turns round in twenty-four hours: and as the sun can  
only

only enlighten one half of the earth at any given instant of time, and the other half must then be in the dark; this motion of the earth will cause the different places on its surface to revolve through the light and the dark in twenty-four hours; in which time, of course, they must have a day and a night: and at the instant when it is mid-day at one place, it must be mid-night at the opposite.—Do you believe what I say with respect to the earth's turning round?

*E.* I do, because I am fully satisfied that you would not willingly deceive me; and you have promised to prove that it does.

*N.* Then, be pleased to stand up for a minute.—It is now seven o'clock in the morning, and you think you are standing upright, on the uppermost side of the earth.—You will think the same if you stand upright at seven o'clock in the evening, when the earth has turned half round because you will then perceive no difference of posture: and yet, at that time, you will be very nearly in the same position as a person is just now, who stands  
on

on the side of the earth opposite to us: which person being as strongly attracted by the earth there, towards its center, as we are here, he is in no more danger of falling off downward, than we are at present of falling upward.

E. Pardon me, sir; if you had not been at the university, I should have thought *falling upward* a very improper expression.

N. So it is; and I do assure you that I never heard such an expression at the university, nor do I remember ever to have used it before.—But, to proceed.

*Up* and *down* are only relative terms. Let us be on what part of the earth we will, we call it *up* toward the sky over our heads; and *down* toward the center of the earth, to which all terrestrial bodies would fall, by the power of the earth's attraction. So that, with regard to open space, what is *up* from any given point of the earth's surface, is *down* from the opposite point thereof. And as the sky surrounds the whole earth, we call it *up* toward the sky over our heads, be where we will; and *down* from our place toward the center of the earth.

*E.* Then, to be sure, we can perceive no difference, as to your position at different times of the day. You have quite satisfied me in this: but, pray, how can the earth move, and we not feel its motion?

*N.* I heard you were at Plymouth last year; had you not then the curiosity to go aboard some of the ships there, or at the Dock?

*E.* My papa and I went to the Dock, with a small party of gentlemen and ladies. Mr. *Falconer*, who was then master of the *Belleisle*, happened to be on shore; and, observing that we were strangers, he most politely invited us to see his ship, which was then lying with many others in the Hamoaze. We most willingly accepted his invitation, and he took us all out in his boat; shewed us first into the cabin of the ship, and, as it was in the afternoon, he genteelly treated the gentlemen with wine, and the ladies with tea; after which, he shewed us the whole inside of his ship of war. The way that the different apartments are laid out, especially the powder-magazine, and how it

it is secured from being dangerous; the method of steering the helm, and many other things which I cannot well remember, was a sight not only highly entertaining, but greatly surprising; and I could not help wondering how it was possible for the art of man to contrive and build such a wondrous huge machine, and how it could be managed and conducted through the pathless seas.

N. It is surprising indeed! but how infinitely more so is the power and skill of the GREAT CREATOR of the universe, who has made such prodigious bodies as the planets of our system are (one of which is a thousand times as big as our earth) and has set them off in the trackless space around us, with such degrees of swiftness as you will be amazed to hear of; and yet, at the end of each circuit they begin the same over again, at the same parts of space from which he set them off at first.—And the disposition of all the apartments of the ship will not bear to be compared, not only with the structure of the human body, but even with that

of the meanest animal on earth.—Was the day calm or windy?

*E.* Scarce a breath of wind was stirring; the sun shone clear, which made the surface of the water around us have a very pleasing aspect: and the sight of the ships about us, and of the town, was a most beautiful prospect.

*N.* I suppose you looked out through the cabin windows whilst you were at tea.—Did you see the same objects all the while?

*E.* I looked out very often: the first object I saw was a large house in the Dock-town; but it seemeth to me as if it moved very slowly toward the right-hand. I soon lost sight of it, and other objects appeared to my view, and disappeared slowly and gradually; which could arise from no other cause than the very slow and gentle turning of the ship the contrary way.

*N.* True: but did you feel the motion of the ship?

*E.* Not in the least; and the whole company agreed, that, if we had not looked  
out,

out, we should not have thought that the ship had any motion at that time.

N. And is not *that single case* sufficient to convince you that the earth may turn round, and carry us all about with it, and we feel nothing of its motion?—especially as the motion of the earth is much more regular and uniform than the motion of a ship, or any other machine that human art can contrive.

E. I confess it is.—But if the earth turns round, how comes it to pass that a stone thrown directly upward falls down again upon the very same place of the earth from which it was thrown up?—For, considering how large a globe the earth is, the parts of its surface must move very fast to turn round once every twenty-four hours. And if it turns at all, its motion must be eastward; because the sun, moon and stars appear to move from East to West. Now, I should imagine, that a stone or ball, thrown directly upward from any place, would fall as far to the westward of that place, as the place itself has got to the eastward, whilst the  
stone

stone was disengaged from the earth, and rising and falling in the same line.

N. Your observation is very sensible.— But you ought to consider, that any body which is put into motion will persevere in that motion till some thing or other turns it aside, or stops its course. The stone partook of the earth's motion before it was disengaged therefrom: the person who took it up had the same motion, by which means it was still communicated to the stone; and therefore its motion was as quick eastward while it was rising and falling in the open air, as the earth's motion is: so that it could not miss falling down again upon the same part of the earth: And, although it would have appeared to a spectator to ascend and descend in the same perpendicular line, yet its real motion was in a curve, and would manifestly have appeared so to an observer at rest in the open air, on whom the earth's motion had no effect.

If a large boat was sailing along, near the shore, two persons opposite to one another in the boat might toss a ball to each other, over and over across the boat, to catch

catch for their diversion; and they would imagine it to be only going to and fro, from one person to the opposite, always in the same line; whereas 'tis certain, that the progressive motion of the ball, going from one side to the other, would be equal to the progressive motion of the boat; for, if it was not, the opposite person (who had a progressive motion) could not catch it. And although it would appear to all the people in the boat to move forward and backward in the same line, yet, to an observer on the shore, who is no way affected by the motion of the boat, the ball would be seen to have a zigzag motion, never returning to either person in the same line in which he tossed it toward the other.

*E.* You have fully convinced me that there is nothing conclusive in my argument against the earth's motion.—And, in confirmation of what you said about a body's being put in motion, that it will naturally persevere therein, till some cause or other turns it aside or stops its course, I had once the experience thereof, and very painful it was. For, crossing our river in the boat, I stood up when it was  
about

about half way over; and as its motion was uniform by the men pulling the rope, I was quite insensible both of its motion and my own. But when it stopt suddenly against the bank of the river, I fell forward on my face, and was much hurt by the fall. Whereas, if I had not, without knowing any thing of the matter, naturally persevered in the motion given me by the boat, I could not have fallen when it was stopt.

N. Indeed, EUDOSIA, you have given a true philosophical account of the cause of your falling: and now, I think we may, for the present, have done talking of this matter.

E. I think so too; for, speaking of the fall makes me almost imagine I still feel it.—But, pray, how do you prove that the earth is round like a globe?

N. I will prove *that* immediately. The sun shines in through the window—

E. What then?

N. Have patience a minute, and look at *this* small globe in my hand, and the flat circular plate that lies on the table.—You see the globe may be hung by the  
thread

thread which is fastened to it. I now twist the thread, and hang the globe by it in the beams of the sun; and the globe casts a shadow on *that* upright board behind it. You see that the globe turns by the untwisting of the thread; but let it turn how it will, it always casts as round a shadow on the board as if it did not turn at all.—I now fix a thread to the edge of the flat circular plate, and hang the plate by the thread a little twisted. You see, that when the broad-side of the plate faces the sun, it casts a round shadow on the board, as the globe did: but as it turns obliquely toward the sun, by the untwisting of the thread, its shadow is of an oval figure on the board; and, when its edge is turned toward the sun, its shadow on the board is only a narrow straight line.

*E.* All this is plain; but I cannot imagine what you are to infer from it.

*N.* The earth always casts a shadow toward that part of the heaven which is opposite to the sun; and the moon appears as flat to us as the board on which the shadow of the small globe was projected. When the earth's shadow falls upon the

C

moon,

moon, we say, *the moon is eclipsed*. These eclipses happen at all different times of the twenty-four hours; and, consequently, when all the different sides of the earth are successively turned toward the Sun. But the earth's shadow on the moon is always bounded by a circular line; and therefore, it is plain, that the earth must be of a globular shape.—For, if it were shaped like *this* flat circular plate, its shadow on the moon could never be circular, but when its broad-side was turned directly toward the sun. At other times, the shadow would be either of an oval figure, or only a straight line, as you have seen on the board. There are several other ways of proving that the earth is round; but I believe you are satisfied that it is so, from what I have now shewn you.

*E.* I am entirely satisfied, and therefore more proofs would be superfluous. But I should now be glad to know how you prove that the earth turns round; and that the sun does not go round the earth.

*N.* Before I proceed to the demonstration, I will ask you a very plain question, which I hope you will not take amiss,

as

as I have not the least design to affront you.

*E.* Indeed I do not believe you have; and therefore I beg you will ask it.

*N.* Suppose you put a small bird on a spit, and put it to the fire; whether is it the best way to turn the spit round with the bird, or to let the spit stand still, and move the fire round about it?

*E.* Your question almost surprises me;—for, not to speak of the wisdom of *man*, sure no *woman* of common sense could be so absurd, as to set about contriving how to make the large fire and grate be carried round the spit.

*N.* True, *Eudisia*.—Now I can assure you, that the sun is at least a million of times as big as the earth; and is therefore more unfit to be moved round the earth, than a great fire, and the grate that holds it, is to be moved round a small bird on a spit.—And as no *man* in his senses would go to work on such an absurd attempt, would it not be horrid blasphemy to suppose, that the DEITY, who is the very essence of wisdom and perfection, would do so?

*E.* Heaven forbid the thought! the bare mentioning such a thing is enough to chill one's blood.—Were I sure, that the sun could be proved to be a million of times as big as the earth, I should ask no farther demonstration of the stability of the sun and the motion of the earth; because I should naturally conclude, that the sun is a million of times more unfit to move than the earth is. And, as the most superlative degree of wisdom and reason is in the Deity, 'tis impossible for me to imagine he could do any thing that is irrational.—My belief is, that he always makes use of the fewest, most simple, and most rational means, to produce the greatest, most noble, and most astonishing effects; such as his infinite goodness and beneficence to his creatures has rendered conducive to their welfare, in numberless instances.

*N.* He certainly does.—And now I will prove to you, that the earth turns round every twenty-four hours; not upon any material axis, but on an imaginary straight line within itself, passing through its center, and terminating in its North and South points,

points, which are called its *North and South poles*; as an orange would turn round in the open air, if you first set it a-whirling and then throw it off your hand in the air.

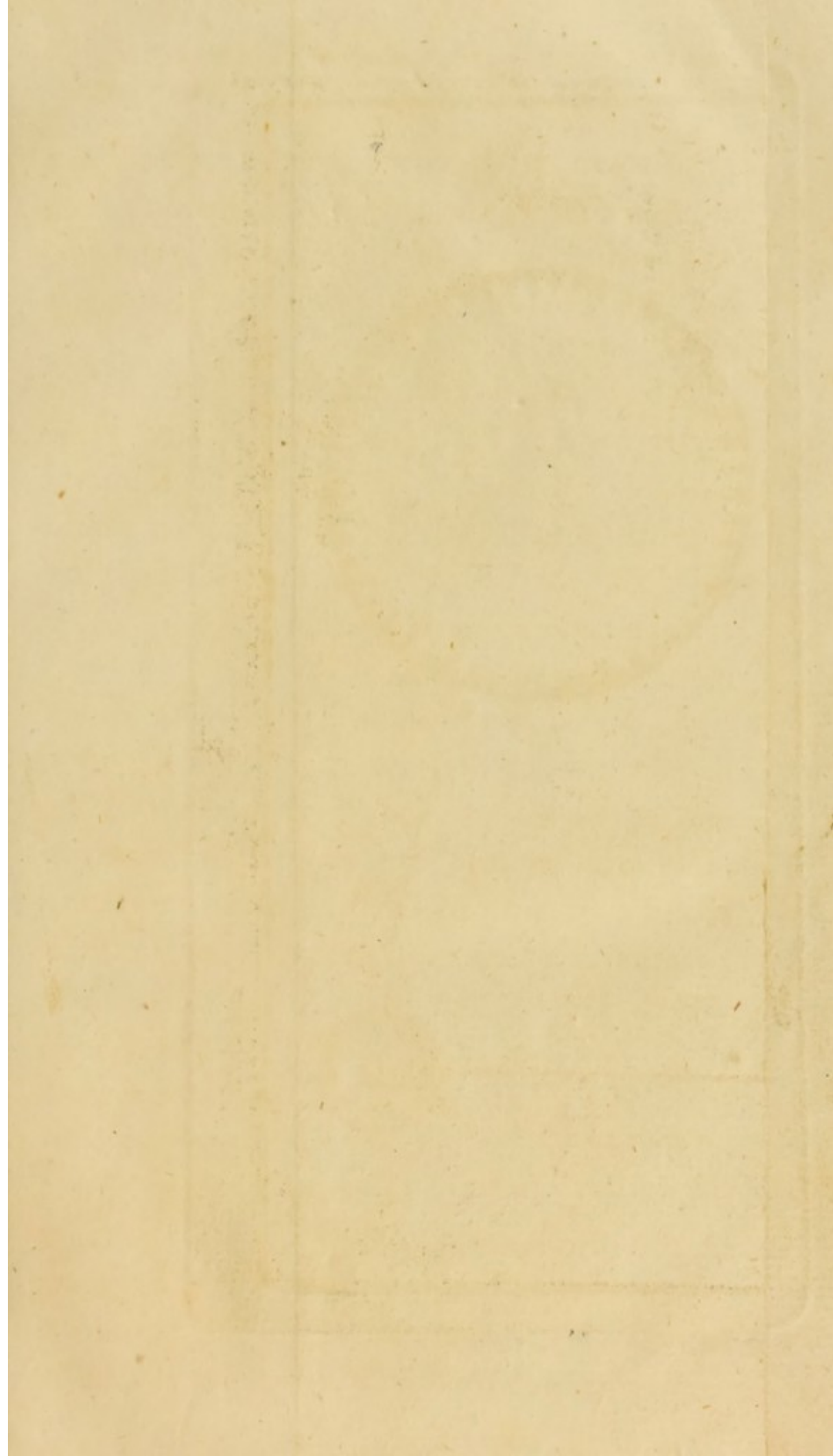
Water naturally runs downward, all around the earth, from those parts which are highest, or farthest from the center, toward those which are lowest, or nearest to it: and this is caused by the power of the earth's central attraction, which draws the water and all other bodies that way. Now, if the earth was perfectly round, and smooth like a polished globe, all the parts of its surface would be equidistant from its center; and water could never run upon it. About three-fourth parts of the earth's surface is covered with the seas, which join or communicate with each other; and if the earth had no motion round its axis or center, the attractive force (which is equal all around at equal distances from the center) would cause the surface of the seas to be of a perfectly round and globular form.

*E.* Undoubtedly it would: for then, as every particle of the water's surface would  
be

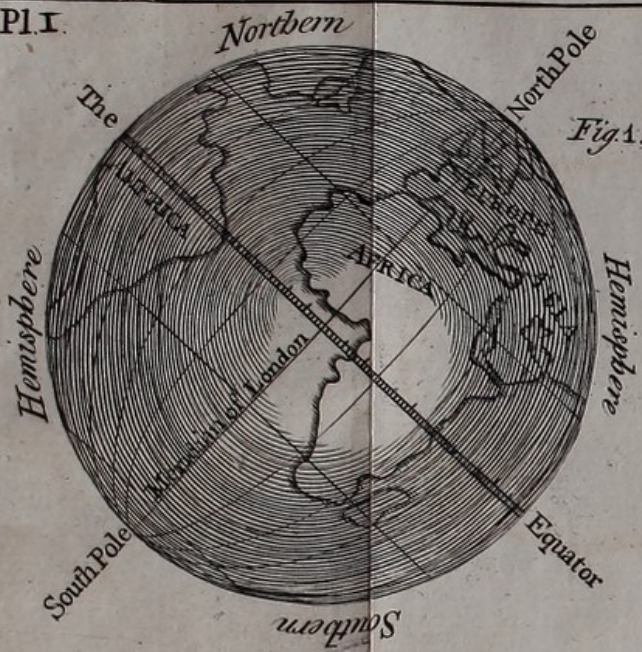
be drawn with equal force toward the earth's center, and these particles do touch each other; none of them could get nearer the center than their neighbouring ones.

*N.* Right.—And now, supposing the earth to be at rest, and the surface of the oceans and seas to be perfectly globular; what do you think the consequence would be, if the earth should begin, and continue to turn round on a line within itself, as if it turned on a real axis?

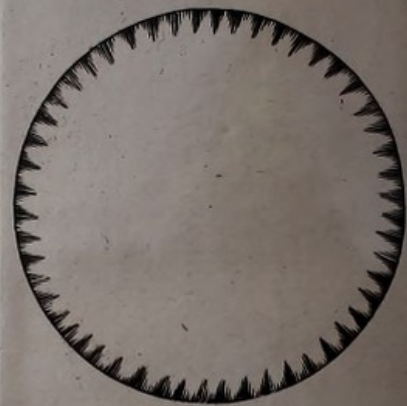
*E.* Let me think a little.—I have observed, that, when our maid took her mop out of a pail of water, the head of the mop was round: but when she began to trundle it on her arm, it immediately became flattened at the parts of the stick which were even with its surface; and it swelled out in the middle.—Pray, brother, if I may be allowed to make a very odd sort of a comparison, may not an imaginary line in the heart of that part of the stick which is within the mop be called the axis round which the mop turns; as you have told me that such a line within the earth, from its North to  
its



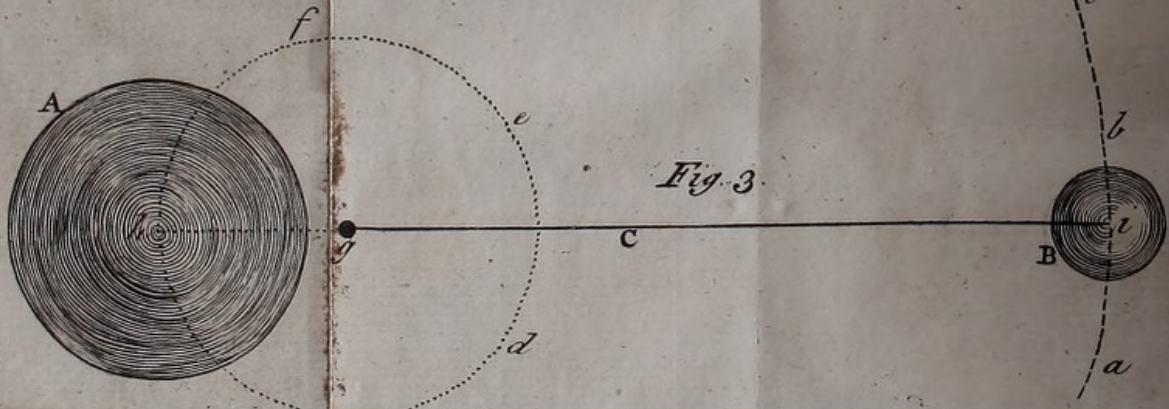
Pl. I.



*Fig. 2.*



*Fig. 3.*



its South poles, is called the axis of the earth?--If so, seeing that the waters on the earth are of as yielding a nature as the cotton of the mop; I apprehend, that, if the earth turned round its axis, the surface of the seas about the poles would become flat, and the surface of the seas which are farthest from the poles would swell out, all round: and so, the figure of the earth would be like that of a whirling mop.

N. No philosopher could have made a more apt comparison, nor have drawn a better conclusion from it. When I told you before, that the earth is round, I did not mean that it is strictly so; although at the distance of the moon it would appear to be round, as its shadow on the moon does to us. I do not here consider the hills as any thing, because they are so little in comparison to the whole bulk of the earth, that they take off no more from its roundness in general, than grains of dust do from the roundness of *that* small three inch globe which you see on the table. *It* is quite round, and covered all over with paper, on which there is a map of the land and water on the earth's surface.

face. The middle line (see Fig. 1. of PLATE 1.) or circle, that is drawn round it, is called the *Equator*, which divides the globe into two equal parts, called *the Northern and Southern Hemispheres*, or half globes. The *North and South Poles* are the *middle points* of the North and South hemispheres, each pole being a quarter of a circle distant from each point of the equator, all around: and a straight line, drawn through the center from pole to pole, is called *the axis* of the globe.

If the thin papers were scraped off from the poles, and almost half way round them toward the equator, the globe would be a little flattened at the poles, and comparatively so much swelled out about the equator; but if it were then viewed from the distance of six or seven feet, it would still appear to be round.

*E.* I believe it would; but what of all this?

*N.* From actual measurement and observation, the earth is proved to be a little flattened at the poles, and swelled out about the equator; the equatorial diameter of the earth being thirty-five miles longer

longer than the axis or polar diameter. This you may think a great deal, but it is very little when compared with the bulk of the earth, as you will easily judge when I tell you, that no less than 25,000 English miles would measure it round: and the highest mountains that are known are not three miles of perpendicular height.—Now, as water naturally runs downward, if the earth had no motion on its axis to keep up its figure, the water of the seas would run from the higher parts about the equator to the lower parts about the poles, and overflow the polar regions for many hundred miles all around; and even Britain itself would be laid several miles under water.

*E.* This is a very plain case: and the not returning of the waters from the seas about the equator is to me an evident proof of the earth's turning round its axis; without which, the surface of the waters would become of a general roundness, as I saw the head of the mop do when the maid left off trundling it.—And now it seems plain, that the Almighty must have made the rigid earth as much

E

higher

higher about the equator than the land is about those places near the poles, as the earth's quick motion about the equatorial parts would cause the waters to rise there. For I see by the globe, that there are great quantities of land about the equator, and many small islands in the seas, which are not overflowed.

*N.* The more you know of these matters, *Eudisia*, still the greater reason you will have to admire the power and adore the wisdom and goodness of the Deity.

*E.* Indeed, brother, I believe I shall.— And I already begin to think, that, if an atheist would be persuaded to learn Astronomy, it would soon cure him of his infidelity.

*N.* So I have often thought, since I knew any thing of the matter.

*E.* I think you told me, that almost three fourth parts of the surface of the earth is covered with seas; and, by looking on *that* small globe, I imagine it may be so. But you have not yet told me, how it is known, that the earth's circumference is 25,000 English miles; and perhaps

haps I should not be able to understand it if you did.

N. The bulk of the earth is ascertained by (what is called) Geometry, and could not have been known by any other kind of learning: and as you do not yet understand any part of that science, I should only confound your head by talking to you on that subject at present.

E. Your saying, “*at present,*” gives me some hopes, that you will endeavour to instruct me in that branch of science afterward.—But can you tell me just now, how many miles of the earth is land, and how many are covered with the seas?

N. The surface of the earthy part of our great globe is divided into four great tracts or spaces, called, *Europe, Asia, Africa,* and *America*; as you see them laid out on the small three inch globe.

According to measurement of the best maps, the seas and unknown parts of land contain 160,522,026 square miles; the inhabited parts 38,990,569; viz. *Europe* 4,456,065; *Asia* 10,768,823; *Africa* 9,654,807; *America* 14,110,874. In all,  
E 2                      199,512,595;

199,512,595 ; which is the number of square miles on the whole surface of our globe.

*E.* I admire the prodigious bulk of the earth ; but infinitely more so, the power that must have set it in motion at first.

*N.* Nothing is great or small but in comparison. We are very big when compared with animals which can be seen only by the help of a microscope : the earth is big indeed when compared with ourselves, who live upon it : the planet Jupiter is a thousand times as big as our earth ; and the Sun is more than a thousand times as big as Jupiter.—If you so justly admire the power that put our small planet the earth into motion, how much more must you admire the power which put the whole planetary system round us in motion !

*E.* I sink into nothing in my own mind. Alas, what have we to be proud of ? If I had been proud before, Astronomy would have cured me effectually of it.

*N.* Indeed it might cure any one of pride : and I believe no astronomer can be

be either proud or impious—But hark! —the bell rings for breakfast; I thought to have satisfied your query about the sun, but must leave it till the next opportunity. Be sure then to put me in mind of it, and afterwards to talk about the solar system.

*E.* I believe I shall have no occasion to remind you

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## DIALOGUE II.

ON THE BALANCE OF NATURE AND THE  
SOLAR SYSTEM.

*Neander.*

WELL, sister; what became of you yesterday after breakfast? I went to my room immediately after, thinking you would follow me, that we might have a little conversation. But, instead of *that*, you have left me quite alone; for I never saw you the whole day afterward except at dinner and supper.

*Eudisia.* Indeed, brother, I was so much pleased with what you told me yesterday morning, that I was willing to make the most and best of it that I could; and therefore employed the rest of my time in writing down every thing that I could remember.

*N.* I am very glad of it: and now I find you intend to emulate a young lady of quality; who, last year, attended a course of lectures on experimental philosophy at Tunbridge Wells; and always, when she went home, wrote down what she had heard and seen. The person who read the lectures informed me, that he was (though with some difficulty) favoured with a sight of the young Lady's manuscript: and assured me, that she had therein given a very good account of the machinery and experiments. I hope you will not refuse to show me your's every day, as you proceed.

*E.* You shall always see it, were it only for this selfish reason, that you may correct and amend what is wrong in it, and then I shall reap the advantage. I will now repeat my yesterday's query: To what is the sun fixed? for you have convinced me that he does not move round the earth.

*N.* The sun is not fixed to any thing at all; nor is it any way requisite he should. I told you that the falling of bodies to  
the

the earth is solely caused by the earth's attraction.

*E.* I remember it very well; and it seems plain to me, that their falling toward the earth's center, on all sides of it, is a demonstrative proof of the earth's attraction. For what else could possibly determine bodies to fall, on opposite sides of the earth, in directions quite contrary to one another?

*N.* Right, *Eudisia*, you are a philosopher already: and I shall have very great pleasure in teaching you, at least, the rudiments of Astronomy.

The tendency of bodies to fall is called their *Gravitation*, and the power which gives them that tendency is called *Attraction*. Now, supposing the sun (PLATE I. *Fig. 2.*) to be the only body that exists in universal space, and that he is put into any part of open space, pray, to what other part of space do you think he would fall?

*E.* I think he could not fall to any other part of space at all; because there would be no other body to attract him: and therefore, I imagine, that he would  
always

always remain where he was placed, *self-balanced on his center*; as my favourite poet *Milton* elegantly expresses it, concerning the earth.

N. Your observation is strictly just. And now, to lead you further on, I tell you, that the sun's attraction reaches many millions of miles all around him; and that all bodies attract each other according to their respective quantities of matter; that is, according to the number of particles of matter they are composed of. I have already told you that the sun is a million of times as big as the earth; and as the sun and earth are within the reach of each other's attraction, whether do you think, that the sun should fall to the earth, or the earth to the sun?

E. I think, that if the sun contains as much more matter than the earth does, as he is bigger than the earth, it is a million times more reasonable, that the earth should fall to the sun, than that the sun should fall to the earth.

N. Right again, sister; but now I must inform you, that the sun is not so compact or dense a body as the earth is; and

therefore he doth not contain as much more matter than the earth does, as he is bigger than the earth. But his quantity of matter is more than 200,000 times as great as the earth's: and, consequently, he attracts the earth more than 200,000 times as strongly as the earth attracts him.

*E.* Then I should think, that the sun and earth would naturally fall toward each other, and come together at last: only, that the earth would fall 200,000 times as fast towards the sun, as the sun would towards the earth.

*N.* And so they would, if there were nothing to hinder them.

*E.* And what is it that hinders them?

*N.* I will begin to answer your question by asking you one.—Did you ever put a pebble into a sling, and whirl it round your head?

*E.* Yes, Sir, when I was a child.

*N.* And did you feel no tendency in the pebble to fly off from the sling?

*E.* O, yes! and the moment I let the string slip from my hand, away the pebble flew,—I likewise remember, that the  
faster

faster I whirled the sling, the greater was the tendency of the pebble to fly off; and that I was obliged to pull the string so much the stronger to keep the pebble from doing so.

N. That observation will be of more service to you by and by, than you at present think of: but it would be too soon to tell you just now how it will.

E. I will wait till you find it proper to tell me. But I am almost impatient to know what you are to infer from the pebble and sling.

N. All bodies that move in circles have a constant tendency to fly off from these circles; which tendency is called their *centrifugal force*. And, in order to keep them from flying off, there must be an *attractive force* at the centers of these circles, equal to the centrifugal force of the moving bodies. The earth goes round the sun once a year, in an orbit or path which is nearly circular; and it would as naturally fly off from its orbit, if the sun did not attract it, as the pebble flew out of the orbit that it described round your

head, when you quitted your hold of the string.

*E.* This is new doctrine to me ; for you never told me before, that the earth goes round the sun. The earth then has two motions, one round its axis in twenty-four hours, and one round the sun in a year.—Can you prove as clearly that the earth goes round the sun, as you have proved that it turns round its axis ?

*N.* I will prove it negatively just now, and positively afterward. If the earth had no motion round the sun, it could have no centrifugal force, to hinder it from falling to the sun, by its own weight or gravitation, which is constituted by the power of the sun's attraction.

*E.* I see that the earth's motion round the sun is indispensably necessary, and am therefore satisfied that it does exist. But I think the sun would require some motion too, in order to give him a centrifugal force ; without which, it seems to me, that, big as he is, the earth's attraction would pull him out of his place. For, I remember, that the pebble and sling pulled

pulled my hand so strongly, although the pebble was small, that I could not possibly keep my hand steady whilst the pebble was in motion.

N. Well done, sister.—The sun really moves in an orbit as well as the earth : and the sun's orbit is as much less than the earth's, as his quantity of matter is greater than the earth's. And, as both these bodies go round their orbits in the same period of time, the sun moves as much slower than the earth does, as his quantity of matter is greater than the earth's. So, what is wanting in the velocity or swiftness of the sun's motion, is made up by his quantity of matter ; and what is wanting in the earth's quantity of matter, is made up by the swiftness of its motion in its orbit : on which account their centrifugal forces are equal to each other's attractions ; and as these attractions keep them from flying out of their orbits by their centrifugal forces, so these forces keep them from falling towards each other by their mutual attractions.—And this is, what we call, *the great balance of nature.*

E. This

*E.* This is a new light to me, and a most delightful one it is. But, although I think I understand it, I wish you would further explain it by a figure.

*N.* Here is a figure (PLATE I. Fig. 3.) which I drew last night on purpose for you; in which, suppose *A* to represent the sun, *B* the earth, and *C* the line of direction in which the sun and earth mutually attract each other: in which line, take a point *g*, as much nearer the center of *A* than the center of *B*, as *B* contains less matter than *A*; the center of *A* being at *h*, and the center of *B* at *i*. If *A* and *B* were allowed to fall against each other, by the power of their mutual attractions, then, in the time that *A* would fall through the space *h g*, *B* would fall through the space *i g*; and both these bodies would meet at *g*, because *B* would fall as much faster than *A*, as its quantity of matter (and consequently its attractive force) is less than that of *A*.

But, in the time the small body *B* goes round the large circle *a b c*, the great body *A* goes round the small circle *d e f*; by which motion, each of these bodies acquires

quires a centrifugal force equal to the attractive force of the other; and the point  $g$  is the center of both the circles which the bodies describe; and is called *their common center of gravity*, or the center of gravity between them.

*E.* I should be glad to know why it is so called.

*N.* I will tell you.—Suppose  $A$  and  $B$  to be two balls of different quantities of matter, and consequently of different weights; and that those balls are connected by a small inflexible wire  $C$ , that has no weight at all (if you can imagine a wire to have no weight, like the immaterial line in which the sun and earth attract each other). Having the wire by a thread fixed to the point  $g$ , which point is as much nearer the center of the great ball  $A$ , than it is to the center of the little ball  $B$ , as the weight of  $B$  is less than the weight of  $A$ : and then, these balls will support and balance each other, like different weights, at the two ends of a common steelyard, by which you have seen meat weighed at home, after it was brought from market. The point  $g$  may represent

represent the center or axis of the steelyard, which bears the weights that are at both its ends. And, as gravity and weight are synonymous terms, the point *g*, or center of the steelyard, is not improperly termed the center of gravity of the weights *A* and *B*.

*E.* I understand you perfectly well; and am much obliged to you for the pains you have taken hitherto, to make every thing so plain to me.

*N.* And, now, if you twist the thread by which the wire and balls are suspended at the point *g*, the untwisting of the thread will cause them both to go round; the great ball in the small circle *d e f*, and the little ball in the great circle *a b c*; and the center of gravity *g* between them will remain at rest.

*E.* From which I infer, that the center of gravity between the sun and the earth is a motionless point.

*N.* And your inference is right.

*E.* I was just going to ask you a question, but am very glad a lucky thought prevented me; for it would have been quite childish.

*N.* Remember

N. Remember what M. *Beaugrand* told you when he began to teach you French; *Never fear, but speak out, right or wrong; if you are wrong I will not laugh at you; I will put you right.*—Now tell me what your intended question was.

E. As we were obliged to hang the wire and balls by a thread, to support their center of gravity; I was just about to ask, what is it that supports the center of gravity between the earth and the sun?

N. Well:—And what was the lucky thought that prevented your asking *that* question?

E. I immediately recollected, that we must support the center of gravity between the two balls, because, otherwise, they would have fallen to the great earth by the power of its attraction. But, as there is no greater body than the sun and earth to attract them, they could fall no way but toward each other: and, therefore, the common center of gravity between them needs nothing to support it.

N. If you had asked the question, I should have told you the very same thing.

*E.* If all the parts of astronomy are as easily learned as those which you have already taught me, I shall have no reason to be vain, even if I become a tolerable good astronomer by your instructions.

*N.* I dare not say they are; but I will make every part of it, which I inform you of, as plain as I can.

*E.* You have already told me that the earth is a planet, and that there are other planets besides, which go round the sun.

*N.* Yes: there are five\* besides our earth: and they are called *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*.

*E.* Then, our sun must be their sun too.

*N.* It is really so; and enlightens them all.

*E.* I could never believe that the Almighty does any thing in vain; and therefore I begin to think, that all the other  
planets

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\* Since this work appears to have been published, two more have been discovered, to one of which Astronomers give the name of the Georgium Sidus.

planets are inhabited as well as our earth. For, to what purpose could the sun shine upon lifeless lumps of matter, if there were no rational creatures upon them to enjoy the benefit of his light and heat?

N. Ay, why indeed?—And I will tell you one thing more, which will confirm your belief that they are inhabited.—They turn round their axis, as our earth turns round its axis; for which plain reason, they have days and nights as our earth has: and the two which are farthest from the sun, namely *Jupiter* and *Saturn*, and which, consequently, have much less light than our earth has, have moons to enlighten them, *Jupiter* four, and *Saturn* five.

E. To me this is a positive proof of their being inhabited; and is enough to make us think, that we are but a small part of the creation, or of the favourites of heaven, and that all the regards of Providence are not attached to our diminutive concerns.

N. The Divine Providence is universal. GOD loves his creatures, as is manifest by what he hath done for us, who, per-

haps, deserve less of his favour than the inhabitants of all the other planets do taken together.—It is as easy to him to take care of thousands of millions as of one individual, and to listen to all their various requests.—On account of his omnipresence, nothing can escape his notice; and on account of his omniscience, nothing can escape his knowledge!

*E.* And, as his omnipotence may be inferred from his works, so I have often thought that his goodness may be inferred from his power. For, as he had power enough to make the world, he certainly has power enough to punish the world: and, consequently, if his goodness were not equal to his power, he would punish us severely for breaking his laws.

*N.* I believe, sister, a more just inference was never made.

*E.* Do all the planets go round the sun in a year, as our earth does?

*N.* No: those which are nearest the sun go soonest round him, and those which are farthest from him are longest in performing their circuits.

*E.* And do they all move round the  
center

center of gravity between the sun and them, as round a fixed point?

*N.* They do.

*E.* Then, as the times of their going round the sun are so various, I cannot see how the sun can describe any regular circle round the common center of gravity between him and them all. For, in order that the sun should move regularly round such a circle, I think all the planets would need to be joined together in one mass.

*N.* 'Tis very true, and we must proceed by degrees. What I showed you by the figure was only on supposition, that there is but one planet belonging to the sun. But as there are six belonging to him, and going round him in very different periods of time, he is only agitated (as it were) round the common center of gravity of the whole system; and describes no regular or perfect circle round it, but is sometimes nearer to it, and at other times farther from it, according as he is attracted by a greater or smaller number of planets toward any side of the heavens.

*E.* In

E. In what times do all the planets go round the sun ?

N. *Mercury* in 87 days, 23 hours, of our time ; *Venus* in 224 days, 17 hours ; the *Earth* in 365 days, 6 hours ; *Mars* in 686 days, 23 hours ; *Jupiter* in 4332 days, 12 hours ; and *Saturn* in 10,759 days, 7 hours : all the same way, from west, by south, to east.

E. And do you know what their distances from the sun are ?

N. Their comparative distances from the sun have been known long ago, both by the laws of nature, and by observation, and are as follow.—If we suppose the earth's distance from the sun to be divided into 100,000 equal parts, *Mercury's* distance from the sun will be equal to 38,710 of these parts ; *Venus's* distance 72,333 ; *Mars's* distance 152,369 ; *Jupiter's* distance 520,096 ; and *Saturn's* distance 954,006.

E. And can you tell how many miles are contained in these parts ?

N. Not so exactly as we could wish ; yet astronomers have come much nearer to the knowledge thereof, by the transit

transit of Venus over the sun, on the 6th of June 1761, and another in the year 1769, than ever they were before.—The method of finding these distances by the transit is purely geometrical; which, as you have not yet learned any thing of geometry, I cannot at present make you understand.

*E.* But, tell me what these distances are, as deduced from the transit in June 1761.

*N.* Mercury's distance from the sun is 36,841,468 English miles: Venus's distance 68,891,486: the Earth's distance 95,173,000: Mars's distance 145,014,148: Jupiter's distance 494,990,176: and Saturn's distance 907,956,130.

*E.* These distances are so immensely great, that I can form no idea of them.

*N.* Then I will endeavour to render them more familiar to you. For we are generally so much used to speak of thousands and millions, that we have almost lost the idea of the numbers they contain.

Suppose

Suppose a body, projected from the sun, should continue to fly at the rate of 480 miles every hour, (which is much about the swiftness of a cannon-ball) it would reach the orbit of Mercury in 8 years, 276 days; of Venus in 16 years, 136 days; of the Earth in 22 years, 226 days; of Mars in 34 years, 165 days; of Jupiter in 117 years, 237 days; and of Saturn in 215 years, 287 days.

*E.* Amazing to think that a cannon-ball would be upwards of 200 years in going from the sun to the remotest planet of the system! The distance must indeed be immense!

*N.* Great as you think it, (and to be sure great it is) yet some of the comets go almost fourteen times as far from the sun as Saturn is: notwithstanding which, they are then nearer to the sun than to any of the stars. For if any comet should go as near to any star as it is to the sun, when farthest from him, it would be as much attracted by that star as it is then by the sun; and its motion being then  
toward

toward the star, it would go on, and become a comet to that star; and we should never hear of it any more.—And now, *Eudisia*, what do you think of the distance of the stars?

*E.* I am lost in wonder;—But supposing there were no comets, pray is there any other way by which we might know that the distance of the stars is so inconceivably great?

*N.* I shall only tell you of one way.—If we are at a great distance from two neighbouring houses, they seem to be small, and at a little distance from one another. But as we approach nearer and nearer to them, they seem to grow bigger and bigger, and the distance between them to encrease. You know this.

*E.* Very well; please to proceed. +

*N.* The earth goes round the sun every year, in an orbit, which is upwards of 190 millions of miles in diameter.—Hence, we are 190 millions of miles nearer to some of the stars just now, than we were half a year ago, or shall be half a year hence: and yet, for all that, the same stars still appear to us of the same  
H magnitude

magnitude, and at the same distance from each other, not only to the bare eye, but also when viewed by the nicest made instruments.—Which shews very plainly, that the whole diameter of the earth's orbit is but a dimensionless point in comparison to the distance of the stars.

*E.* All further proofs of the immense (and, I should think, almost infinite) distance of the stars would be superfluous. But as we were talking about the comets, pray, are they not dangerous?—We are always frightened when we hear of their appearing, lest their fiery trains should burn the world.

*N.* That is owing to people's not knowing better. The orbits of the planets are all nearly in the same plane, (as if they were circles drawn on a flat board) but the orbits of the comets are elliptical, and all of them so oblique to the orbits of the planets, and also to each other, that no comet can ever touch a planet. And as to those appearances, which are called the tails of the comets, they are only thin vapours, which arise from the comets, and which could not hurt any planet, if  
it

it should happen to go through that vapour when the comet is crossing the plane in which the planet's orbit lies. If these trains were fire, we could not see any thing through them that is beyond them. For, if you hold a candle between you and any object, you cannot see that object through the flame of the candle ; but the smallest stars are seen through the tail of a comet.

*E.* This is a comfortable doctrine indeed.

*N.* Besides, you know that the world must be converted to Christianity before it be burned; which, we can hardly believe will be within the time that you and I can live, according to the ordinary course of nature.

*E.* Alas, brother; our people who go into those remote parts where Christianity was never heard of behave so unjustly and cruelly to the poor natives, as might rather frighten them from the christian religion, than induce them to embrace it. I confess I am not at all surpris'd, when I hear, that the native Americans rise sometimes in large bodies, and destroy

those who call themselves Christians, on account of their barbarous ways of using that people.

N. It is not at all to be wondered at : for their principles are *Good for Good*, and *evil for evil*.

E. As it makes me melancholy to think or speak of these things, I beg we may resume our intended subject. Considering how far the planets are from the sun, and in what times they go round him, they must move very fast in their orbits. I should be glad to know how many miles they move every hour.

N. Mercury moves 109,699 English miles every hour ; Venus, 80,295 ; the Earth, 68,243 ; Mars, 55,287 ; Jupiter, 29,083 ; and Saturn, 22,101.

E. And so we are carried 68,243 miles every hour along with the earth in open space, without being in the least sensible of that rapid motion.

N. We are indeed, sister.

E. And can you tell me what the magnitudes of the sun and planets are ?

N. When the distance of an object is known, there are easy geometrical rules  
for

for deducing its real bulk from its apparent bulk.—According to the fore-mentioned distances, the sun's diameter is 893,760 miles, (and consequently he is 1,410,200 times as big as the earth); Mercury's diameter, 3,100; Venus's, 9,360; the Earth's 7,970; Mars's diameter, 5,150; Jupiter's, 94,100; and Saturn's diameter, 77,990 English miles.

The moon's distance from the earth's center is 240,000 English miles, her diameter is 2,170; she moves (with respect to the earth) 2,290 miles in her orbit every hour; and she goes round the earth, from change to change, in 29 days, 12 hours, 44 minutes.

*Jupiter* has four moons going round him in different times and at different distances. His first or nearest moon goes round him in 1 day, 18 hours, 36 minutes; the second, in 3 days, 13 hours, 15 minutes; the third, in 7 days, 3 hours, 59 minutes; and the fourth, or farthest moon from him, in 16 days, 18 hours, 30 minutes.

*Saturn* has five moons, the nearest of which goes round him in 1 day, 21 hours,

19 minutes; the second, in 2 days, 17 hours, 40 minutes; the third, in 4 days, 12 hours, 25 minutes; the fourth, in 15 days, 22 hours, 41 minutes; and the fifth, or outermost, in 79 days, 7 hours, 48 minutes. This planet is encompassed by a broad thin ring, set edge-ways round it, and the distance of the ring from the planet is equal to the breadth of the ring. The sun shines for almost 15 of our years together on the northern side of the ring, then goes off, and shines as long on the southern side of it: so there is but one day and one night on each side of the ring, in the time of Saturn's whole revolution about the sun, which takes up almost 30 of our years.

*E.* A long day and night, indeed, for the inhabitants of the ring, if any such there be. Undoubtedly, if it is inhabited, it must be by things very different from us; as we have no reason to believe but that the DEITY has accommodated their days and nights as well for them as he has ours for us.—But you told me, that the other planets turn round their axis, as our earth does: do they all turn round the

the

the same way, or eastward, so as to cause the sun and stars to appear to go round westward; and in what times do they turn round?

N. By viewing them with good telescopes, we see spots upon most of them, which adhere to their surfaces, and appear and disappear regularly on their opposite sides. By the motions of these spots, which are all eastward, we know that Venus turns round her axis in 24 days, 8 hours of our time; by which divide 225 of our days, the time in which Venus goes round the sun, or the length of her year, and we shall find, that her year contains only  $9\frac{1}{4}$  of her days. Mars turns round in 24 hours, 40 minutes of our time, and Jupiter in 9 hours, 56 minutes. We cannot tell in what times Mercury and Saturn turn round their axis, because no spots have been seen upon them, even by the best telescopes. --The sun turns round his axis in 25 days, 6 hours, from west to east, also.

E. Why should the sun turn round? for, as he is the fountain of light, he can have no days and nights.

N. To

N. To turn away his dark spots from long facing the planets, and thereby to dispenſe his light the more equally all around him to the planets. But, are you not tired by this morning's long converſation ?

E. Far from it, brother, though I am ſure you may. But what ſhall I do ? for I fear I cannot remember much of what you have told me this morning, ſo as to write it down.

N. Never mind that, *Eudolia* ; for I believe I ſhall publiſh theſe our converſations, for the ſake of other young ladies ; many of whom are, no doubt, willing to learn Aſtronomy, but have no body to teach them. And then you can have the whole together in print.

E. If you do, Sir, I muſt inſiſt upon your not mentioning my name.

N. Your deſire ſhall be complied with : and in concealing your real name, I ſhall alſo conceal my own.

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### DIALOGUE III.

#### ON GRAVITY AND LIGHT.

*Neander.*

SO, sister ; I find you are not willing to slip the morning opportunity, when we can be undisturbed, and by ourselves. Have you made any remarks upon our last conversation ?

*Eudisia.* Yes, brother.—In the first place, I remember you told me, that the planet *Mercury* moves 109,699 miles every hour in its orbit, and *Saturn* only about 22,000. I observed likewise, that the further the planets are from the sun, they not only take longer times to go round him, but also move slower in every part of their respective orbits. Can you assign any reason for this ?

I

N. The

*N.* The nearer that any planet is to the sun, the more strongly it is attracted by the sun; the farther any planet is from the sun, the less is the force of the sun's attraction upon it. And, therefore, those planets which are the nearer to the sun must move the faster in their orbits, in order thereby to acquire centrifugal forces equal to the power of the sun's attraction: and those which are the farther from the sun must move the slower, in order that they may not have too great a degree of centrifugal force for the weaker attraction of the sun at those distances.

*E.* Then I understand, that the sun's attraction, at each particular planet, is equal to the centrifugal force of each planet; and, by that means, the planets are all retained in their respective orbits. Is it not so?

*N.* Accurately so.

*E.* Then, as the power of the Deity is manifest, in having set off such large bodies as the planets are, with such amazing degrees of velocity; so his great wisdom is conspicuous, in having so exactly adjusted their velocities, and, consequently,

ly,

ly, their centrifugal forces, to the different degrees of the sun's attraction at the distances the planets are from him.—Here is a wonderful balance indeed! Can there be an atheist?—I am sure no man could be so, after hearing such things as you have told me of.

*N.* Tis sad there are atheists; but they must all be stupid fools.—The Almighty has laid the great book of nature open to our view; so that, every one that runs may read. Supposing matter had existed from eternity, (which by the bye, is too great a compliment to be paid to matter) I imagine the greatest atheist in the world could hardly bring himself to believe that stones could have hewed themselves, bricks made themselves, trees shaped themselves into beams and boards, and mortar made itself; and then all these materials have jumbled themselves together, so as to build a house. And what is a house in comparison to a planetary system; or the skill required to build it, when compared with the organization of any insect?

*E.* Nothing at all.—But I am apt to lead you into digressions. Doth the  
 1 2 power

power of the sun's attraction decrease in proportion as the distance from him increases?

N. No: his attractive force diminishes in proportion as the squares of the distances (that is, as the distances multiplied by themselves) from him increase. So that at twice the distance from the sun's center, his attractive force is four times less: at thrice the distance, it is three times three times, or nine times less; at four times the distance, the attraction is four times four times, or sixteen times less; and so on.—And this we find, from the comparative distances of the planets from the sun, and their different velocities in their orbits: besides, I have often seen this experimentally confirmed by a machine called *the whirling-table*.

E. If I understand this; supposing there are four planets so placed, as that the distance of the second from the sun is twice as great as the distance of the first; the distance of the third, three times as great; and the distance of the fourth, four times as great as the distance of the first: the fourth will be attracted only with a sixteenth

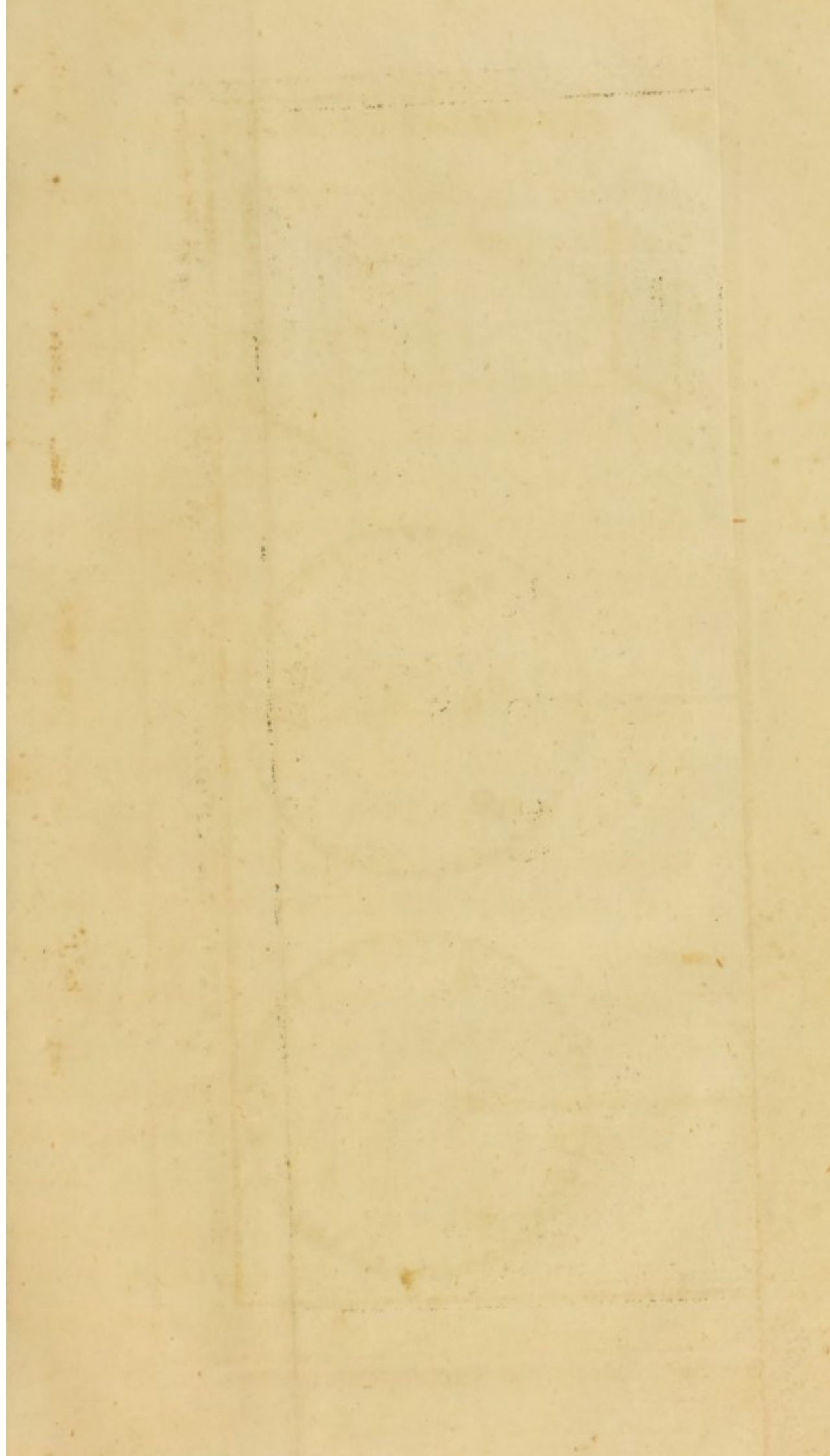


Fig. 1.

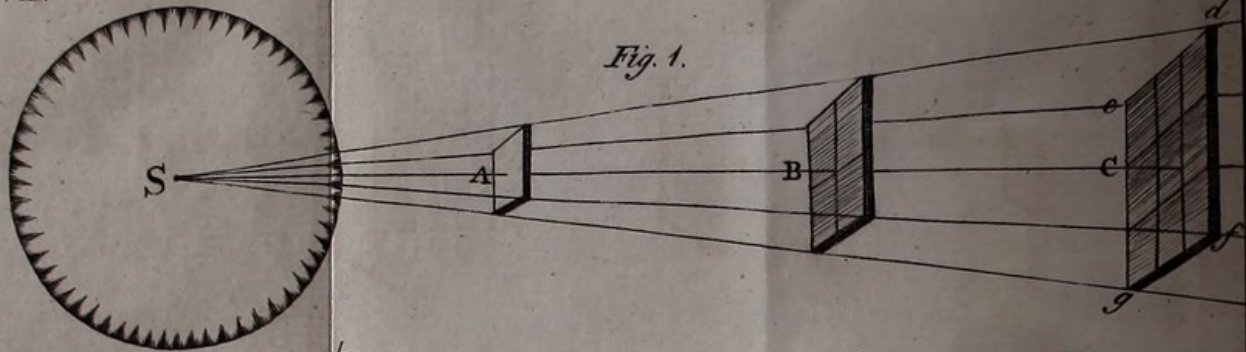


Fig. 2.

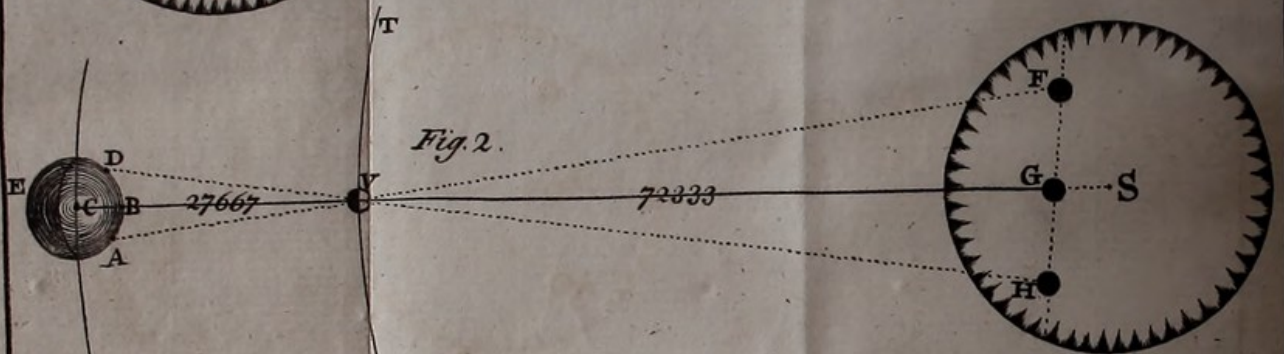
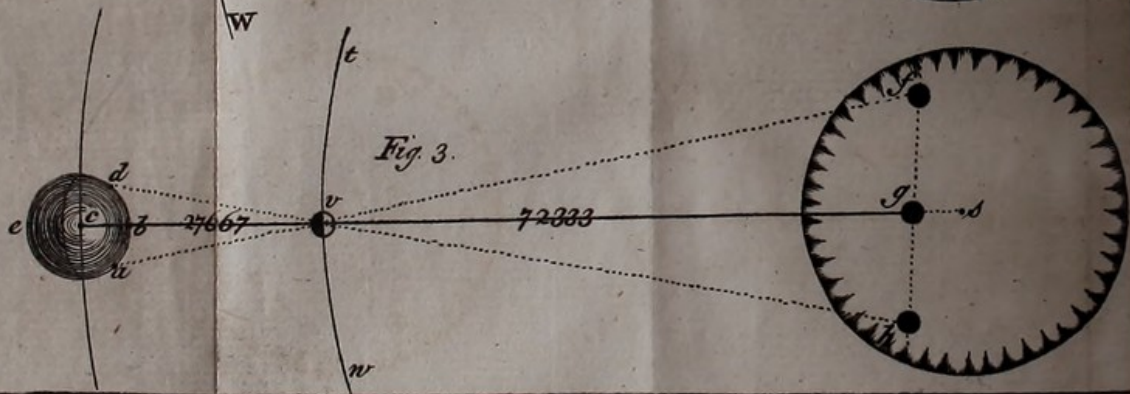


Fig. 3.



teenth part of the force wherewith the first is attracted ; the third only with a ninth part of the force ; and the second with only a fourth part of the force that attracts the first.

N. Exactly so.

E. I should be glad to know the reason why the sun's attraction decreases in proportion to the squares of the distances from him. Why do you shake your head?

N. Because you ask me a question which Sir ISAAC NEWTON himself could not solve ; although he was the prince of philosophers.

E. But can you give me no idea at all of it?

N. I could ; and a very plain one too, if the attractive force (the effect of which we call gravity) acted only according to the surface of the attracted body.

E. Your *if* implies that it does not : but if it did, why should it decrease in that proportion ?

N. I have drawn a figure for your inspection (PLATE II. *Fig. 1*) which indeed is for a quite different purpose : but it would

would exactly solve your question, if gravity acted as all mechanical causes do; only on the surface of bodies.

Let  $S$ . be the centre of the sun; and  $Sd$ ,  $Se$ ,  $Sf$ ,  $Sg$ , be, as it were, lines of attractive force, drawing the three square plates,  $A$ ,  $B$ , and  $C$ , towards  $S$ . These lines touch only the four corners of the plates; but we may suppose the whole space within them to be full of such attractive lines; laying hold of all the parts, or points (if you will) of the surface of each plate; and every particle of matter in each plate requiring an equal degree of power to draw it equally fast toward the sun.

Now, let the plate  $B$  be twice as far from the sun's center as the plate  $A$  is; the plate  $C$  three times as far, and the attractive forces equal on each plate, as if the above mentioned four lines  $Sd$ ,  $Se$ ,  $Sf$ , and  $Sg$ , were four cords, equally stretched, and pulling all the plates with equal forces toward  $S$ .—But, the plate  $B$  being twice as long, and twice as broad as the plate  $A$ , it is plain, by the figure, that  $B$  contains four times as much surface as  $A$  does, and four times as great a quantity  
of

of matter, supposing it as thick as  $A$ ; and the plate  $C$ , being three times as broad, and three times as long as  $A$ , contains nine times as much surface and matter as  $A$  does, supposing it of an equal thickness with  $A$ .

Suppose now, that the intermediate lines of attraction, between the four corner lines, are so close together, as that they lay hold of every point of the surface of  $A$ , and draw it toward  $S$  with all their force; it is plain, that they can only lay hold of every fourth point of the surface of  $B$ , and of every ninth point of the surface of  $C$ ; so that, the plate  $B$  will want three fourth parts of the attraction that would be sufficient to draw it toward  $S$  as fast as the plate  $A$  is drawn; and  $C$  will want eight ninth parts of the attraction that would be sufficient to make it move as fast as  $A$  toward  $S$ .

*E.* I see this very well: but, if gravity acts not according to the quantity of surface, pray how doth it act?

*N.* Exactly in proportion to the solid contents of bodies; that is, to the quantities of matter they contain. For, you know,

know, that if you would take the plate *C* as it is, and weigh it in a balance; then take it out, and cut it in the lines drawn on its surface, by which means you would divide it into nine square pieces: if you then lay them above one another in the scale, they will be just as heavy as they were before, when they lay at each other's edges, all in one piece, in the scale. Or, if you suppose them to be so cut, and then joined together at each other's backs, and put them at the distance *Sc* from the sun, as before; they will have only a ninth part of the surface toward the sun as before: and yet, the sun's attractive force on them will be just the same.

*E.* Then, it seems, there is no way of accounting for the manner in which gravity acts, but by resolving it into the will of the Deity; seeing that the quantity of surface has nothing to do in the case.

*N.* Indeed there is not. And, therefore, when I henceforth speak of gravity, I would have you always understand, that I do not thereby mean a *Cause*, but the *effect* of a cause, which we do not comprehend.

hend. Besides, you know, that if gravity acted according to the surfaces or bulks of bodies, a cork would be as heavy as a piece of lead of the same bulk as the cork.

*E.* Very true.—But, as you told me that the figure we have been looking at was not intended to shew how gravity acts; may I enquire what you intend to teach me by it; as you said you drew it for me?

*N.* It is to shew, that the light of the sun, or of any other luminous body, decreases in proportion as the square of the distance from the luminous body increases. The rays of the sun's light go out in straight lines from all points of the sun's surface: and, consequently, the farther they go off from the sun, the more they spread; and so they cover the more of the surfaces of bodies at the greater distances.

*E.* How is it known that light moves in straight lines?

*N.* Because, if we endeavour to look at the sun, or at a candle, through the

bore of a bended pipe, we cannot see it ; but through a straight pipe we can.

*E.* Enough, Brother ; please now to explain the figure.

*N.* Let *S* be the sun's center, and *S d*, *S e*, *S f*, *S g*, be four rays of light, going out from the sun's surface in straight lines (in the same direction as if they proceeded from the center), and suppose the space within these rays to be filled with others. Take the distances *S A*, *S B*, *S C*, from the sun's center, so as *S B* shall be twice as great as *S A*, and *S C* thrice as great. Then, at the distance *S A* place the little square plate *A*, on which all the rays will fall that fill the above-mentioned space at *A*. At the distance *S B*, place the square plate *B*, which being twice as long and twice as broad as the plate *A*, it contains four times as much surface as *A* does : and if *A* be taken away, all the light that fell upon it, will fall upon, and cover the whole surface of *B* ; which being four times as large in surface as *A* is, and having only as much light upon it  
as

as *A* had, every point of the surface of *B* can have no more than a fourth part of the surface of *A*. And, lastly, at three times the distance *SA*, place the square plate *C*; which being three times as long and three times as broad as the plate *A*, it contains nine times as great a surface: and then if *B* be taken out of the way, so as to let all the light that fell upon it go on to the plate *C*, the light will just cover the surface of that plate; which being nine times as large as the surface of *A*, and having no more light upon it than *A* had, 'tis plain, that the light upon every point of *C* is but a ninth part so strong and vivid as it was upon every point of *A*.

*E.* Nothing can be plainer than this: and it follows of course, that at four times the distance of *A* from the sun, his light is sixteen times weaker than at *A*; at five times the distance, it is twenty-five times weaker: and so on. I thank you for making this so plain.

K 2

N. Indeed

*N.* Indeed I deserve none of your thanks for it. I copied the figure from doctor Smith's Optics. That worthy gentleman was my good old master; and he is master of Trinity College in Cambridge.

*E.* Seeing that the comparative distances of all the planets from the sun are known, I make no doubt but you can tell me, what the comparative quantities of the sun's light on all the planets are.

*N.* Very easily.—The sun's light is seven times as great on Mercury as on the Earth; about twice as great on Venus; at Mars, it is not half so great, or strong, as we have it on the Earth; at Jupiter, only a twenty-eighth part so strong as at the Earth; and at Saturn, is but about a ninetieth part so strong as with us.

*E.* Then, I should be almost tempted to think—but I cannot—will not indulge such a thought, as that the Deity is partial: for I cannot imagine the inhabitants of our Earth to be better than those of the other planets. On the contrary,

trary, I would fain hope they have not acted so absurdly with respect to him, as we have done.

*N.* Tell me freely what the thought was that arose in your mind, which you are so willing to suppress.—The Deity is no other way a respecter of persons, than that of properly distinguishing between the good and the bad; and so rewarding the one, and punishing the other accordingly.

*E.* It seemeth to me, that the inhabitants of the nearest planets to the sun must be blinded by too much light; and that those of the farthest planets from the sun must be punished all their lives with so weak a light, as can be called little better than darkness.—We could not bear seven times as much light as we have from the sun; nor be able to do our work with only a ninetieth part of the light we have.

*N.* Your reflection, sister, is very natural. But, after asking you two or three plain questions, I believe I shall be able

able to give you full satisfaction on that head.

*E.* Pray ask them, and I will answer them if I can.

*N.* After you have been a while out in the snowy street, can you see as well to work with your needle immediately on coming into your room, as you did before you went out ?

*E.* No.

*N.* Can you bear the strong reflection of the sun's light from the snow, just as well when you have been walking half an hour in it ?

*E.* No.

*N.* Can you give such a reason for this as would satisfy a philosopher ? For you know that the snow reflects not less light for your having been a while walking in it ; nor is your room a bit the darker for your having been out of it.

*E.* I wish I could, but indeed I cannot.

*N.* Then

N. Then I will tell you.—Our eyes are made so, that their pupils (which let in the light, whereby we see objects) dilate when the light is weak, that they may take in the more of it; and contract when the light is strong, that they may admit the fewer of its rays.—Whilst you are in your room, the pupils of your eyes are dilated; and for that reason, when you go out, they take in too much of the light reflected from the snow, which you find is hurtful. But they soon contract so, as to admit no more of that strong light than you can easily bear.—And then, when you come into your room, with the pupils of your eyes contracted, the room, being not so light as the street, appears darker to you than it did before you went out: but, in a short time, the pupils dilate again; and then they let in a sufficient quantity of light for you to work by.

Now, supposing all the other planets to be inhabited by such beings as we are, (though, for reasons I shall mention afterwards, we cannot believe they are)

are) if the pupils of their eyes who live on the planet Mercury are seven times as small as ours are, the light will appear no stronger to them there than it doth to us here. And if the pupils of their eyes who live in Saturn are ninety times as large as ours, (which they will be, if they are nine times and an half as large in diameter as ours; and which will appear to be no deformity where all are alike, and other forts have never been seen) the light there will be of the same strength as it is to our eyes here.—Pray, *Eudisia*, how many full moons, do you think, would there need to be placed in a clear sky, to afford us moon-light equal to common day-light, when the sun doth not shine out, and all our light is by reflection from the clouds?

*E.* Indeed, I cannot tell:—but am apt to think, that fixty or an hundred, at most, would do. For, when the full moon is not clouded, she shines so clear, that I can read by her light.

*N.* Sixty, or an hundred!—I assure you, that you are greatly mistaken: for  
it

it would require ninety thousand ; and *that* number would fill the whole of our visible sky.

*E.* You amaze me ; but I know you will not deceive me. Pray, how can you find any method of comparing moonlight with day-light, so as to ascertain the great difference between the quantities thereof ?

*N.* Have you never observed the moon pretty high up in the morning after the sun was risen, when the moon was about three quarters old ?

*E.* Yes, brother : and when I have seen her, as it were, among whitish clouds, she appeared much of the same colour as they did ; very dim in comparison with what she appears in the night.

*N.* And yet, she was just as bright then as she is in the night ; only the superior light of the day made her seem so much otherwise. Like a candle, which appears very bright in the night-time ; but set it in the street in daylight, and it will seem very dim, al-  
L though

though its real brightness is still the same.

*E.* I think I could almost tell what you are to infer from all this ; but will not speak, lest I should be mistaken again. And therefore I beg you will proceed.

*N.* When the sun is hid by clouds, all the light we have is by reflection from them. The moon reflects the sun's light in the night-time, as the clouds do in the day : and as she can reflect no more light in the day than a small bit of a whitish cloud does, that covers as much of the sky, as the moon covers, she can reflect no more in the night.—And as the full moon fills only a ninety-thousandth part of the sky, her light is no more than equal to a ninety-thousandth part of the common day-light. Now as the light of the sun at Saturn is equal to a ninetieth part of his light at the earth, and common day-light at the earth is 90.000 times as great as moon-light ; divide 90,000 by 90, and the quotient will be 1,000 : which shews, that

that the sun's light at Saturn is 1000 times as great as the light of the full moon is to us.

*E.* I see plainly that it must be so.—  
Oh!

*N.* Why do you sigh, *Eudisia*?

*E.* Because there is not an university for ladies as well as for gentlemen. Why, *Neander*, should our sex be kept in total ignorance of any science, which would make us as much better than we are, as it would make us wiser?

*N.* You are far from being singular in this respect. I have the pleasure of being acquainted with many ladies who think as you do. But if fathers would do justice to their daughters, brothers to their sisters, and husbands to their wives, there would be no occasion for an university for their ladies; because, if those could not instruct these themselves, they might find others who could. And the consequence would be, that the ladies would have a rational way of spending their time at home, and would have no taste for the too common and expensive

ways of murdering it, by going abroad to card-tables, balls and plays: and then, how much better wives, mothers, and mistresses they would be, is obvious to the common sense of mankind.—The misfortune is, there are but few men who know those things: and where that is the case, they think the ladies have no business with them; and very absurdly imagine, because they know nothing of science themselves, that it is beyond the reach of women's capacities.

*E.* But, is there no danger of our sex's becoming too vain and proud, if they understood these things as well as you do?

*N.* I am surprized to hear you can talk so oddly.—Have you forgot what you told me two days ago? namely, that if you had been proud before, the knowledge of Astronomy, you believed, would make you humble?

*E.* You have caught me napping, as the saying is:—but I will not take up more of your time at present with digressions. I remember, this morning,  
to

to have heard you mention the light's *going* from one place to another, as if it took some time in moving through open space. I know that sound does so; because I have seen the flash of a distant cannon before I heard the noise that it made.

N. True, sister; and you did not see the flash at the very instant when it was given; though you saw it very soon after.

E. And do you know with what degree of swiftness light moves?

N. Yes; and you shall soon know too. The Earth's orbit lies far within the orbit of Jupiter.

E. Undoubtedly; because Jupiter is much farther from the sun than the Earth is.

N. Then you know, that when the Earth is between Jupiter and the sun, the sun and Jupiter appear opposite to each other in the heavens. And when the sun is nearly between us and Jupiter, the sun and Jupiter appear nearly in the same part of the heavens.

E. Undoubtedly

*E.* Undoubtedly they must.

*N.* And therefore, when the sun and Jupiter appear almost close together, the Earth is almost the whole diameter of its orbit farther from Jupiter, than when it and Jupiter appear opposite to each other in the heavens.

*E.* Certainly.

*N.* The times when Jupiter's moons must be eclipsed in his shadow are easily calculated; because, by telescopic observations, the times in which they go round him are accurately known; and the apparent vanishing of these moons in the shadow may be very well perceived through a telescope; or the instants when they recover their light again, by the sun's shining upon them, at their going out of the shadow. And it has been always observed, since telescopes were invented, that these eclipses are seen sixteen minutes sooner when the Earth is nearest to Jupiter, than when it is farthest from him. So that, if there were two Earths moving round the sun in the same orbit, and always keeping opposite

opposite to each other; when one of them is at its least distance from Jupiter and the other at its greatest, an observer on the nearest would see the same eclipse sixteen minutes sooner than an observer on the farthest would. Which shews, that light takes sixteen minutes to move through a space equal to the width or diameter of the earth's orbit, which is 190 millions of miles. And, consequently, it must take eight minutes of time in coming from the sun to the earth, as the sun is nearly in the center of the earth's orbit: that is, at the half of 190 millions of miles, or 95 millions of miles from the earth.

*E.* I understand this; but a difficulty rises in my mind.

*N.* Only mention it, and I will remove it if I can.

*E.* The rays of the sun's light come directly from him to the Earth; but his rays from Jupiter's moons come to us only by reflection. Are you sure that reflected light moves with the same velocity that direct light does?

*N.* There

N. There is no reason to believe but that it does. And I imagine, I can very easily convince you that it does so.

If the particles of light did not fly off from the planets as fast as they came upon them, there would still be an accumulation of light upon them; which would make them appear every night brighter and brighter; but, in reality, they do not. And if the light flew off faster from the planets than it comes upon them, they would appear dimmer and dimmer every night; which is not at all the case.

E. But are *all* the rays which the sun darts on any planet *reflected* from it, and none of them lost or *absorbed* in the matter of which the planet is composed? Or, if *some* of them be absorbed, will not this invalidate your argument?

N. Not at all, if the *absorbed* rays bear a constant proportion to the *whole* number of rays with which the planet is successively illuminated; and this must undoubtedly be the case; for the same parts of the planet's surface which either re-  
flect,

fect, or absorb the rays that fall upon them *this* moment, will be equally disposed to reflect or absorb the rays that fall upon them in the *next*: and so the *same proportion* between the absorbed and reflected rays, or between them and the whole quantity of light thrown on the planet, will be continually preserved.

*E.* But what if some parts of the planet's surface be more hardened by drought, or softened by wet, as on our earth; or be in any other respect more disposed, either to reflect, or absorb the Sun's rays at some times than at others; would not this vary the proportion you have mentioned?

*N.* If we may judge of this from our own globe, where the contrary qualities of drought and wet, hardness and softness, smoothness and roughness of some parts of its surface, so far as they result from any alterations of *weather*, &c. if taken upon an average for a whole year, or other given time, and throughout any half of the Earth's surface; they will, very nearly, if not exactly, balance

each other. The same may be therefore supposed to hold good in the other planetary worlds; and so the proportion before mentioned will not be sensibly altered.

*E.* You have quite removed my difficulty, brother; and I thank you for having done it. But, as light comes from the Sun to the Earth in eight minutes of time, its swiftness must be amazingly great. Let me try whether I can compute it: for you taught me not only the four common rules of arithmetic before you went to the university, but even the rule of three. The Sun's distance from the Earth is 95 millions of miles, in round numbers; and light moves] through that space in 8 minutes of time; divide, therefore, 95,000,000 by 8, and the quotient is 11,875,000 for the number of miles that light moves in a minute. Now, I remember that you told me a cannon-ball moves at the rate of 480 miles in an hour, which is 8 miles in a minute; I therefore divide 11,875,000 by 8, and the quotient is

is 1,484,375 ; so that light moves more than a million of times as swift as a cannon-ball.—Amazing indeed!

*N.* It is so :—And now I will tell you something which is full as amazing.

*E.* What can that be : do you mean the power of the Almighty ?

*N.* Far from it : I only mean the inconceivable smallness of the particles of light.

*E.* And how do you know that they are so inconceivably small ?

*N.* The force with which a body strikes any obstacle is directly in proportion to the quantity of matter in the body, multiplied by the velocity with which it moves. And, consequently, as the velocity of light is, in round numbers, a million of times as great as the velocity of a cannon-bullet ; if a million of the particles of light were but as big as a common grain of sand, we could no more keep our eyes open to bear the impulse of light, than we

could to have sand shot point blank against them from a great cannon.

Another way of proving that the particles of light are so small as to exceed all human comprehension is this: Let a lighted candle be set on the top of a spire steeple, in the night-time, and there will be a very large spherical space filled with the light of the candle before a grain of the tallow be consumed; and as *that* grain of tallow is divided into so many particles, as fill all the space in which the light is diffused, can you possibly imagine how small the particles are into which it is so divided?

*E.* Indeed I can form no idea thereof.

*N.* A very good computist has found, that the particles of blood of those animals which can only be seen by means of a microscope, are as much smaller than a globe whose diameter is only a tenth part of an inch, as that small globe is less than a whole earth. And yet, that their particles of blood are like  
mountains

mountains to a grain of sand, when compared with the particles of light.

*E.* I am glad to hear our breakfast-bell: for, if I should hear more of these subjects at present, I know not but what I should, for some time, lose the power of thinking.

*N.* I had just done with the subject of light; but am sorry to hear that you must go from home, for a few days, on a visit. However, during your absence, I intend to draw out two or three figures, in order to describe the late transit of Venus to you by them: and give you some idea of the method by which the distances of the planets from the Sun were found, by observations made on that transit.

*E.* I am very much obliged to you, Sir, for the trouble you have taken, and are to take further, on my account: and shall return as soon as possible.—You know I could not refuse Miss Goodall's invitation.

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## DIALOGUE II.

*On the Transit of VENUS, June 6th 1761; and how the distances of the PLANETS from the SUN were found thereby.*

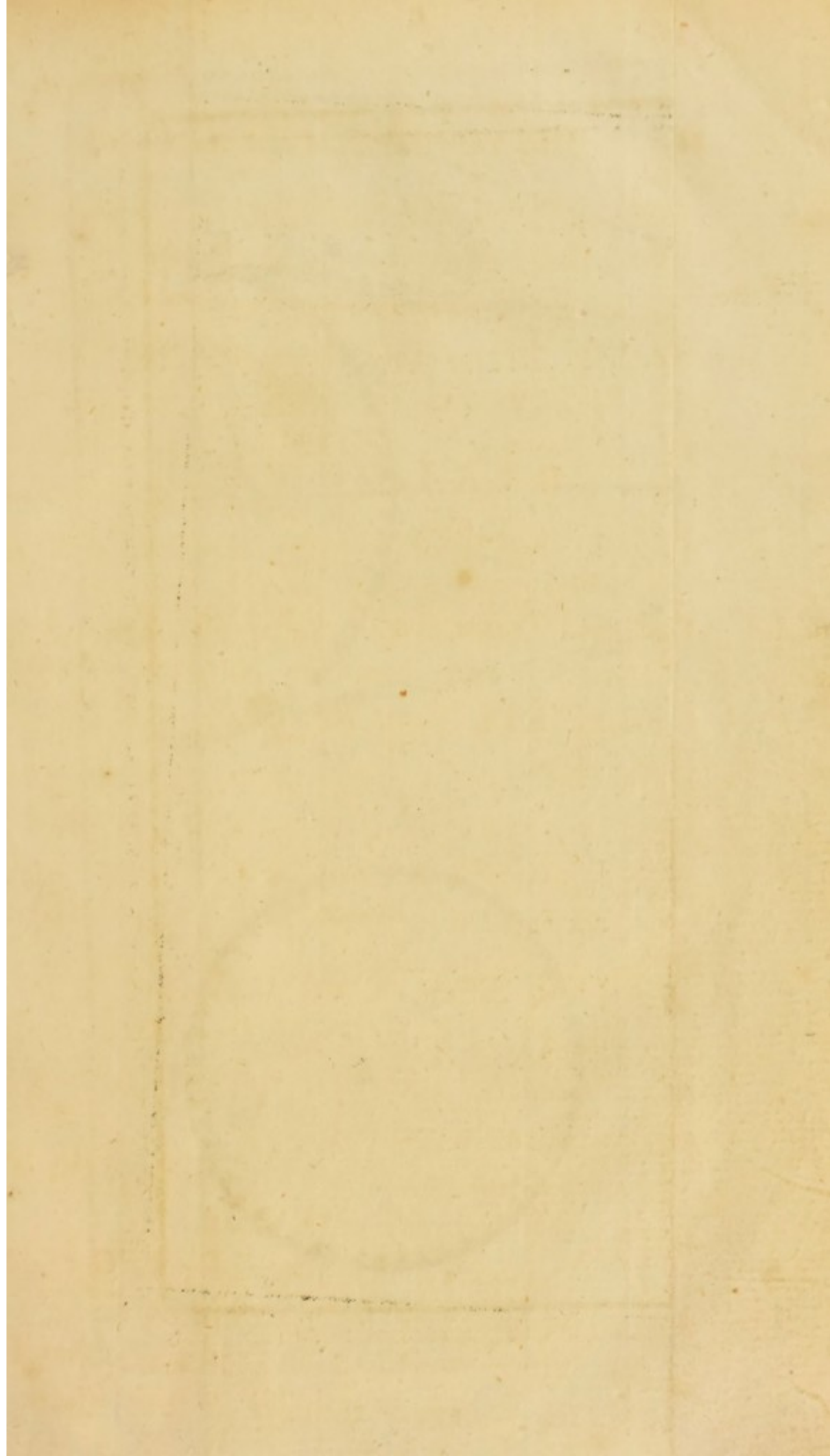
*Neander.*

DEAR Sister, I am very glad to see you again: I suppose you found Mr. and Mrs. Goodall, and their daughters, to be very agreeable company.

*Eudosia.* Quite so, and I have spent three days very happily with them.

*N.* It is very obliging in Mr. Goodall and Miss Sophy to see you safe home.

*E.* They would do it, for all that I could say: even though I told them,  
that



Pl. III.

Fig. 1.

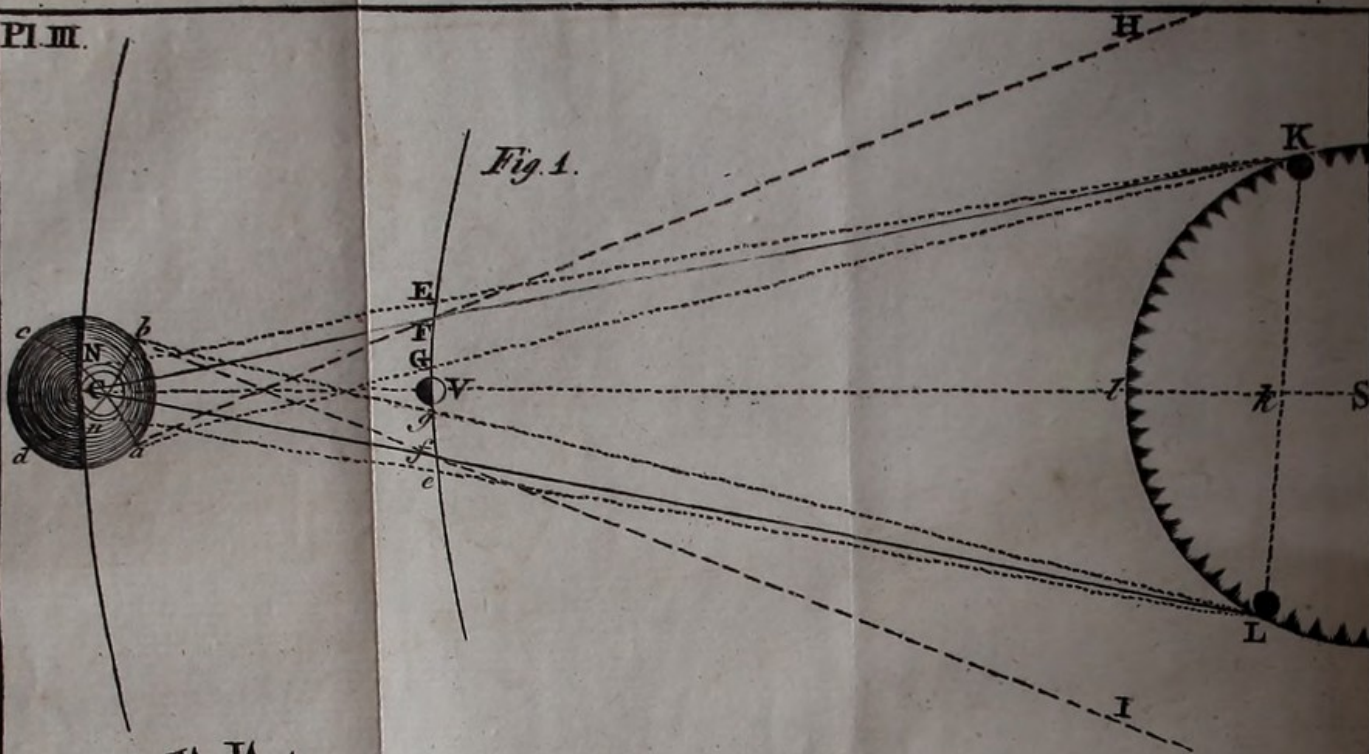
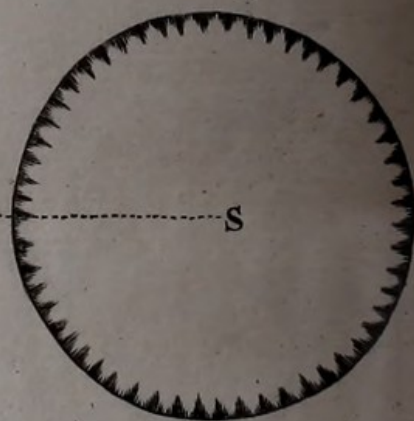
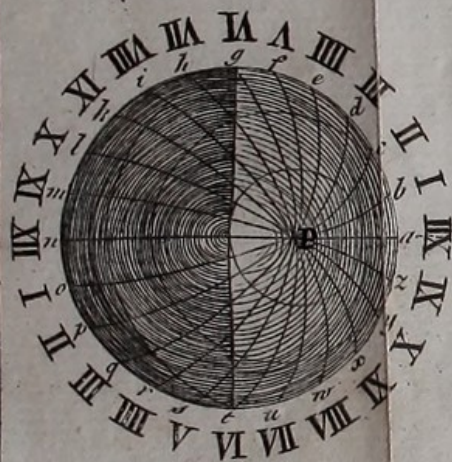


Fig. 2.



that the servant who was sent for me was very careful.

*N.* Mr. *Goodall* and I spent an hour together last night: and though he was full of his praises of your good sense, he did not say one word about your astronomical conversations; by which, I imagine, you spoke nothing about them in that family. Yet I am far from doubting, that it would have been very agreeable if you had.

*E.* Truly, brother, if I had, you must have heard of it: and then I should not have wondered if you had said that I am not over-stocked with good sense. I must know these things better before I begin to speak of them; and even then, not to speak, unless I am desired by those to whom I think the subject will be entertaining. You told me, the morning I went away, that our next conversation should be on the transit of Venus; and how the distances of the planets from the Sun were found thereby.

*N.* And

N. And to shew you that I have not forgot my promise, here are the figures which I told you I would draw out for that purpose. [See PLATE II. *Fig. 2. and 3. and* PLATE III. *Fig. 1.*] But, in these delineations, we must often sacrifice one truth to explain another: and in the present case it is unavoidable. For, if we were to make the bulks of the planets in our figure no greater than they are in proportion to their distances from the Sun, the planets would be mere points; and a large sheet of paper would be too small for the lengths of the lines of distances. So that, in order to make the present subject plain, we must enlarge the planets, and contract their distances from the Sun; otherwise, we could not, at present, render the effects intelligible which arise from some of the planetary motions.

E. Very well, brother: please to proceed.

N. The diameter of the Earth is no more than a point in comparison of its distance from the Sun; and therefore, if  
the

the Sun were viewed, at the same instant, by two observers on opposite sides of the Earth, his center would appear to both of them to be in the same point of the heavens. But, when Venus is between the Earth and the Sun, (as she was at the time of her late transit) her distance from the Earth is between three and four times less than the Sun's distance from the Earth. And therefore, if Venus be then viewed by two observers on the Earth, who are at a great distance from one another, she will appear to each of them, at the same instant, to be on different parts of the Sun's surface.—Thus in *Fig. 2.* PLATE II. let *S* be the Sun, *V* Venus, and *A B D E* the Earth. Let one observer be at *A*, another at *B*, and a third at *D*; all looking at Venus at the same moment of absolute time. To the observer at *V*, Venus (*V*) will appear upon the Sun at *F*, as she is seen in the right line *AVF*: to the observer at *B*, she will appear upon the Sun at *G*, being seen by him in the right line *BVG*: and to the observer at *D*, Venus will appear  
N                      upon

upon the Sun at  $H$ , because he sees the planet in the right line  $DVH$ . Or, if you will suppose Venus to be at rest at  $V$ , during the time that the observer at  $A$  is carried, by the Earth's motion on its axis, from  $A$  to  $D$ , through the arc  $ABD$ ; 'tis plain, that, to this observer, the planet  $V$  will appear to have moved on the Sun from  $F$  to  $H$ , through the space  $FGH$ .

Let us now suppose, that the Earth  $abde$  (*Fig. 3.*) is nearer the Sun  $s$  than is represented in *Fig. 2.* in which case, Venus  $v$  will be proportionably nearer the Earth; and the arc  $abd$ , through which the observer is carried, will bear a greater proportion to the distance of Venus  $v$  from the Earth, in *Fig. 3.* than the same arc  $ABD$  (in *Fig. 2.*) bears to the distance of Venus  $V$  from the Earth. So that, if one observer should be placed at  $a$ , another at  $b$ , and a third at  $d$ , the observer at  $a$  would see Venus on the Sun at  $f$ , the observer at  $b$  would see her on the Sun at  $g$ , and the observer at  $d$  would see her on the Sun at  $h$ , all at the same

same instant of time. Or, if Venus kept at rest at  $v$ . whilst the observer at  $a$  was carried from  $a$  to  $d$  by the Earth's motion; Venus would, in that time, appear to him to have moved from  $f$  to  $h$  on the Sun. But the space  $fgh$  in *Fig. 3.* is longer than the space  $FGH$  in *Fig. 2.* and therefore, the nearer the Earth is to the Sun, the greater will the space be through which Venus appears to move upon the Sun, by the observer's real motion along with the Earth, in any given time: and the farther the Earth is from the Sun, the less will the space be through which Venus appears to move upon the Sun, by the observer's real motion, in the same time.

And, consequently, as Venus is really moving on in her orbit, in the direction of  $TVW$ , (in *Fig. 2.*) or  $tvw$  (in *Fig. 3.*) whilst the observer is carried by the Earth's motion on its axis from  $A$  to  $D$ , or from  $a$  to  $d$ ; 'tis plain, that Venus will appear to move sooner over the Sun, if the Earth's distance from the Sun be only  $bvs$  (as in *Fig. 3.*) than if it

be  $BVS$ , (as in *Fig. 2.*) So that, the whole duration of her tranfit over the Sun must be fhorter, if the Earth's diftance from the Sun be only  $bvs$ , than if it be greater, as  $BVS$ .—Do you underftand this, *Eudofia*?

*E.* I think it fo plain, that any body might underftand it.

*N.* Then, we have done with thefe figures, and fhall proceed to *Fig. 1.* of PLATE III. in which, let  $abcd$  be the Earth,  $V$  Venus, and  $S$  the Sun. The Earth turns eaftward on its axis, in the direction  $abcd$ ; and Venus moves in her orbit in the direction  $EVc$ .

Now, fuppofe the Earth to be tranfparent like glafs, and that you were placed at its center  $C$ , and kept looking at the Sun  $S$ , during the time in which Venus moves in her orbit from  $F$  to  $f$ , through the fpace  $FGVgf$ : in this cafe, the Earth's motion on its axis could have no effect on your pofition, becaufe it could not carry you any way from  $C$ . Then, when Venus was at  $F$  in her orbit, fhe would appear to you as at  $K$   
juft

just within the Sun's surface, touching his eastern edge at  $K$ ; that is, at her first internal contact with the Sun's eastern edge. As she moves on, from  $F$  to  $f$  in her orbit, she would appear to you to move on the Sun, from  $K$  to  $L$ , in the line  $KkL$ , which is called *the line of her transit over the Sun*. And when she was at  $f$  in her orbit, she would appear at  $L$  on the Sun, just beginning to leave his western edge, or at her last internal contact with the Sun. Now, please to remember, that if Venus could be seen from the Earth's center  $C$ , she would move from  $F$  to  $f$  in her orbit, in the time that she would appear to move from  $K$  to  $L$  on the Sun; or from her first internal contact to her last

*E.* A bare inspection of the figure shews it: for, when Venus is at  $F$  in her orbit, she would appear just within the Sun at  $K$ ; because then, as viewed from the earth's center  $C$ , she would be seen in the straight line  $CFK$ ; and when she came to  $f$  in her orbit, she would seem just beginning to leave the Sun at  $L$ , because

because she would be seen in the straight line  $C f L$ .

*N.* Very well.—Now let us suppose that an observer is placed on the Earth's surface at  $a$ ; and that he is carried from  $a$  to  $b$ , by the Earth's motion on its axis, in the time that Venus moves in her orbit from  $F$  to  $f$ .

When Venus is at  $F$ , she appears at  $K$  on the Sun, as seen from the earth's center  $C$ ; but to the observer at  $a$  she will not appear to be then entered upon the Sun; because (if she were then visible in the sky) she would be seen in the line  $A F H$ , eastward from the Sun; and must move on from  $F$  to  $G$  in her orbit, before the observer at  $a$  can see her on the Sun at  $K$ , in the right line  $a G K$ . So that her transit will begin as much later to the observer at  $a$ , than it does to the observer at  $C$ , as she is in moving from  $F$  to  $G$  in her orbit.

When Venus comes to  $g$  in her orbit, the observer will be carried by the Earth's motion from  $a$  to  $b$ ; and then he will see her in the line  $c f L$ , just beginning

ning to leave the Sun at  $L$ ; but she must move on from  $g$  to  $f$  in her orbit, before she begins to leave the Sun at  $L$ , as seen from the Earth's center  $C$ , in the right (or straight) line  $C f L$ ; and then, to the observer at  $b$ , she will appear quite clear of the Sun to the west, in the line  $B f I$ . So that the whole duration of the transit from  $K$  to  $L$  on the Sun, will be shorter, as seen by the observer in motion from  $a$  to  $c$ , than as seen by the (supposed) observer at rest at the Earth's center  $C$ . For, to the former, she will move only from  $G$  to  $g$  in her orbit, during the time she appears to move, from  $K$  to  $L$  on the Sun: whereas, to the latter, she must move from  $F$  to  $f$  in her orbit, in the time she appears to pass over the Sun from  $K$  to  $L$ .

The nearer the Earth is to the Sun, the greater will the difference of the durations of the transit be from  $K$  to  $L$  on the Sun, as seen from the Earth's surface and from its center: and the farther the Earth is from the Sun, the less will the difference between the durations of the transit

transit be, as seen from the Earth's surface and from its center, accordingly.

*E.* Certainly so, by what you already told me in your explanation of the second and third figures of the second *Plate*. For, the nearer the Earth is to the Sun, the nearer also, in proportion, it must be to Venus; and the farther it is from the Sun, the farther also it must be from Venus. So that the space through which the observer is carried by the Earth's motion, from *a* to *b*, (*PLATE III Fig. 1.*) will bear a greater proportion to the distance of Venus from the Earth in the former case than in the latter: and so, will affect the times of duration of the transit, as seen from the Earth's center and from its surface, accordingly.—But I should be glad to know, why you suppose an observer to be placed at the Earth's center, as it is a thing impossible to be done: and if he was there, he could neither see the Sun or Venus.

*N.* Because the motions of the planets are calculated in the astronomical tables, as if seen by an observer at rest. And,

as the apparent breadth of the Sun is known, and the time of Venus's going round the Sun is also known; the time of her appearing to move through a space equal to the Sun's breadth, as seen by an observer at rest is easily calculated, and is the same as would be observed by a person placed at rest, at the center of the Earth. And then, at all kinds of distance of the Earth from the Sun, it is easy to calculate how much the duration of the transit would be shortened by the motion of an observer on the Earth's surface, on the side of the Earth next to Venus, and who is then moving in a contrary direction to the motion of Venus in her orbit, that the duration of the transit would be to an observer at the Earth's center, or even on its surface if the Earth had no motion on its axis; in which case, the observer on the surface would be at rest. But as that observer is really in motion with the Earth, when the duration of the transit is observed by him, and, consequently, known how much shorter it appeared to him, than

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it would have done if he had been at rest; the distance of the Earth from the Sun may thereby be found: which, as I told you already, is thereupon computed to be 95,173,000 English miles.

*E.* The distance of the Earth from the Sun, in miles, being known; I should be glad to know how you find the distance of all the other planets from the Sun. For we cannot send people from the Earth to those planets to observe transits.

*N.* I told you already, in our second dialogue, that the relative or comparative distances of all the planets from the Sun are known long ago, both by the stated laws of nature, and by observation; and they are as follow:

If we suppose the Earth's distance from the Sun to be divided into 100,000 equal parts, (let these parts contain how many miles they will) Mercury's distance from the Sun must be equal to 38,710 of these parts; Venus's distance, 72,333; Mars's distance, 152,369; Jupiter's distance 520,096; and Saturn's distance, 954,006.

Now,

Now, as the number of miles is in proportion to the number of parts, and the 100,000 parts by which the Earth is distant from the Sun contain 95,173,000 miles; we say, by the rule of three, as 100,000 parts are to 95,173,000 miles; so are 38,710, Mercury's distance from the Sun in parts, to 36,841,468, his distance from the Sun in miles. So are 72,333, Venus's distance from the Sun in parts, to 68,891,486, her distance from the Sun in miles. So likewise are 152,369, Mars's distance from the Sun in parts, to 145,014,148, his distance from the Sun in miles. And so are 520,096, Jupiter's distance from the Sun in parts, to 494,990,976, his distance from the Sun in miles. And lastly, (carrying on the proportions) so are 954,006, Saturn's distance from the Sun in parts, to 907,956,130, his distance from the Sun in miles.

*E.* I thank you, brother, for having explained the whole of this matter so much to my satisfaction. But I have heard that the late transit was observed

by people at very different parts of the Earth.—Pray did you find that all the observations (as you got accounts of them) agreed so well, as to give all the same conclusion?

N. I cannot say they did so nearly as we could wish; which might have been owing to two causes. First, that the differences of longitude (as it is called) between many places where those observations were made, are not yet well ascertained: and secondly, that all the observers did not use telescopes of an equal magnifying power, which they should have agreed to do before-hand. And undoubtedly, they who used the highest magnifying telescopes, could more accurately determine the instant of Venus's two internal contacts with the Sun, than those could who used smaller magnifying telescopes. But 'tis to be hoped, that all proper care will be taken in observing the transit on the 3d of June 1769. And Astronomers will do well to make the most and best of it  
they

they can; as there will not be another transit in less than 105 years afterward.

*E.* How can *that* be?—For as the Earth goes round the sun in a year, and Venus in 225 days; I should think, that Venus would pass between the Earth and the Sun once every two years at most.

*N.* So she would, once in every 584 days, if her orbit lay in the same plane with the Earth's orbit, like one circle made within another on a flat paper. But one half of Venus's orbit lies on the North side of the plane of the Earth's orbit; and the other half on the south side of it: so that her orbit only crosses the Earth's orbit in two opposite points.—And, therefore, Venus can only pass directly between the Earth and the Sun, when, at the times of her conjunctions with the Sun, she is either in or near one or other of those points. At all other times, she either passes above or below the Sun, and is then invisible, on account of her dark side being toward the Earth. But its being so also, at the  
time

time of her late transit, made her very conspicuous on the Sun, like a black patch on a circular piece of white paper. At her last transit, she passed below the Sun's center, about a third part of the Sun's breadth: and at her next, she will pass as far above it.

*E.* I understand this thoroughly.--But, I think, there are some lines in the figure (PLATE III. *Fig.* 1.) which you have not yet explained.

*N.* Then, shew me them, and I will.

*E.* They are the lines *N E K* and *ne L*.

*N.* True: I had almost forgot them. Suppose an observer at *N*, on the side of the Earth farthest from Venus, to be carried from *N* to *n* in the same direction with Venus's motion in her orbit from *E* to *e*, in the same time that an observer at *a* is carried from *a* to *b*, in a contrary direction to the motion of Venus in her orbit: the duration of the transit will be longer, as seen by the observer who is carried from *N* to *n*, than it

it would be to an observer at rest at the Earth's center  $C$ . For, when Venus is in her orbit at  $E$ , she will appear upon the Sun at  $K$ , as seen from  $N$  in the right line  $NEK$ ; but she must go on from  $E$  to  $F$  before she can be seen from  $C$ , upon the Sun in the right line  $CFK$ : and as seen from  $C$ , in the right line  $CfL$ , she will appear as just beginning to leave the Sun at  $L$ , when she is at  $f$  in her orbit. But she must move on from  $f$  to  $e$ , before she can appear as beginning to leave the Sun, when seen by the observer at  $n$ , who is carried from  $N$  to  $n$  by the Earth's motion on its axis, in the time of Venus's moving from  $E$  to  $e$  in her orbit. So that the visible duration of the transit will be longer as seen by the observer who is carried from  $N$  to  $n$ , than it would be to an observer at rest; and shorter, as seen by an observer who is carried from  $a$  to  $b$ . And the difference between these visible durations will be of greater advantage towards finding the Earth's distance from the Sun, than what could be gained only from observations made on the side of the Earth which is nearest to Venus, during the time of her transit.

*E.* Pray, who was it that first thought of this method of finding the distances of the planets from the sun? I imagine he must have been a very great astronomer.

*N.* He was so indeed: the man who first proposed this method was the great Doctor HALLEY. And as he was morally certain, that, according to the common course of nature, he could not live to see that transit; he most earnestly recommended it to future astronomers, that they might observe it when he was dead. And, in order to furnish them with proper information, he gave in a paper on the subject to the Royal Society; which paper was soon after published in the Philosophical transactions.

## DIALOGUE V.

*On the method of finding the LATITUDES and LONGITUDES  
of PLACES.*

*Neander.*

GOOD-morrow, sifter:—you have been later than usual of coming this morning.—What's the matter? You look pale.

*Eudisia.* I was taken ill last night about twelve, of an asthma, which frightened me, as I never was so before; and kept me awake till five o'clock this morning. Then it left me, and I fell asleep, and have quite over-slept my time; for now it is eight o'clock.

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N. Why

N. Why did you not ring your bell, in order that something might have been brought to relieve you: especially as you know that our mother (among many other good medicines) always keeps an electuary of honey, powder of liquorice, of elecampane, seeds of anise, and flowers of sulphur; which is exceeding good for that disorder, and has cured many of it.

E. I was loth to surprize any body in the night, especially as the asthma did not continue long violent.—I raised my head a good deal; so it left me gradually; and now I feel nothing of it.

N. I am very glad of *that*—But I think it would be quite wrong to enter upon any such subject this morning, as we have already been about. And therefore, I hope you do not come now with any such intention.

E. Indeed I do, if it were but to take off my drowfiness; and I feel no other ailment at present.

N. Well then;—with what subject shall I entertain you this morning?

E. I

E. I heard you yesterday, for the first time, mention the *Longitude of places*. But as I scarce know what either *Longitude* or *Latitude* means, I should be glad to know: especially as we have heard so much lately about the finding the Longitude. And as I never heard of any difficulty about finding the Latitude, I imagine the latter is much more easily found than the former.

N. It is so indeed, sister.

E. What is the reason of that?—But I believe my question is premature: for I should have asked first what those terms mean?

N. Right, *Eudisia*; and now I will inform you.—*Every circle*, be it great or small, is divided (or supposed to be divided) into 360 equal parts, called *Degrees*. Now, if we take a great circle round the Earth, which divides the Earth into two equal parts, every degree of that circle contains  $69\frac{1}{4}$  English miles; as is the case with the degrees of the equator, and nearly so with those of a great circle taken

round the Earth, through the poles.

The *Latitude* of a place is the number of degrees that the place is from the Equator, towards the North or South pole: and is denominated *North* or *South*, as the given place is on the North or South side of the Equator.—Thus in the little globe, (*Fig. 1.* of PLATE I.) all the places in the northern hemisphere, from every point of the equator to the North pole, have North Latitude: and all the places from every point of the equator to the South pole have South Latitude. As the poles are the farthest points of the Earth from the equator, they have the greatest Latitude; which is 90 degrees, or a fourth part of 360, the whole circumference of the globe.

The North and South points or poles of the Heaven are directly over the North and South poles of the Earth.—And therefore, as the Earth turns round its axis, which terminates in its North and South poles, every point of its surface is carried round in 24 hours, except

cept its poles, which are at rest. This motion of the Earth will cause an apparent motion of every point of the heaven, in a direction contrary to the Earth's motion, excepting its poles, which appear always at rest; because they are directly over the poles of the Earth, which are at rest.

*E.* May I put in a word just now, before you proceed farther?

*N.* Why not?

*E.* I should think that the poles of the Heaven would change among the stars, on account of the Earth's motion round the Sun in a year. For, undoubtedly, if the Earth's axis (or line on which it turns round every 24 hours) were produced to the Heaven, it would describe a circle therein, equal in diameter to that of its whole orbit; which you have already told me is 190 millions of miles.

*N.* And so it does.—But if it should, by its track, make as dark a circle in the Heaven, as can be made with ink by a pair of compasses on paper; the distance

tance of the starry Heaven is so great from us, that a circle therein of 190 millions of miles in diameter, would not appear so big to us as the smallest dott you can possibly make with a fine pen upon paper.— Which shews, that if the Earth were as big as would fill its whole orbit, it would appear no bigger than a dimensionless point, if seen from the stars. For, notwithstanding the Earth's constantly changing its place in its orbit, the poles of the Heaven could never be perceived to change their places a single visible point, even when observed with the nicest instruments. And therefore, we always consider the poles of the Heaven to be fixed points; and to keep constantly just over the poles of the Earth.

*E.* You have satisfied me entirely on this head; and, at the same time, convinced me, that the distance of the stars must be inconceivably great. Now, please to proceed.

*N.* Now, let us suppose a great circle to be drawn round the Heaven, through  
its

its North and South poles, and to be divided into 360 degrees, like a circle drawn round the Earth through *its* North and South poles.

As the Earth is but a point in comparison to the distance of the starry Heaven; let us be on what part of the Earth we will, we see just one half of the Heaven, if the horizon or limit of our view all around be not intercepted by hills. And as the poles of the Heaven are directly over the poles of the Earth; so the equinoctial in the Heaven is directly over the Earth's equator, all around.

Now, as the Earth is round, and the Heaven appears to us to be round like the concave surface of a great sphere or hollow globe; 'tis plain, that if we were at the Earth's equator, the equinoctial in the Heaven would be over our heads; and the North and South points, or poles of the Heaven, would appear to be in the North and South points of our horizon, or limit of view. But if we go one degree from the equator towards ei-  
ther

ther the North or South pole of the Earth, the like pole of the Heaven would appear to be one degree elevated above our horizon, because we would see a degree of the Heaven below it; and the contrary pole of the Heaven would be one degree hid below the limit of our view.—If we go two degrees from the equator, the pole will appear to be two degrees elevated above our horizon; and so on, till we go to either of the Earth's poles, 90 degrees from the equator; and then, the like part of the Heaven would be just over our head, or 90 degrees above our horizon; which is the greatest elevation it can have, as seen from any part of the Earth. And as the number of degrees we are from the Earth's equator is called our Latitude, so the number of degrees of the elevation of the celestial pole is equal thereto. At London the North pole of the Heaven is elevated  $51\frac{1}{2}$  degrees above the horizon; which shews, that London has  $51\frac{1}{2}$  degrees of North Latitude from the equator. And as Latitude begins at the equator

equator, the places thereon have no Latitude at all.

*E.* But how can you tell by what number of degrees the pole is elevated? for there is no visible circle in the Heaven divided into degrees, to reckon by.

*N.* But we have an instrument called a Quadrant, which is a quarter of a circle, drawn on a plate of metal, and divided into 90 degrees; and it has a plumb line with a weight hanging from its center, which line always hangs toward the Earth's center, when allowed to hang freely. And if we look at the pole along one of the straight edges of the quadrant, the other edge will be as many degrees from the plumb line, as are equal to the number of degrees of the pole's elevation above the horizon of our place.—And, by that means, the elevation of the pole, and consequently the latitude of the place, is known.

*E.* Is there a star fixed exactly in the North pole, by which means you can know by sight where *that* pole is?

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N. No;

N. No; but there is a star of the second magnitude, about two degrees from the North pole, and it is called *the Pole star*. And as the Earth's motion on its axis causeth an apparent motion of all the stars round the poles of the Heaven: the pole star appears to us to describe a circle of four degrees diameter, round the pole itself, every 24 hours. And therefore, if we subtract two degrees from the greatest observed height of the pole star, or add two degrees to the least observed height thereof, the result gives the elevation of the pole at the place of observation.

As the North pole is elevated  $51\frac{1}{2}$  degrees above the horizon of London; all those stars which are within  $51\frac{1}{2}$  of that pole never set below the horizon of London. And therefore, if the greatest and least altitudes of any of these stars be taken with a quadrant, half the difference of these altitudes being added to the least, or subtracted from the greatest, gives the elevation of the pole above the horizon.

And

And thus, we can very easily and accurately find the Latitude of any place, by means of any star which never sets below the horizon of that place.

The Latitude' of any place may also be found by the Sun's altitude at noon, on any day of the year, quite independent of the stars.—I will first endeavour to shew you the reason of this, and then shew you the method.

The Equinoctial in the Heaven is directly over the Equator on the Earth. And just as many degrees as the Latitude of any given place is from the Equator, so many degrees is the point of the Heaven, which is over the place, from the Equinoctial. Consequently, if we can find how many degrees the point of the Heaven, which is directly over our place, is from the Equinoctial, we thereby find how many degrees our place is from the Equator; or our Latitude.

The Sun is in the Equinoctial twice every year; namely, on the 20th of March, and 23d of September; and then he is directly over the Earth's Equator.

From the 20th of March to the 23d of September, the Sun is on the North-side of the Equinoctial, and from the 23d of September to the 20th of March, he is on the South-side of it. The number of degrees that the Sun is from the Equinoctial, on any day of the year, is called *the Sun's Declination* for that day; and is denominated *North* or *South*, as the Sun is on the North or South side of the Equinoctial.—So that, *Declination* in the Heaven is the same as *Latitude* on the Earth.

There are tables, ready calculated, which shew what the Sun's declination is, at the noon of every day of the year; as it is North or South on that day.—And the point of the Heaven, which is directly over any place, is 90 degrees above the horizon of that place.

Now, to find the Latitude of the place, as suppose London, which is on the North side of the Equator; observe the Sun's altitude at noon, by means of a quadrant, on any day of the year: and then, if, by the tables, you find the  
Sun's

Sun's declination to be North on that day, subtract the declination from the Sun's meridian altitude, (that is, from his height at mid-day, as found by the quadrant) and the remainder will be the height of the Equinoctial; which height being subtracted from 90 degrees, will give the Latitude of the place.

Thus, on the 21st of June, the tables shew us, that the Sun's declination is  $23\frac{1}{2}$  degrees North; and if the Sun's altitude be observed with a quadrant on the noon of that day, the altitude will be found to be just 62 degrees. Now subtract  $23\frac{1}{2}$  degrees from 62, and the remainder will be  $38\frac{1}{2}$  degrees for the height or elevation of the highest point of the Equinoctial above the horizon of London; which height being subtracted from 90 degrees, leaves remaining  $51\frac{1}{2}$  degrees for the Latitude of London.

If the Sun's declination be South, add its quantity to the Sun's observed altitude at noon, and the sum will be the elevation

vation of the highest point of the equinoctial above the horizon of the place; which elevation being subtracted from 90 degrees, will leave a remainder equal to the Latitude of the place.

Thus, on the 21st of December, the tables shew us, that the Sun's declination is  $23\frac{1}{2}$  degrees South: and if his altitude at noon be taken at London on that day by a quadrant, it will be found to be just 15 degrees; which being added to  $23\frac{1}{2}$  degrees of South declination, gives  $38\frac{1}{2}$  degrees for the height of the equinoctial, which height, being subtracted from 90 degrees, leave  $51\frac{1}{2}$  remaining, for the Latitude of London, as before.—Do you understand all this, *Eudisia*?

*E.* I think I do, on account of the reasons you have given for the process.—But I will consider it by and by; and then tell you if I find any difficulty.

*N.* Do so: and now we will talk about the Longitude. The curve lines which you see drawn on the globe, from pole to pole (PLATE I. *Fig. 1*) are called *Meridians*; and

and each of them is a meridian to every place through which it passes; because when it comes even with the Sun, by the turning of the globe on its axis, the Sun is then at the greatest height, as seen from all places on that meridian; and consequently, it is then mid-day or noon to each of them. —There are only 24 meridian semicircles on the globe, at equal distances from each other; but we may suppose the whole spaces between them to be filled up with other such meridians, because every place, which is ever so little to the East or West from the meridian of any given place, has a different meridian from *that* of the given place.

The whole circumference of the equator is divided into 360 equal parts or degrees: and the English astronomers and geographers begin (what they call) the Longitude, at the meridian of London, and thence reckon the Longitudes of other places to the East or West, as the meridians of those places lie East or West from the Meridian of London.

So

So that, the Longitude of any place, East or West of the meridian of London, is equal to the number of degrees intercepted between the meridian of that place and the meridian of London: according to the English way of reckoning. Thus, a meridian drawn through *Copenhagen* in *Denmark*, would cut the Equator 13 degrees eastward of that point where the meridian of London cuts it; and a meridian drawn through *Philadelphia*, in North-America, would cut the equator 74 degrees westward of the point where the meridian of London cuts it: and therefore, we say, the Longitude of *Copenhagen* is 13 degrees East from the meridian of London (which is termed *the first meridian* by the English) and the longitude of *Philadelphia* is 74 degrees west.

All people, who know what *Latitude* and *Longitude* mean, reckon Latitude to begin at the Equator, that they may find the Latitude by the elevation of the pole above the horizon.—But, as they may begin the Longitude at the meridian  
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dian of any place; I suppose most nations reckon the Longitude of all other places from the meridian of the principal city of their own kingdom or nation.

*E.* Why is it so difficult a matter to find the Longitude of any place from the meridian of any other place, in comparison of finding the Latitude?

*N.* Because we have a fixt point, or pole, in the Heaven, which shews us our Latitude by its elevation above the horizon of our place: but there is no visible meridian in the Heaven, to keep directly over the meridian of any place on the Earth.—If there were such a meridian, the Longitude of all other places from it might be as easily found, by its elevation above their horizons, as their Latitudes are found by the elevation of the pole, or by the declination of the Sun from the equator.

*E.* I understand you perfectly well.—But, pray, what are the best methods that have been yet proposed for finding the Longitude?

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N. The best method, in theory, is by a machine that will measure time exactly, so as to go as true at sea, as a good clock does on land.

E. Please to explain this.

N. The Earth's circumference is 360 degrees; and as it turns round its axis eastward every 24 hours, it turns 15 degrees every hour; for 24 times 15 are 360. Therefore, every place whose meridian is 15 degrees east of the meridian of London, will have noon, and every other hour, one hour sooner than it is so at the meridian of London. Every place whose meridian is 30 degrees eastward of the meridian of London will have noon, and every other hour, two hours sooner than it is so at the meridian of London; and so on: the time always differing one hour for every 15 degrees of Longitude: On the contrary, every place whose meridian is 15 degrees west from the meridian of London will have noon, and every other hour, one hour later than it is so at the meridian of London; and every place whose meridian is

30 degrees west from the meridian of London will have noon and every other hour two hours later than it is so at the meridian of London; and so on.

*E.* Although this seems plain, I should be glad to have it illustrated by a figure.

*N.* And here is one (*Fig. 2. of PLATE III.*) ready for you; in which, let *S* be the Sun, *a b c d e f*, &c. the Earth, turning eastward round its axis, in 24 hours, according to the order of the letters. Let *P* be the North pole of the Earth, and *a P*, *b P*, *c P*, *d P*, &c. be as much of 24 meridian semicircles as can be shewn in the figure, at 15 degrees distance from each other: and suppose *a P* to be the meridian of London.

Then, whichever side of the Earth is at any time turned toward the Sun, it will be *day* on that side, and *night* on the other; as expressed by the *light* and *shaded* parts of the Earth in the figure. And, as it must be XII o'clock at noon on any meridian which is turned toward the sun, at any moment of absolute time, because *that* meridian will then be

in the middle of the enlightened half of the Earth, as on the meridian  $P a$ ; it is plain that it will be twelve o'clock at night, at the same instant, on the opposite meridian  $n P$ , because it is then in the middle of the dark: VI o'clock in the morning on the meridian  $t P$ , and VI in the evening on the meridian  $g P$ ; and so all the intermediate hours, on the intermediate meridians, at the very instant when it is noon on the meridian  $P a$ . So that, supposing  $P a$  to be the meridian of London, it is plain, that when it is XII o'clock *there* it will be I o'clock in the afternoon on the meridian  $P b$ , because *that* meridian is past by the sun 15 degrees, or one hour, to the eastward; II o'clock in the afternoon on the meridian  $P c$ ; III o'clock on the meridian  $P d$ ; and so on. But, it can only be XI in the forenoon on the meridian  $P z$ , when it is noon on the meridian  $P a$ ; because  $P z$  is then an hour short of being even with the Sun: X o'clock in the forenoon on the meridian  $P y$ , because that meridian

ridian wants two hours of being even with the Sun; and so on.

Now as every master of a ship knows how to find the time of the day at the place of his ship, by the height of the Sun; or the time of the night by the height of any given star that revolves at a good distance from either of the celestial poles; if he first finds the latitude of the place of his ship he may find the Longitude of that place in the following manner, if he can depend upon the true going of his watch.

Before he sets out for any port, as suppose from London, let him set his watch to the exact time at *that* port; and then, let him sail where he will, his watch will always shew him what the time is at that port from which he set out.

Now suppose him to be at sea on his way to the West-Indies; and that he has sailed from London at *a* as far westward as *x*, and then wants to find the Longitude of the place of the ship at *x*. He first finds the Latitude of the place *x*, and

and then, by the altitude of the Sun, finds the time at that place; which we shall suppose to be IX o'clock in the morning; he then looks at his watch, which shews, the time at London, on the meridian *P a*, and finds that it is XII o'clock at noon on the meridian of London. By this he knows, that he is three hours to the west of London; and as every hour of time answers to 15 degrees of Longitude, he finds that the meridian of the place of his ship is 3 times 15, or 45 degrees west from the meridian of London. And, as every hour answers to 15 degrees of longitude, so every four minutes answers to one degree. If he had been as far eastward (as at *d*) from the meridian of London, he would have found it to be III o'clock in the afternoon at the place of his ship, when his watch would have shewn him that it was then only mid-day at London: and so, in *that* case, he would have known that the Longitude of his ship was 45 degrees East from the meridian of London.

E. This appears to me to be a very  
rational

rational and easy method of finding the Longitude, if a watch can be made that will keep exact time at sea.—Pray, has there ever been such a watch made, so as that it can be depended upon? for otherwise I should think it very dangerous; because, for every four minutes that it would either gain or lose, it would cause an error of a whole degree in reckoning the Longitude.

*N.* Mr. *Harrison* has succeeded the best of any who ever yet attempted to make such a watch. But *that* watch has been found not to keep time quite so exactly as was expected, after some months trial at the Royal Observatory at Greenwich. Yet it must be acknowledged that Mr. *Harrison* has very great merit, and deserves the reward he has got for his ingenuity: and many are of opinion, that he can still make a watch that will measure time more exactly than the one which has been already tried (and for which he has got the reward), as it is the only one he ever made.

Another method (and which is a very  
ed of moon's motion to be  
collected just at One o'clock in the morn-  
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sure oil) for finding the Longitude, has been practised for many years: and *that* is, by the eclipses of Jupiter's satellites; but it is attended with two inconveniences; first, as it requires the telescope to be quite steady, by which those eclipses are observed, it cannot be put in practice at sea, on account of the unsteadiness of the ship: and, secondly, no observations of these eclipses can be made in the day-time, because Jupiter is not then visible.

*E.* But I should think it must still be very useful in finding the Longitude of places on the land, where the telescope may be kept quite steady.—Pray, explain the method by which the Longitude has been thus found.

*N.* The English astronomers have calculated tables which shew the times of those eclipses, all the year round, on the meridian of London; and the French have done the like for the meridian of Paris.—Now, suppose an Englishman to be at *Kingston* in *Jamaica*, and that he observes either of Jupiter's moons to be eclipsed just at One o'clock in the morning:

ing: he looks at the tables, to see at what time the same eclipse is on the meridian of London; and finds the time *there* to be at 8 minutes after VI in the morning. The difference of the times, as reckoned at *London* and at *Kingston* in Jamaica, is thus found to be 5 hours 8 minutes, or 308 minutes; which being divided by 4, (because 4 minutes of time answer to one degree of Longitude) quotes 77 for the number of degrees by which the meridian of Kingston is west from the meridian of London: and thus he finds, that Kingston is in 77 degrees of West Longitude from London.

*E.* You have explained this matter very fully; and I thank you for it.

*N.* I thought to have done it in much fewer words: and am afraid I have quite tired you this morning, as you cannot be very well after having such a bad night.

*E.* But I am quite well now, brother; and you have finished in very good time, as the bell just rings for breakfast.

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## DIALOGUE VI.

*On the CAUSES of the different lengths of DAYS and NIGHTS, the vicissitudes of SEASONS, and the various phases of the MOON,*

*Neander,*

**I** AM very glad to see you so early this morning, *Eudocia*.—I hope you rested well last night, and had no return of your late complaint.

*Eudocia.* I slept very well from ten o'clock till five; and am quite well.

*N.* I am very glad to hear it.—What subject do you purpose for us to enter upon this morning?

*E. I*

*E.* I should be glad to know the reason why the days and nights are of different lengths at different times of the year. For, although 'tis plain, that the turning of the Earth round its axis once every 24 hours must cause a continual succession of day and night in that time; the same as if the Earth were at rest, and the Sun moved round it in 24 hours; I do not understand the reason why the days and nights are continually varying in their lengths, unless it were by a particular motion of the Sun northward and southward, across the Equator, in a year.—But, from what you have already told me, it appears plain, by the stated laws of nature, that the Sun cannot have any such motion.

*N.* Indeed he cannot.—And you shall soon see the reason of the different lengths of days and nights, and of all the four seasons of the year, without any motion of the Sun northward and southward across the Equator.—Please to light *that* candle, by way of a Sun, and set it upon the table;

whilst I shut the windows, so that we may have no light in the room but from the candle.

*E.* There it is, brother.

*N.* Now, I put a wire axis through our small three inch globe, so as to reach a little way out from its surface in the North and South poles.——I move the globe round the flame of the candle, keeping it always at the same height from the table, and its axis perpendicular to the table: and you see that the candle is always even with the Equator of the globe, and enlightens it just from pole to pole.

*E.* Exactly so.

*N.* And that one half of the globe is enlightened by the candle, whilst the other half is not: and consequently, that it appears as if it were *day* on the side of the globe next the candle, and *night* on the opposite side.

*E.* Very plain.

*N.* I now turn the globe round its axis many times during the time I  
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move it round the candle as before ; and you see that every part of its surface from the North pole to the south, goes equally through the light and shade. So that, if the globe was turned round its axis once every 24 hours, and carried round about the candle once in a year, every point of its surface, from pole to pole, would be twelve hours in the light, and twelve hours in the dark.

*E.* Undoubtedly it would.

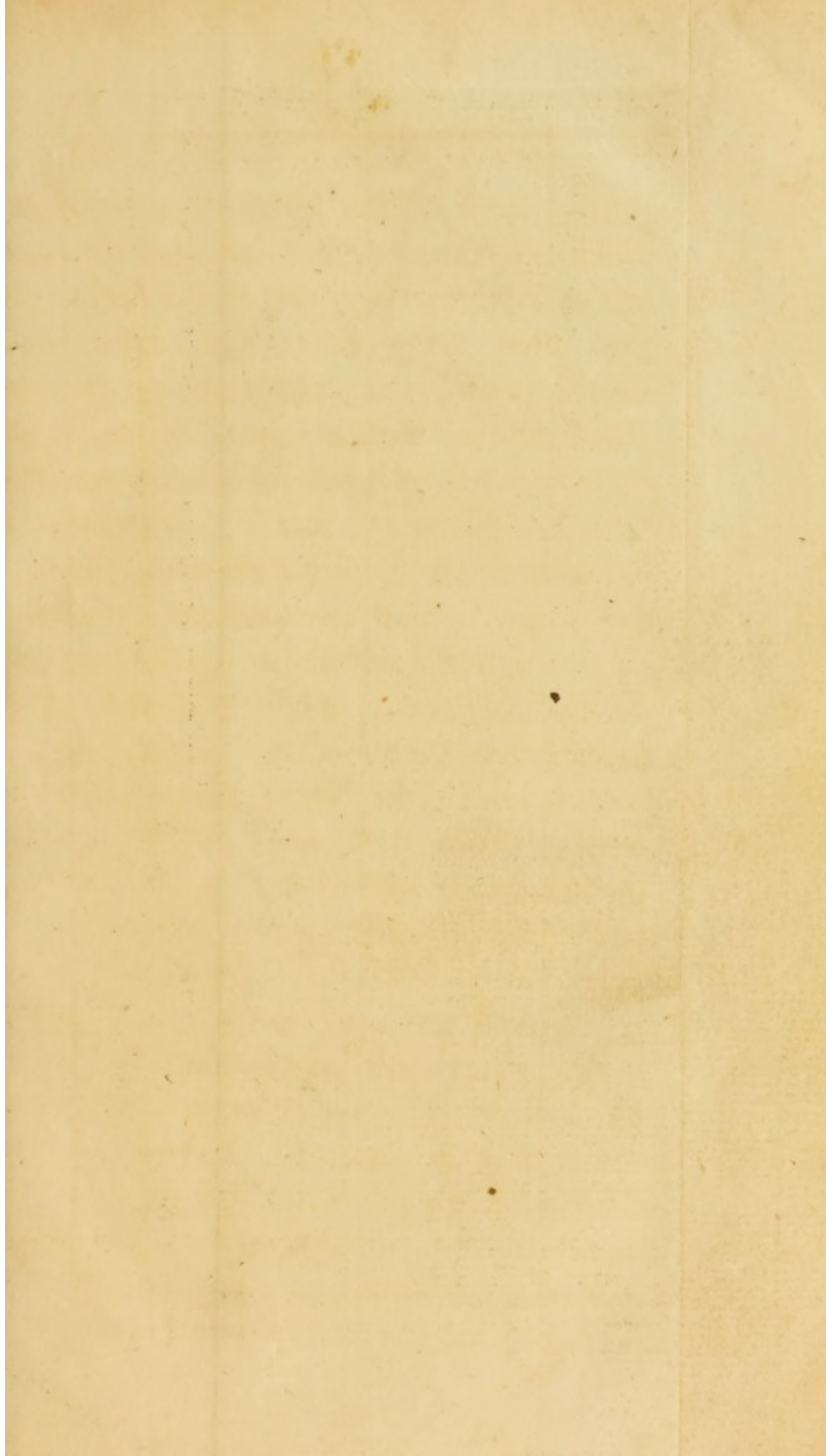
*N.* Then, you see, that supposing the candle to have no motion from one side of the Equator to the other, and the axis of the globe to keep perpendicular to its orbit, in its whole course round the candle, the days and nights could never vary in their length.

*E.* Self-evident.

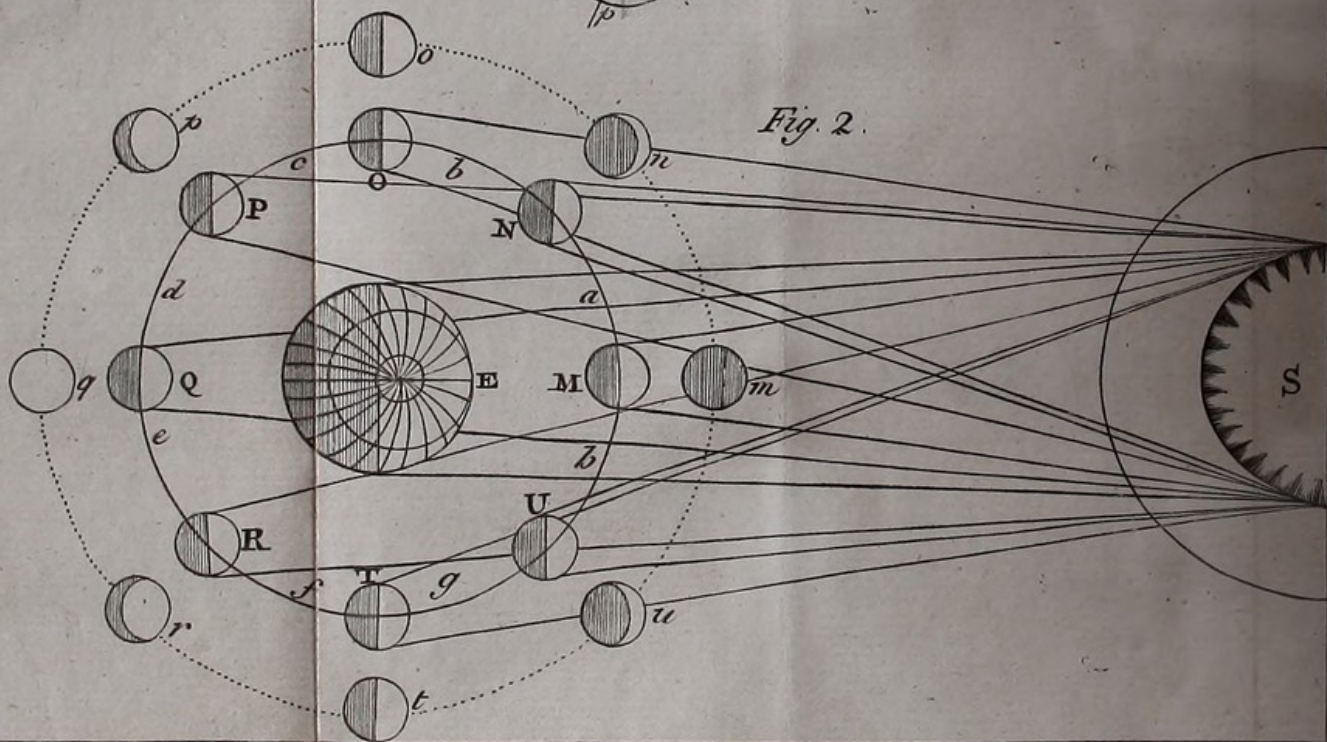
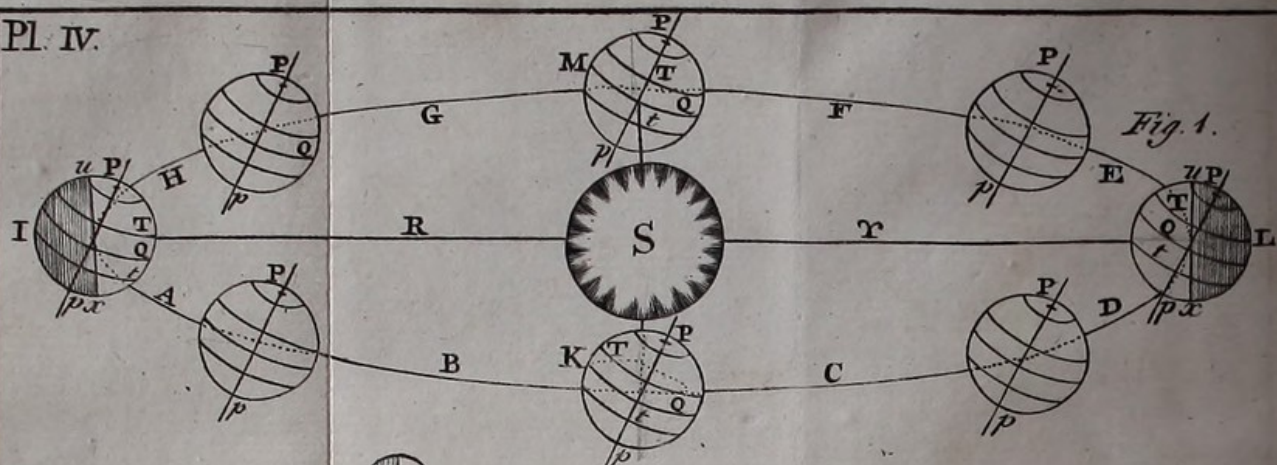
*N.* I now incline the North pole of the axis a little toward the candle, and turn the globe round its axis.—You now see that the candle shines as far over the North pole as the axis of the globe is inclined toward the candle ; and that all  
those

those places of the northern hemisphere which go through the dark, go through less of it than they do of the light; so that their days are longer than their nights: and the candle, being on the North side of the Equator, shines as far short of the South pole, as it shines over the North pole: and consequently, all the places on the southern hemisphere of the globe, which go through the light, go through a less portion of it than they do of the dark; and so have their days shorter than their nights.

But, make the North pole of the axis decline from the candle, and turn the globe round its axis; the candle will not enlighten the globe to the North pole, but it will shine round the South pole. And now, all the northern places of the globe which go through the light, go through less of it than they do of the dark; so that the days are shorter than the nights on the North side of the Equator, and the contrary on the South side of it.—You now see, that turning the poles of the Earth alternately, more  
or



Pl. IV.



or less, toward and from the Sun, will have the same effect, as if the Sun really moved northward and southward to different sides of the Equator.

*E.* It will, indeed.—But do the poles of the Earth incline toward the Sun, and from him, in that manner, at different times of the year?

*N.* They do: and here is a figure, (PLATE IV. *Fig.* 1.) by which the whole of that matter may be very easily explained.

Let *ABCDEFGHI A* represent the Earth's orbit (seen obliquely, which causeth it to appear of an elliptical shape). And let *I* be the earth, going round the Sun *S* according to the order of the letters *A, B, C, D,* &c. once every year.

Now, suppose a great circle *P u I p x*, to be drawn round the Earth, through its North pole *P* and its South pole *p*; and let *Q* be the Equator.

Divide the great circle *P u I p x* into 360 equal parts or degrees; and set off  $23\frac{1}{2}$  of these degrees from *P* to *u*. Then, at the distance *P u* from the North pole, draw

draw a circle all round it; which call *the North polar circle*; and suppose just such another circle to be drawn around the South pole.

Make the Earth's axis  $P p$  incline  $23\frac{1}{2}$  degrees toward the right-hand side of the plate; and let the Earth  $I$  be carried round the Sun  $S$ , in the orbit  $A, B, C, D$ , &c. in the time of its turning  $365\frac{1}{4}$  times round its axis: and, in its whole course, let its axis  $P p$  still incline  $23\frac{1}{2}$  degrees toward the right-hand side of the plate.

Then 'tis plain, that when the Earth is at  $I$ , the whole North polar circle falls within the enlightened part of the Earth; and all the northern places between the Equator  $\mathcal{Q}$  and the North polar circle  $u$  are more in the light than in the dark: and therefore, as the Earth turns round its axis, these places will have longer days than they have nights: and the Sun will point as far North of the Equator  $\mathcal{Q}$  as shewn by the straight line  $R$ , as he shines round the North pole  $P$ ; for the distance  $\mathcal{Q} T$ , northward from the Equator,

Equator, is equal to the distance  $P u$  from the North pole; which is  $23\frac{1}{2}$  degrees.—This is the Earth's position on the 21st of June, when our days are at the longest, and nights at the shortest.

At the distance  $Q T$  ( $23\frac{1}{2}$  degrees Northward from the equator) describe the circle  $T$ , round the globe, parallel to the equator: and as the Sun is directly over the circle  $T$ , in the right line  $R$ , and can never be farther North of the Equator; but begins then to recede as it were, southward from the circle  $T$ , that circle is called *the Northern Tropic*, or limit of the Sun's greatest North declination from the Equator  $Q$ .

As the Earth moves on in its orbit, from  $I$  to  $K$ , its axis  $P p$  inclines more and more sidewise to the Sun  $S$ ; as it still keeps parallel to the position it had when the Earth was at  $I$ : for which reason, the northern places are gradually turned away from the Sun; and their days grow shorter, and their nights longer.

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When at the Earth is at  $K$ , its axis  $Pp$  inclines neither toward the Sun nor from him, but is sidewise to him: so that the Sun is then directly over the Equator, and enlightens the Earth just from pole to pole. And, as the Earth's rotation on its axis then carries all the parts of its surface between the poles equally through the light and the dark, the days and nights are equally long at all places of the Earth. This is the Earth's position on the 23d of September.

As the Earth advances from  $K$  to  $L$ , through the part  $CD$  of its orbit, the North pole  $P$  and all the northern places of the Earth are gradually more and more turned away from the Sun  $S$ : and those places of the northern hemisphere which go through the light and the dark, go through more of the dark than of the light; so that their days become gradually shorter, and their nights longer.

When the Earth comes to  $L$  in its orbit, its North pole  $P$  is as much turned away from the Sun  $S$ , as it was turned toward

toward him when the Earth was at *I*; and therefore, when the Earth is at *L*, the whole North polar circle *u* is in the dark; and the Sun points  $23\frac{1}{2}$  degrees (as shewn by the right line *r*) to the South of the equator *Q*, and is then over the circle *t*, which is parallel to the Equator, and is called *the southern tropic*, because it is the utmost limit of the Sun's South declination from the Equator. This is the Earth's position on the 21<sup>st</sup> of December, when all those places in the northern hemisphere, which go through the light and the dark, go through the least portion of the light, and the greatest of the dark, that they can do on any day of the year. And therefore, the days are then at the shortest, and nights at the longest, in the Northern half of the Earth, all the way from the Equator *Q* to the North polar circle *u*; within which circle there is no day at all.

As the Earth advances from *L* to *M*, through the part *EF* of its orbit, its axis *Pp* is gradually more and more turned

sidewise to the Sun; the northern places fall more and more into the light, and their days lengthen and nights shorten. And when the Earth comes to *M*, which is on the 20th of March, its axis neither inclines toward the Sun nor from him, but sidewise to him; and then, the Sun is directly over the Equator *Q*, and enlightens the Earth from its North pole *P* to its South pole *p*: and as it turns round its axis, every place on its surface from pole to pole goes equally through the light and the dark, and has the day and night of an equal length, that is, twelve hours each.

Lastly, as the Earth goes on from *M* to *I*, in the part *G H* of its orbit, its North pole *P*, and all its northern places from the Equator *Q* to that pole, advance gradually more and more into the light; and so, have their days longer and nights shorter, till the Earth comes to *I* on the 20th of June, when the days in those places are at the longest, and nights at the shortest; because they incline the most to the Sun that they can do on any day

day of the year; and consequently, they then go through the greatest portions of the light, and the least of the dark, all the way from the Equator to the North polar circle *u*; within which circle there is then no darkness at all.

And thus, as the Earth's axis still inclines toward one and the same side of the heavens, in its whole annual course round the Sun; as in the figure it does toward the right hand side of the plate; it is evident, that its axis must incline constantly, more or less toward the Sun during our summer half of the year; and more or less from him during our winterhalf. That, when it is summer in the northern hemisphere, it must be winter in the southern, and the contrary: and that there can be no difference of seasons at the Equator, because it is in the middle between the poles, and always equally cut in halves by the boundary of light and darkness *u x*.

*E.* This very plainly shews the reason of the different lengths of days and nights, and also of all the variety of seasons.

seasons.—But, as I apprehend the matter, each pole, in its turn, must be continually in the light for half a year together, and in the dark for the other half: so that it appears there can be but one day and one night at each pole, in the whole year.

N. You are quite right, *Eudisia*; and have told me the very thing that I was about to inform you of.

E. I came into your room yesterday about one o'clock; but you happened then to be out: and seeing a book lying open on your table, I looked into it; and found mention made of the *ecliptic*, the *signs* thereof, and the *Sun's place*. Pray, what is the *ecliptic*, and what are its signs?

N. If the plane of the Earth's orbit were produced out to the stars, like a broad circular thin plate, its edge would form a great circle among the stars; which great circle (tho' only an imaginary one) we call *the Ecliptic*. And as the Earth moves in the plane of such a circle, in its whole course round the Sun,  
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it will be always seen from the Sun as moving in such a circle among the stars: and, at any given time, in the *opposite* point of that circle to the point of it in which the Sun then appears, as seen from the Earth. So that, as the Earth goes round the Sun once a year, the Sun will appear to us to describe a great circle among the stars, in a year.

Astronomers divide this circle into twelve equal parts, called *Signs*, and each sign into 30 equal parts called *Degrees*. And in *whatever* Sign and Degree the Earth would appear, as seen from the Sun, at any given time, the Sun must then appear in the *opposite* Sign and degree as seen from the Earth: and the part of the *Ecliptic* in which the Sun's center appears to be, as seen from the Earth at any given instant of time, is called the *Sun's place in the Ecliptic*, at that time.

These *Signs* are called *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, and *Pisces*. The month and days of the year, in which

which the Sun appears to enter these Signs, are as follow:

<i>Aries,</i>	<i>Taurus,</i>	<i>Gemini,</i>	<i>Cancer,</i>	<i>Leo,</i>	<i>Virgo,</i>
March	April	May	June	July	August
20	20	21	21	23	23
<i>Libra,</i>	<i>Scorpio,</i>	<i>Sagittarius,</i>	<i>Capricornus,</i>	<i>Aquarius,</i>	<i>Pisces,</i>
Sept.	Octob.	Novemb.	Decemb.	Jan.	Feb.
23	23	22	21	20	19.

*E.* Then, let me see; I think I could tell, by this, what the Sun's place in the Ecliptic is, on any day of the year. Each sign has 30 degrees; this is the 11th day of July, and the Sun does not enter *Leo* till the 23; so that he must yet be in *Cancer*. Take 11 from 23, and there remain 12; so that the Sun is now 12 degrees short of the last point of *Cancer*; and, consequently, he is in the 18th degree thereof.

*N.* You are perfectly right, sister: and I think we have done with this part of our subject.

*E.* And will you allow me this morning to enter upon any other?

*N.* Why not; and continue it too till the bell calls us to breakfast.

*E.* Which, I hope, will not be in less than half an hour; and till then, I should

should be glad to learn something about the Moon.

N. Very well: it is your province to ask questions, and mine to answer them.

E. What is the cause of the Moon's appearing of such different shapes as she does to us every month, always increasing from change to full, and decreasing from full to change?

N. Be pleased to light the candle again, and set it on yonder table, at the farther end of the room, whilst I close the window-shutters. And then, do you stand at a good distance from the candle, and look toward it.

E. Very well, brother;—Now.

N. Here is a small ivory globe, with a wire through it, by way of an axis.—I will now move *that* globe round your head: and, as I carry it about, do you turn yourself round, and keep looking at it. Let the candle represent the Sun, your head the Earth, and the globe the Moon. As the candle can enlighten only that half of the globe which is turned toward it, so the Sun can only enlighten

that half of the Moon which is at any time turned toward him. The other half is in the dark, and the Moon goes round the Earth in her orbit once a month.

As I carry the globe round your head, the dark side of it is toward you when it is between your head and the candle; the light side when it is carried half round, or opposite to the candle with respect to your head; and in the middle between these two positions, you have half the light and half the dark side toward you.

*E.* Very true.—And when the globe is between me and the candle, the whole of its enlightened side disappears: when you move it a little way from that position, I see a little of its enlightened side, appearing horned, like the Moon when she is a few days old. When you carry it a quarter round, I see half its enlightened side, which appears just like the Moon when she is a quarter old. As you move it farther onward, I see more and more of its enlightened side; and it continues to

increase.

increase like the Moon, till it is just opposite to the candle, when I see the whole of its enlightened side; and then it appears quite round, like the full Moon. After which, I see less and less of its enlightened side, which gradually decreases like the Moon, until you bring it again between me and the candle; and then, the whole of its enlightened side disappears, as before.

*N.* And doth not this shew very plainly, why the Moon must appear to us to increase from the change to the full; and decrease from the full to the change?

*E.* Very plainly, indeed: and, I think, it also shews that the Moon does not shine by any light of her own; but only by reflecting the Sun's light that falls upon her. For, if she shone by her own light, we should always see her round, like the Sun.

*N.* That is a very good and just observation, sister; and it is a remark that

I might possibly have forgotten to make.

*E.* But, if you had not explained the different appearances of the moon by means of a globe and a candle; how would you have done it by a figure?

*N.* Here is a figure for that purpose (PLATE IV. *Fig. 2*), in which, let *S* represent the Sun, *E* the Earth, *M* the Moon; and *a b c d e f g h a* the Moon's orbit, in which she goes round the Earth from change to change, according to the order of the letter, that is, eastward in the heavens; although the Earth's daily motion round its axis, the same way, being quicker than the Moon's progressive motion, makes her appear to go round westward. When the Moon is at *L*, between the Earth and the Sun, her dark side is then toward the Earth; and she disappears, because *that* side reflects no light. When she is at *N*, a little of her enlightened side will be seen from the Earth; and then she will appear horned, as at *n*. When she is at *O*, half her enlightened side will be toward

toward the Earth, and she will then appear as at *o*, or in her first quarter, being then got a quarter of her orbit out from between the Earth and the Sun. When she is at *P*, more than half of her enlightened side is toward the Earth; and she appears (what we call) gibbous, as at *p*. When she is opposite to the Sun, as at *Q*, the whole of her enlightened side is toward the Earth; and she appears round and full, as at *q*.

*E.* Let me interrupt you a little here.—Pray how can the Sun shine upon the Moon, when the Earth is directly between her and the Sun? For, I should think, that the Earth would stop the Sun's light from going to the Moon.

*N.* It does sometimes; and then the Moon is eclipsed; and sometimes the Moon comes directly between the Earth and the Sun at the time of her change; and then we say, the Sun is eclipsed. But we shall talk of those matters afterwards.

*E.* I am very glad of it; and now, Sir, pray proceed.

*N.* When

*N.* When the Moon is at *R* in her orbit, part of her enlightened side is turned away from the Earth ; and she appears gibbous again, as at *r*. When she is at *T* (three quarters round her orbit from between the Earth and the Sun) half of her light and half of her dark side is toward the Earth, and she appears half decreased, or in her third quarter, as at *t*. When she is at *U* in her orbit, the greatest part of her enlightened side is turned away from the Earth ; and she appears horned, as at *u*.— And when she is between the Earth and the Sun again, as at *M*, she is quite invisible ; because the whole of her unenlightened side is then toward the Earth.

*E.* This does well ; but I like the candle and ball still better.

*N.* For this very good reason, that they are more like the works of nature than any figures we can draw on paper.

*E.* How long is the Moon in going round her orbit from change to change ?

*N.* Twenty-

N. Twenty-nine days, twelve hours, forty-four minutes, three seconds.

E. And what is her distance from the Earth's center?

N. Two hundred and forty thousand English miles.

E. How many times would ~~a~~ take round the Earth, to go round the Moon's orbit?

N. Sixty times : and therefore, every degree of the Moon's orbit is equal in length to 60 degrees of a great circle (or 4155 miles) on the Earth's surface.

E. What is the Moon's diameter ; and in what proportion is it to the Earth's?

N. The Moon's diameter is  $2183\frac{1}{2}$  miles ; and it is in proportion to the Earth's diameter as 100 are to 365, or as 20 to 73.

E. What are those spots which we see on the Moon? I think I have heard some people say that they are seas.

N. So they were thought to be, before there were good telescopes to view the Moon.

Moon by. But now they are found to be only darker places of the land in the Moon, which do not reflect the Sun's light so copiously as the whiter parts do. For we see they are full of pits and deep valleys. but if they were seas, they would have even and smooth surfaces.

*E.* So they certainly would, brother.— But as it may be known by these spots whether the Moon turns round her own axis or not;—if she does turn round, I should be glad to know in what time; because I should thereby know the length of her days and nights.

*N.* She turns round her axis exactly in the time she goes round her orbit; and this we know by her keeping always the same side toward the Earth.

*E.* Then she can have only one day and one night between change and change, or in 29 days, 12 hours, 44 minutes, 3 seconds of our time.

*N.* Exactly so.

*E.* And is her axis inclined to her orbit, as our Earth's is to its orbit?

*N.* No :

N. No: her axis is perpendicular to the ecliptic, in which the Earth moves; and nearly perpendicular to her own orbit.

E. Then her days and nights must always be equally long; and she can have no different seasons?

N. You are very right, *Eudisia*.

E. But pray, brother, how is it possible that we can see only one and the same side of the Moon, at all times, if she turn round her axis?—For, I should think, that if she has such a motion, we must see all her sides.

N. Take up *that* little globe by its axis, between your fore finger and thumb.

E. There it is.

N. Now, hold its axis, without turning, (as you hold your pen when you write) and carry it round the ink-horn on the table.

E. I do.

N. And do you not see, that as you carry the globe round, without turning it

X

at

at all on its axis, all sides are successively shewn to the ink horn?

*E.* They are indeed.

*N.* Carry it round the ink-horn again; and try whether you can make it still keep one and the same side toward the ink-horn, without turning round on its axis, by turning the axis round between your fore finger and thumb.

*E.* I find it impossible to do so:—for in each revolution of the globe about the ink-horn, in order to make the globe keep still the same side toward it, I am obliged to turn the axis once round betwixt my finger and thumb: and, as the axis is fixt in the globe, I cannot turn the axis round without turning the globe round too.

*N.* Well, sister, seeing that the Moon goes round the Earth in her orbit, as you carry the globe round the ink-horn; is not her keeping the same side always toward the Earth a full proof of her turning round her axis?

*E.* It

*E.* It certainly is: and I can also see, that as the Sun is on the outside of the Moon's orbit, her keeping always the same side toward the Earth, makes her shew herself all round to the Sun between change and change.—For, in the time that I carried the globe round the ink-horn, and kept always the same side toward it; you, who were on the out-side of the circle in which I carried the globe so round, saw all its sides.

*N.* You are very right.—But I am sorry to hear our breakfast-bell: for we have not yet done with the Moon.

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DIALOGUE VII.

On the MOON's motion round the EARTH and SUN; and the ECLIPSES of the SUN and MOON.

*Neander.*

SO, sister;—if yesterday had not been Sunday, I believe you would not have given yourself *that* day's rest from your astronomical studies.

*Eudisia.* To me, brother, these studies are recreations, which I esteem better than bare rest. And, on Sunday we rest not; but are better employed in the duties of the day, than we generally are on all the other days of the week.

*N.* True;

N. True; and therein our duty is closely connected with our interest.—Shall we now resume our subject about the Moon? as I told you, last Saturday morning, that we had not done with her.

E. If you please, Sir.

N. Then you must always start the game; and when *that* is done, we will pursue it.

E. I think the Moon would always appear full as seen from the Sun, if she were big enough to be seen by an observer placed on the Sun's surface.

N. She certainly would; because, whichever side of her is turned toward the Sun at any time, *that* side would be fully enlightened by the Sun.

E. And I imagine, that if an observer were placed on the side of the Moon which always keeps toward the Earth, the Earth would appear to him in all the different shapes that the Moon does to us. Only, that when the Moon is *new* to us, the Earth would be *full* to the Moon; and when the Moon is *full* to us, the Earth would disappear, or be *new* to the Moon.

N. What

N. What reason have you for thinking so, *Eudisia*?

E. Because, which-ever side of the Earth or Moon is turned toward the Sun at any time, *that* side is then enlightened by the Sun. And therefore, when the dark side of the Moon *M* (*Fig. 2. of PLATE IV.*) is toward the Earth *E*, the enlightened side of the Earth is then fully toward the Moon; and must appear to her like a great full Moon. And when the enlightened side of the Moon at *Q* is fully toward the Earth, the dark side of the Earth is toward the Moon; and therefore it cannot appear to the Moon, as the Moon at *M* does not appear to us. And farther, when the Moon appears half full to us (or in her first quarter) at *O*, the Earth must appear half decreased to the Moon, being then half way between its full and change, as seen from her. And lastly, when the Moon is in her third quarter at *T*, as seen from the Earth, the  
Earth

Earth must appear as in her first quarter to the Moon; it being then the middle time between the new and full Earth, as seen from the Moon.

N. You are exactly right, sister: and as the surface of the Earth is 13 times as large as the surface of the Moon; when the Earth is full to the Moon, its surface appears 13 times as big to the Moon, as the surface of the full Moon does to us.

E. If the Moon be inhabited on the side which always keeps toward the Earth, I think these inhabitants may as easily find their Longitude as we can find our Latitude.

N. Tell me how: and if you can make that out, I shall say you *think* very well.

E. When you explained the Longitude to me, you made me understand, that if there were a visible meridian in the Heaven, keeping always over one and the same meridian on the Earth, (which it would do if it revolved eastward in 24 hours as the Earth does) the Longitude  
of

of any other meridian of the Earth from *that* meridian, might as easily be found, as the elevation of the pole above the horizon is found.—Now, seeing that the Moon keeps always one and the same side toward the Earth, 'tis plain, that the Earth will be always over an observer's head who is on that part of the Moon's surface which seems to us to be her center. And therefore, if Longitude on the Moon were reckoned from the meridian of that observer, those on all her other meridians on the same side might find how many degrees lie between their meridian and that which is under the Earth, by observing how many degrees the Earth is East or West of their meridian. But, as those inhabitants who live on what we call the *back* of the Moon, never see the Earth, they are deprived of *that* easy method of finding their Longitudes.

N. Truly, sister, I ought to make you a very *fine speech* for that thought: but having no talent that way, all I shall  
say

say is, that I am very well pleased by it.

*E.* I am very glad to hear you say so, because you thereby assure me that I am right.—But now a difficulty occurs to my mind, which I beg you will remove.

*N.* Only tell it me; and I will remove it if I can.

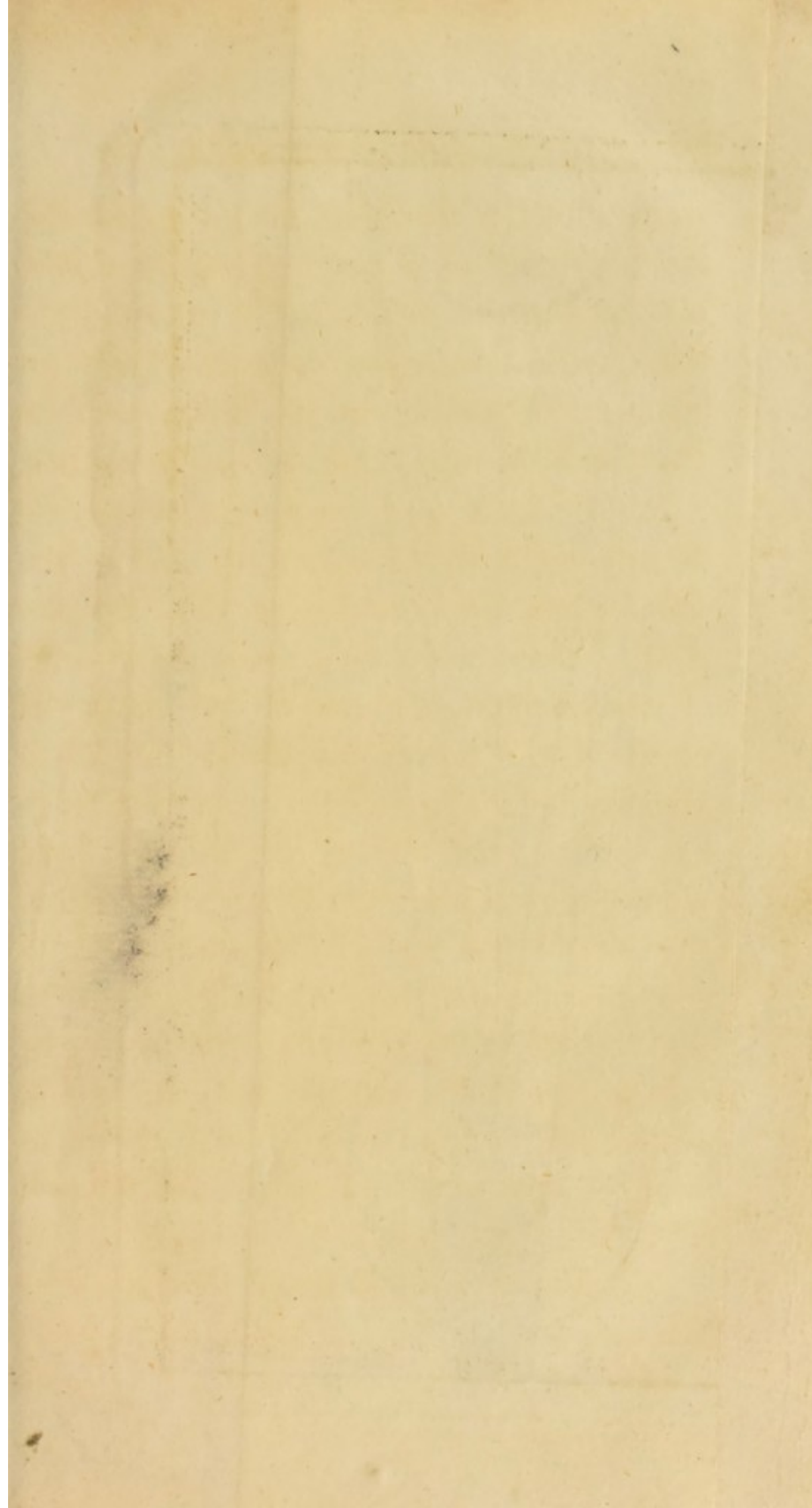
*E.* The Moon goes round the Earth every month; and as the Earth goes round the Sun in a year, the Moon must do so too.——How happens it, that the Earth, by moving at the rate of 68,000 miles every hour in its orbit, does not go off, and leave the Moon behind.

*N.* The Moon is within the sphere of the Earth's attraction: and therefore, let the Earth move in its orbit as fast as it will, the Moon must accompany it. For you know, that if you put a pebble into a sling, and whirl it round your head, the pebble will go round and round your head, whether you stand still in one and the same place, or whether you  
Y walk

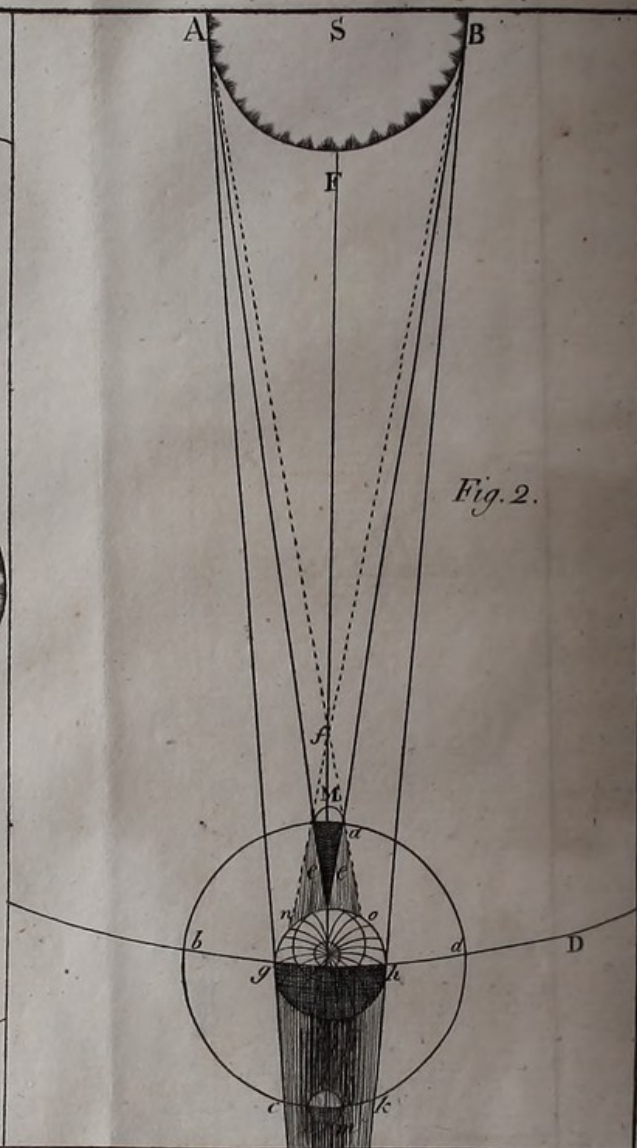
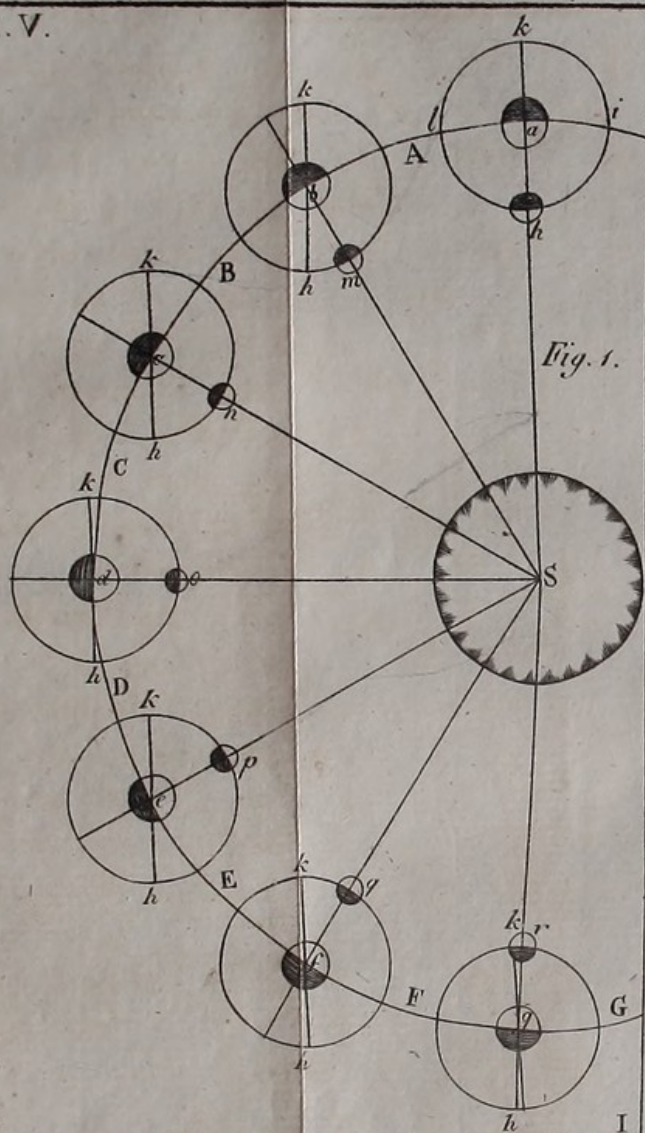
walk directly forward, or go round the circumference of a large circle. And the tendency of the pebble to fly off, and the force with which you hold the string to confine the pebble in its orbit, will be the same in one case as in the other.

*E.* I thank you, brother, for having set me right in this matter; and at the same time for convincing me, by the simile, that the Moon's centrifugal force, or tendency to fly out of her orbit, is equal to the power by which the Earth attracts her, and thereby retains her in her orbit: for, if her centrifugal force were greater than the Earth's attraction, she would fly out of her orbit, and so abandon the Earth. And if her centrifugal force were less than the power by which the Earth attracts her, she would come nearer and nearer the Earth in every revolution, and would fall upon it at last.

*N.* I find, dear *Eudisia*, that you very seldom need to be set right: and when  
I do



Pl. V.



I do, you always improve upon it, by making farther observations.

*E.* By the last figure you explained it would seem, that the Moon goes just round her orbit between change and change. But I think, that as both the Earth and Moon go round the Sun in a year, the Moon must not only go round her orbit between change and change, but even advance as many more degrees as the Earth has moved in its orbit during that time, in order to be again in conjunction with the Sun. For, in whatever part of the dial-plate of my watch I find the hour and minute hands in conjunction, I observe that the minute-hand must go as much more than round to the same point again, before it overtakes the hour-hand, as the hour-hand advances in the interval between its last conjunction with the minute-hand and its next.

*N.* You are very right; and your inference from the hour and minute hands of the watch is full as good as mine

from the pebble and fling. I drew a figure last Saturday afternoon, in order to explain this matter to you by it. But, as you understand the thing so well already, we have no occasion for the figure.

*E.* Nay, brother!—I beg you will shew me the figure, and explain it too, if your time will permit.

*N.* Then, here it is: (PLATE V. *Fig. 1*) Let *ABCDEFG* be one half of the Earth's orbit; which will do as well for us, just now, as if the whole of it had been drawn. Let *S* be the Sun, *a* the Earth, *h* the Moon when new, or between the Earth and the Sun; and *ikl* the Moon's orbit, in which she goes round the Earth according to the order of the letters *h i k l*: and let the Earth, together with the Moon and her (imaginary) orbit, go round the Sun in a year.

Draw a diameter *kh* of the Moon's orbit, when the Earth is at *a*; so as, if that line were continued, it would go on straight to the Sun's center *S*: 'tis plain, that when the Moon is in the end  
*h* of

*h* of *that* line, she must be new, or between the Earth and the Sun.

As the Earth moves on, from *a* to *b*, from *b* to *c*, from *c* to *d*, from *d* to *e*, &c. the said diameter *kh*, *kh*, *kh*, *kh*, will still continue parallel to the position *kh*, that it had when the Earth was at *a*: that is, it will always keep perpendicular to the bottom-line *HI* of the plate. And therefore, if it pointed *once* toward a fixed star, whose distance from the Sun is so great, that the whole diameter of the Earth's orbit bears no sensible proportion to that distance (which is really the case), the point *h* would *always* keep between the Earth and the same star.

*E.* I understand you very well: but do you say *The stars are fixed*?

*N.* I do say so; and will convince you afterward that *they are*.

*E.* I beg pardon for interrupting you so often.—Pray, now proceed.

*N.* In the time the Moon goes round from *h* to *h* again, in direction *h i k l h*, she goes quite round her orbit; which she would always do between change and

and change, if the Earth always remained at  $a$ .

But as the Earth advances as far in its orbit as from  $a$  to  $b$ , between any change of the Moon and the next that succeeds it, 'tis plain, that when the Earth is at  $b$ , and the Moon new at  $m$ , she will have gone more than round her orbit from  $h$  to  $h$  again, by the space  $h m$ . And as all circles, be they ever so great or ever so small, contain 360 degrees (a degree being not limited by any certain number of miles, but by the length of the 360th part of a circle) the space  $h m$ , by which the Moon has gone more than round her orbit, from her change at  $h$  to her change at  $m$ , will contain just as many degrees and parts of a degree, as the Earth has moved in that time from  $a$  to  $b$  in its orbit.

At the second change of the Moon from  $h$ , the Earth will be at  $c$ , and the Moon at  $n$ : by which time she will have gone twice round her orbit from  $h$  to  $h$  again, and as much more as the space or part  $h n$  of her orbit contains, which consists of as many degrees

degrees as the part  $abc$  of the Earth's orbit does.—And so on, through the whole figure.

*E.* I see all this very plainly ; and that the figure includes six changes of the Moon, as from  $h$  to  $m$ , from  $m$  to  $n$ , from  $n$  to  $o$ , from  $o$  to  $p$ , from  $p$  to  $q$ , and from  $q$  to  $r$ .—But at the *last* of these changes, it seems (by the figure) that the Earth has not gone half way round the Sun : for the last line of conjunction  $Srg$  is not quite even with the first line of conjunction  $ahS$ .

*N.* Nor should it be ; for if it be rightly drawn (and I find I must take care how I draw figures for you), it must want  $57\frac{1}{2}$  degrees of the Earth's progressive motion in half a year. For six courses of the Moon, from change to change, contain only 177 days, 4 hours, 24 minutes, 18 seconds, which want 5 days, 7 hours, 35 minutes, 42 seconds, of 182 days, 12 hours, which is the half of a common year. And, in that difference of time the Earth moves some-

somewhat more than 5 degrees in its orbit.

E. I remember you told me that the time from change to change is 29 days, 12 hours, 44 minutes, 3 seconds: Pray in what time does the Moon go round her orbit?

N. In 27 days, 7 hours, 43 minutes, 5 seconds.

E. And how far doth the Earth move in its orbit between change and change of the Moon?

N. Twenty-nine degrees, six minutes, twenty-five seconds.—And here you are to understand that a minute is the 60th part of a degree, and a second is the 60th part of a minute.

E. Then, 'tis plain, that between change and change, the Moon goes 29 degrees, 6 minutes, 25 seconds, more than round her orbit.

N. True *Eudosiā*; and now I have only to tell you farther, on this subject, that the Moon's going round her orbit is called her *periodical revolution*; and that her  
going.

going round from change to change is called her *synodical revolution*.

*E.* I thank you, Sir, for having told me so much.—But are you not tired at present with hearing and answering my questions?

*N.* Very far from it—I love these subjects; and my talking with *you* about them will keep *me* from forgetting them.

*E.* Then, I should be exceedingly glad to know something about eclipses.

*N.* You shall know *that* very soon.—In *Fig. 2.* of PLATE V. let *S* be the Sun, *M* the Moon, and *E* the Earth; *a b c d* the Moon's orbit, in which she moves according to the order of the letters; and *C b d D* a part of the Earth's orbit, wherein it moves in the direction *C D*.—the Moon is new when she is at *M*, and full when she is at *m*.

Draw the straight line *A e E* from the eastern edge of the Sun, close by the eastern edge of the Moon, to the Earth *E*: then draw the straight line *B e E* from the western edge of the Sun, close by the western edge of the Moon, to the Earth

*Z*

*E.* let

*E*; let these lines be supposed to turn round the middle line *FME*; and the space *ee*, within them, between the Moon and the Earth, will include the Moon's dark shadow, which is of a conical figure, (like an inverted sugar-loaf) and covers only a small part of the Earth's surface at *E*: and only from that small part the Sun will be quite hid by the Moon, and appear to be totally eclipsed; and it can be quite dark *only* at that part, because the Moon stops not the whole of the Sun's light at that instant of time, from any other part of the Earth.—Tis evident, that if the Moon were nearer the Earth, her dark shadow would cover a large part of its surface: and if she were farther from the Earth, her shadow would end in a point, short of the Earth's surface; and then she could not hide the whole body of the Sun from any part of the Earth; and those who were just under the point of the dark shadow would see the edge of the Sun, like a fine luminous ring, all round the dark body of the Moon.

But

But although the Moon can hide the whole body of the Sun only from a small part of the Earth, at any time, when the Sun appears to be thus eclipsed by the Moon; yet, in all such Eclipses, the Moon hides more or less of the Sun from a very large proportion of the Earth's surface. For,

Draw the straight line  $A f o$  from the eastern edge of the Sun, close by the western edge of the Moon, to the Earth at  $o$ .—Then draw the straight line  $B f n$  from the western edge of the Sun, close by the eastern edge of the Moon, to the Earth at  $n$ . Let these lines ( $A f o$  and  $B f n$ ) be supposed to turn round the middle line  $F M E$ , and their ends ( $n$  and  $o$ ) will describe a large circle on the Earth's surface, around  $E$ ; within the whole of which circle, the Sun will appear to be more or less eclipsed by the Moon at  $M$ , as the places within that circle are more or less distant from its center  $E$ , where the dark shadow falls. For, when the Moon is at  $M$ , an observer on the Earth at  $n$  will see the eastern  
edge

edge of the Moon, just, as it were, touching the western edge of the Sun at *B*; and an observer at *o* will see the western edge of the Moon, just, as it were, touching the eastern edge of the Sun: but to all the places between *n* and *o*, the Moon will hide a part, or the whole of the Sun, according as they lie between *n* and *E*, or between *o* and *E*, or directly at *E*.—This faint shadow, all round the dark one, from *n* to *o*, on the Earth's surface, is called the *Penumbra*, or partial shadow of the Moon.

*E.* How many miles are contained in the diameter of the circle which the *Penumbra* fills on the Earth's surface?

*N.* About 4700, when its center falls directly in a right line from the Sun's center to the Earth's at a mean rate.—But when the *Penumbra* falls obliquely on the Earth's surface, its figure thereon will be elliptical; and then, the space that it covers will be much larger; especially if the Moon be then at her least distance from the Earth.

*E.* What!

*E.* What! brother; is not the Moon's distance from the Earth always the same?

*N.* By no means: for the Moon's orbit is of an elliptical (or oval) figure; and every ellipsis has two centers, which are between the middle and the ends of its longest diameter; and the Earth's center is one of the centers (or, *as they are called*, focuses) of the Moon's elliptical orbit.—So that when I formerly told you, that the Moon's distance from the Earth's center is 240,000 miles, I only meant her *mean* (or middle) distance between her greatest and least distances.

*E.* Then I understand, that the Moon's distance from the Earth must be continually changing.—But supposing the Sun to be eclipsed when the Moon is at her least distance from the Earth; what is the diameter of the spot upon the Earth's surface that would be quite covered by the Moon's dark shadow; from all parts of which spot the Sun would be totally hid by the Moon?

*N.* About 180 miles.

*E.* As

*E.* As the Moon's distance from the Earth is little more than a 396th part of the Sun's distance from it, (as I have computed) I suppose the Moon's shadow at the Earth will move almost as fast as the Moon moves in her orbit.—Pray, in what time will the dark part of the shadow move over about 180 miles of the Earth's surface?

*N.* In four minutes and a half; and would go over *that* space sooner, if the Earth's motion round its axis, (which is eastward, and consequently the same way that the Moon's shadow goes over the Earth) did not keep the place on which the shadow falls longer in the shadow than it would be, if the Earth had no such motion.

*E.* Then an eclipse of the Sun can never continue total above four minutes and an half, at any place of the Earth?

*N.* It never can, even when it falls on the Equator, where the parts of the Earth's surface move the quickest of all. And when it falls upon any part of  
Britain,

Britain, whose motion is slower, because it is nearer the motionless pole, it would be sooner over.

*E.* How then could the Sun be darkened so long as three hours, at the time of our SAVIOUR's crucifixion, as it is mentioned to be in the Gospels?

*N.* There is no way of accounting for *that* darkness, upon astronomical principles: for it was entirely out of the common course of nature?

*E.* How do you prove that it was out of the common course of nature?

*N.* Because our Saviour was crucified on a full Moon day; and then, the Moon being opposite to the Sun, could not possibly hide the Sun from any part of the Earth.

*E.* I should be very glad to know how you can prove, that the crucifixion was on a full Moon day.

*N.* Because it was at the time of the Passover; and the Passover was always kept at the time of full Moon.

*E.* You have made this very clear.—  
And now, if you please, I should be  
glad

glad to have the cause of the Moon's eclipses explained.

*N.* In the same figure, draw the straight line *A g c* from the eastern edge of the Sun, close by the eastern edge of the Earth at *g*; and the straight line *B h k* from the western edge of the Sun, close by the western edge of the Earth at *k*.—Let these two lines be supposed to turn round the middle line *F M m*, and they will include the space between the part which is filled by the Earth's shadow *n c k h*—'Tis plain, that, when the Moon is at *m* in her orbit, she is totally covered by the Earth's shadow and eclipsed by it; as it must then fall upon her, because the Earth is between her and the Sun.

*E.* But how is it, that the Moon is at all visible, when the Earth must entirely stop the Sun's light from falling upon her; and she has no light of her own? For, the same side of the Moon that is toward the Earth at her change, is also toward the Earth at her full.—And, as we cannot see her at the change, I should think we could not see her  
when.

when she is totally eclipsed; because *that* side of her which is dark in the former case, when the Sun cannot shine upon it, should be as dark in the latter, when the Earth intercepts the Sun's rays from it.—But the Moon was very visible in her last total eclipse; for I saw her, and she appeared of a colour somewhat like that of tarnished copper.

N. You are very shrewd in your remarks, sister:—and I will tell you why the Moon is not invisible when she is totally eclipsed.

The air, or atmosphere, which surrounds the Earth, to the height of about 47 miles, is the cause of this. For, all the rays of the Sun's light which pass through the atmosphere, all round the Earth, in the boundary (*g h*) of light and darkness, are, by the atmosphere, bent inward, toward the middle of the Earth's shadow: and those rays, so mixed with the shadow, fall upon the Moon, and do enlighten her in some small degree. She reflects the rays back to the Earth which fall upon her, and so she

A a

is

is visible *only* on that account. For, if the Earth had no atmosphere, its shadow would be quite dark ; and the Moon would be as invisible, when she is totally immersed therein, as she is at the time of her change.

*E.* I thank you, brother, for all these informations ; but I still want more.

*N.* Only say what they are ; and I will inform you if I can.

*E.* I see plainly by the figure, that the Sun can never be eclipsed (in a natural way) but at the time of the new Moon ; because the Moon's shadow cannot fall upon the Earth at any other time ; and that the Moon can never be eclipsed but when she is full ; because that is the only time when the Earth's shadow can fall upon her. But though we have a new and a full Moon in every month of the year, I find my almanack mentions but very few eclipses ; and generally, about half a year between the times of their happening.

*N.* If the Moon's orbit *a b c k d a* lay exactly even (or in the same plane) with  
the

the Earth's orbit  $C b d D$ , as it is drawn on the flat paper, the Sun would be eclipsed at the time of every new Moon, and the Moon at the time of every full. But one half of the Moon's orbit lies on the North side of the plane of the Earth's orbit, and the other half on the South side of it: and consequently, the Moon's orbit only crosses the Earth's orbit in two opposite points.—When either of these points are between the Earth and the Sun, or nearly so, at the time of new or full Moon, the Sun or Moon will be eclipsed accordingly. But at all other new Moons, the Moon either passeth above or below the Sun, as seen from the Earth: and, at all other full Moons, the Moon either passeth above or below the Earth's shadow. One of those points is called *the Ascending Node* of the Moon's orbit; because, when the Moon has past by it, she ascends northward, or to us, above the plane of the Earth's orbit; and the opposite point is called *the Descending Node* of the Moon's orbit; because, as soon as she has past by it, she descends southward;

which, to us in the northern parts of the Earth, is below the plane of the Earth's orbit.

*E.* Supposing that either of these nodes were between the Earth and the Sun just now ; how much time would elapse before the other could be so ?

*N.* It would be just half a year, if a line drawn from the one to the other kept always parallel to its present position (like the above-mentioned diameter of the Moon's orbit, *k h*, in *Fig. 1.*): but the nodes move backward or toward the West, contrary to the Moon's motion eastward in her orbit, at the rate of  $19\frac{1}{2}$  degrees every year.—So that from the time of the Sun's being in conjunction with either of the Moon's nodes, to the time of his being in conjunction with the other, is only 173 days, 7 hours, 3 minutes.

*E.* As there must be *some* distances from these nodes, within which the Sun and Moon must be eclipsed ; I should be glad to know what these distances are ?

*N.* They.

N. They are only 17 degrees for the Sun, and 12 for the Moon.

E. Now, let me see.—The Moon's whole orbit contains 360 degrees ; of which there are only 17 on each side of each node, within which the Sun may be eclipsed.—Twice 17 is 34, about one node, and there are as many about the other : in all, 68 degrees out of 360, for eclipses of the Sun.—And, as there are 12 degrees on each side of each node, within which the Moon can be eclipsed, there must be no more than 48 degrees in all, out of the whole 360, for the eclipses of the Moon. Am I right, brother? If I am, 'tis no wonder that we should have so many new and full Moons, and so few eclipses.

N. You are quite right, *Eudisia* ; and I am very glad to find that you make such a quick progress.

E. I know that the times of eclipses may be calculated before-hand, because I see they are always predicted in the almanacks. Can you calculate them ?

N. Yes.

E. I wish

E. I wish you would teach me to do so too, if you think I have a sufficient capacity for that branch of science.

N. You have much more ; and I will instruct you with pleasure ; for you have not only learnt the four common rules of arithmetic, but even as far as the Rule of Three. —And in these calculations, no farther arithmetic is necessary than *addition* and *subtraction*. But you must learn first to calculate the times of new and full Moons.

E. That I will do with very great pleasure.

N. Then we will set about it to-morrow morning, if you please : but the whole will take up a week at least : during which time we must suspend our usual confabulations.

E. I wish *to-morrow* were come already.

N. You remember the book which you saw a few days ago in this room ; in which you told me you had taken notice of something concerning the ecliptic and its signs. —Did you look at the title-page of that book ?

E. I

*E.* I remember the book very well ; but did not look at the title-page.

*N.* It is *Ferguson's Astronomy*. I sent for it to a Bookseller's shop, in Dame-street, Dublin, on purpose to make you a present of it. There it is ; and I am sure you are qualified to read and understand it.

*E.* I heartily thank you, dear *Neander*, for this present.

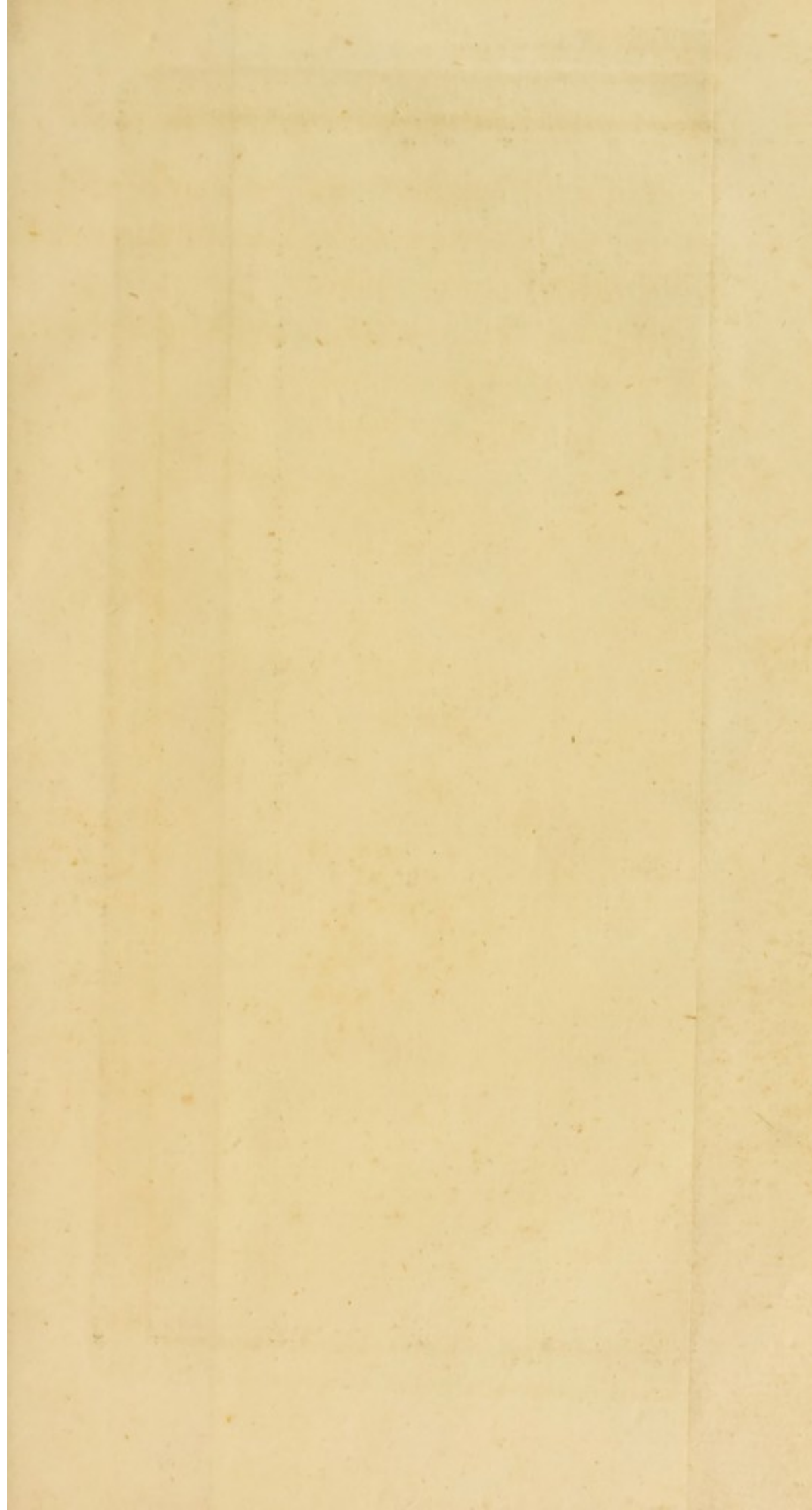
*N.* There are in it plain and easy tables and precepts for calculating the true times of new and full Moons and eclipses. And, if you have any spare time to-day, I wish you would begin, by yourself, to read the precepts, and compare them with the tables, and with the examples of calculation.—And then, if you find any thing difficult, mark it ; and I will help you out to-morrow morning. Mean time, if there be any thing else, which you would have us to talk about, before we are called to breakfast, (which is later than usual to-day) tell me what it is.

*E. I*

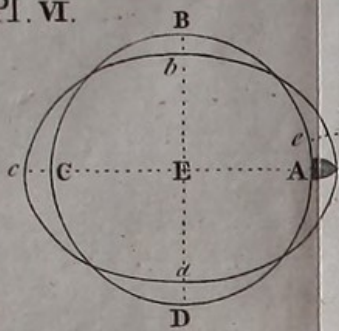
E. I wish I understood the cause of the ebbing and flowing of the sea. But now the bill begins to ring for us.

N. Very well.--Be here in about an hour after breakfast.

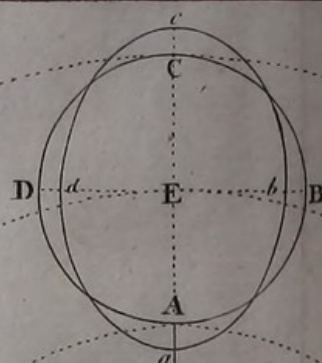
## DIALOGUE



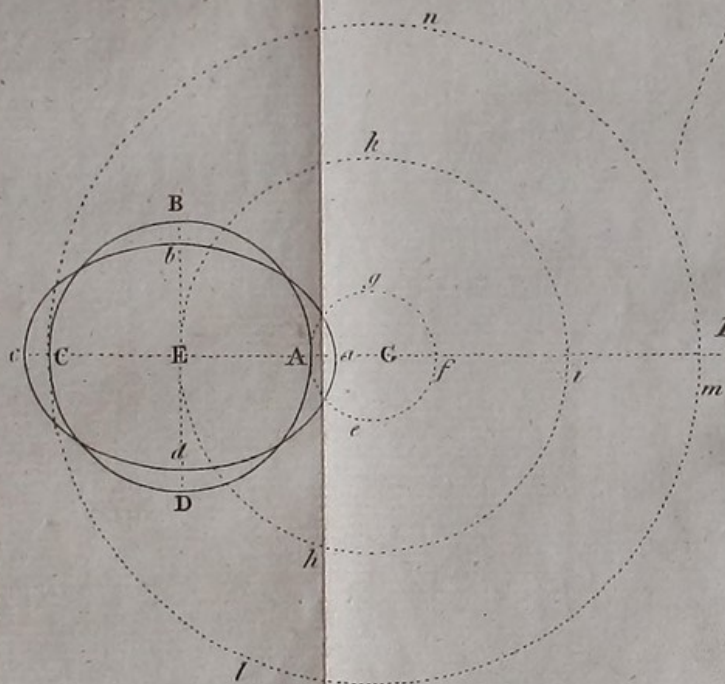
Pl. VI.



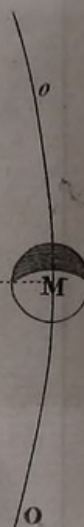
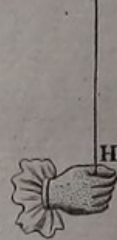
*Fig. 1.*



*Fig. 2.*



*Fig. 3.*



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## DIALOGUE VIII.

On the CAUSE of the EBBING and FLOWING of the SEA.

*Neander.*

**Y**OU are very punctual, sister.—I have drawn out some figures for you since breakfast; and, just as you entered the room, I was putting the last letter of reference to them. Here they are.

*Eudisia.* I thank you, brother; and do suppose that, by these figures, you intend to explain the cause of the ebbing and flowing of the Sea.

*N.* I do.—In *Fig. 1.* of PLATE VI. let *ABCD A* be the Earth, all covered with water, except the top of an island *A a*.

B b

Let

Let the Earth be in constant motion, turning eastward round its center  $E$ , every 24 hours according to the order of the letters  $ABCD$ ; and let  $M$  be the Moon, moving eastward in her orbit  $Oo$ , as from  $M$  to  $o$ , in 24 hours, 50 minutes. You know that the Earth and Moon are within the reach of each other's attraction; and therefore, as the Earth attracts the Moon, so the Moon re-attracts the Earth.

*E.* Yes, Sir.

*N.* Do you remember my telling you, some days ago, that the attraction diminishes, as the square of the distance from the attracting body increases?

*E.* I remember it very well.

*N.* Then you know, that the Moon must attract the side  $A$  of the Earth which is nearest to her (at any time) with a greater degree of force than she attracts the Earth's center  $E$ ; and that she attracts the center  $E$ , with a greater degree of force than she attracts the side  $C$  of the Earth, which is then farthest from her.

*E.* Certainly.

*E.* Certainly.

*N.* And that the Earth and Moon would fall towards one another, by the power of their mutual attractions, if there was nothing to hinder them: and that the Moon would fall as much faster toward the Earth than the Earth would fall toward the Moon, as the quantity of matter in the Earth is greater than the quantity of matter in the Moon.

*E.* Undoubtedly so: because every particle of matter attracts with an equal degree of force; and therefore, the body which has the greater quantity of matter must attract the other with so much the greater degree of force.

*N.* Well done, *Eudisia*. Let us now suppose the Earth and Moon falling toward each other. The earthy parts of our globe being connected, and cohering together, would not yield to any difference of the Moon's attractive force; but would all move equally fast toward the Moon: as if a cord were tied to each end of a great folio book on the table, and you should pull

one cord with the force of four pounds, and I pull the other cord the same way with the force of eight pounds, so as to move the book; all the parts of it will move equally fast, notwithstanding the different forces by which you and I pull it. But the waters are of a yielding nature; the coherence of their particles being very small: and therefore, they will be differently affected, according to the different degrees of the Moon's attractive force, at different distances from her.

And therefore, as the waters at *A* are more attracted by the Moon than the Earth is at its center *E*, they move faster toward the Moon than the Earth's center does; and consequently, with respect to the Earth's center, they rise higher toward the Moon, as from *A* to *a*: and as the center *E* moves faster toward the Moon, than the waters on its surface at *C* do; the waters at *C* will be, as it were, left behind: and consequently, with respect to the center *E*, they will be raised, as from *C* to *c*.

*E. So*

*E.* So far I understand you perfectly well.

*N.* But as there is still the same quantity of water on the whole Earth, the waters cannot rise at one place without falling at another.—And therefore, the waters must fall as low at *b* and *d* as they rise, at the same time, at *a* and *c*: so that an observer placed over *E*, at a distance from the Earth, would see the surface of the waters not of the round shape *A B C D*, as they would be if the Moon did not disturb them by her attraction, but of the elliptical shape *a b c d*.

Then, as the Earth turns eastward round its axis, 'tis plain, that when the island *A a* is at *A*, it will be in the *high water*, under the Moon *M*: when it is at *B*, it will be in the *low water*, six hours from under the Moon: when it is at *C*, it will be in the *high water* again, twelve hours from under the Moon: and when it is at *D*, eighteen hours from being last under the Moon, it will be in the *low water* again. So that if the Moon had no progressive motion in  
her

her orbit  $O o$ , but kept always in the same right line  $A M$ , the island  $A a$  would have two ebblings and two flowings of the Sea every 24 hours.

*E.* It would. But I find the tides are put down, in my almanack, later every day than on the day before. And now, I apprehend the reason of this to be, that as the Moon goes eastward round her orbit in a month, and the Earth turns eastward round its axis every 24 hours; the Moon makes *part* of a revolution in the time that the Earth makes *a whole* rotation: and therefore, the Earth must turn as much more than round its axis, before the same island can come even with the Moon again, as the Moon has advanced in her orbit during that interval of time.

*N.* You are right, *Eudisia*:—for, in the time of the island's revolving from  $A$  to  $A$  again (in the direction  $A B C D A$ ) which is 24 hours, the Moon moves from  $M$  almost to  $o$  in her orbit: and therefore, after the island has come round to  $A$  again,  
it

it must move on from *A* to *c*, before it can be in the middle of the tide of flood the next day, under the Moon, which will have then moved from *A* to *o*.

*E.* How long is the island in moving from *A* to *c*?

*N.* Full 50 minutes : and so much later are the tides every day than they were on the day before. The sailors call it only 48 minutes ; and it would be exactly so, if the Moon were 30 complete days and nights going round from change to change. But as the time is only 29 days, 12 hours, 54 minutes, 3 seconds, (at a mean rate) she must move a little farther every day than she would if she took the full 30 days : and this difference is equal to about 2 minutes of time of the Earth's motion on its axis.

*E.* Then as the Moon goes round her orbit, from change to change, in  $29\frac{1}{2}$  days, (in round numbers) the island *A a* can only come  $28\frac{1}{2}$  times round from the Moon to the Moon again, in that time ; and consequently

quently, it can have no more than twice that number of tides of flood, at *a* and *c*; or 57 tides of flood, and as many of ebb between change and change of the Moon.

*N.* You are very right: and consequently, in two courses of the Moon, from change to change, which is 59 days, 1 hour, 28 minutes, 9 seconds, there are only 57 double tides of flood and as many of ebb.

*E.* This account of the tides would be extremely natural, and easy to be understood, if the Earth and Moon were continually falling toward one another. But seeing that the Moon's motion in her orbit gives her a centrifugal force, equal to the force with which the Earth attracts her, she cannot fall toward the Earth at all. And, from what you told me, in our second dialogue, about the Earth and the Sun, I should think, that if the Earth itself did not describe a small orbit round the common center of gravity between it and the Moon, in the time the Moon goes round her orbit, the Moon's attraction would

would take the Earth away, as it could have no centrifugal force to balance her attraction.

*N.* Dear sister, you cannot imagine how much pleasure it gives me to talk with you on these subjects on account of the proper inferences and applications you make.—The Earth and Moon do really move round the common center of gravity between them every month: and it is *that* center of gravity that describes the very orbit in which the Earth's center would move round the Sun in a year, if the Earth had no Moon to attend it.

*E.* You may thank yourself, *Neander*, for all those inferences and applications; as they only result from your explanations, and leading me so gradually on, from one subject to another. But pray, how many miles is it from the Earth's center to the common center of gravity between the Earth and Moon? Undoubtedly *that* distance, compared with the Moon's distance from the Earth's center, must be in proportion to the quantity of matter in the

C c

Moon

Moon compared with the quantity of matter in the Earth.—If you will tell me how much greater the quantity of matter in the Earth is than the quantity of matter in the Moon, I will try to compute how far the common center of gravity between them is from the Earth's center.

N. The Earth's quantity of matter is 40 times as great as the Moon's.

E. Very well.—And the Moon's mean distance from the Earth's center is 240,000 miles.—Now, I divide 240,000 by 40, and the quotient is 6,000; which, I think, must be the distance of the common center of gravity between the Earth and the Moon from the Earth's center: and that the said common center of gravity must always be in a right line between the centers of the Earth and Moon; because both these bodies move round it.—Am I right, brother?

N. Indeed you are: and, before we talk further about the common center of gravity between the Earth and the Moon, I will endeavour to illustrate this affair  
about

about the tides to you, in a different manner from what I have done. For I find, that even if I had intended to explain it by the falling of the Earth and Moon toward each other, you would have justly believed that I was misleading you.

Here is a circular hoop (*Fig. 2.*) *ABCD*, of thin plate brass. You see it is very flexible: for, as I pull out the parts *A* and *C* to *a* and *c*, the parts *B* and *D* fall into *b* and *d*; and the hoop becomes of the elliptical shape *a b c d*.

*E.* True;—and just like the shape of the surface *a b c d* of the water, (in *Fig. 1.*) as affected by the Moon's attraction.

*N.* But, if I quit my hold of the hoop at *a* and *c*, it will return to its former circular shape *A B C D*.

*E.* I see it does, now you have left it at liberty.

*N.* And, if the Moon's attraction should cease (*Fig. 1.*) the waters *a b c d* would return from their elliptical shape *a b c d*, to their former round shape *A B C D*.

*E.* Yes; for they would run from the highest parts *a* and *c* to the lowest parts *b* and *d*, till their surface was equally distant from the Earth's center *E*, all around.

*N.* Now, I tie the end *A* (*Fig. 2.*) of the string *AH* to any part, as *A*, of the circular hoop *ABCD*, and take hold of the other end *H* of the string with my hand. If I whirl the hoop round my head like a sling, what do you think will happen?

*E.* Why; the hoop will endeavour to fly off, as a pebble in a sling would do.

*N.* True; but do you think that all the parts of the hoop will then have an equal tendency to fly off?

*E.* Let me consider——I think they will not. For as the part *C* will go round your head in the same time as the part *A*, but faster, because it is further distant from your hand; I imagine that the part *C* will have as much more tendency to fly off than the part *A* has, as its distance from your hand is greater.

*N.* Exactly

N. Exactly so, because it will move so much faster, as the circle it describes is larger. Now observe, I whirl it round my head. What shape is it *now* of?

E. It is of the elliptical shape *a b c d*.

N. Yes, for the tightness of the string draws out the side next my hand, from *A* to *a*; and the centrifugal force of the other side throws it out as far, from *C* to *c*.— And now, if an inflexible circular ring (like the rigid Earth) *A B C D* should light upon the elliptical hoop *a b c d*, and turn 29 times and an half round the center *E*, in the time the hoop and circle were moved once round my head; would not any point, as *A*, of the circular ring come successively even with the highest parts *a* and *c* of the elliptical hoop, and with the lowest parts *b* and *d* of it; as the island *A a* (*Fig. 1.*) comes to the high water at *a* and *b*, and the low water at *c* and *d*, by the Earth's motion on its axis?

E. It would. And I think that *Fig. 3* is somewhat anagolous to *Fig. 2*.

N. It

N. It is very much so; and now is the proper time to explain *Fig 3*.

Let  $A B C D$  be the Earth,  $M$  the Moon,  $O o$  part of the Moon's orbit, and  $G$  the common center of gravity between the Earth and the Moon, round which both these bodies move once a month; the Moon in the direction  $O o$ , and the Earth in the direction  $E h$ . By this motion all the parts of the Earth will have a centrifugal force, or tendency to fly off in or parallel to the line  $A E C$ : and the centrifugal force of each part will be directly in proportion to its distance from the common center of gravity  $G$ ; because the space through which these parts move will be respectively as their distance from  $G$ ; that is, as the semidiameters of those circles which they all describe in the same period of time. Thus, the centrifugal force of the point  $A$  will be as the line  $A G$ ; the centrifugal force of the center  $E$  will be as the line  $E G$ ; and the centrifugal force of the point  $C$  will be as the line  $C G$ : for the point  $A$  describes the small circle  $A e f g A$  in the time the point  $E$  describes

describes the larger circle  $E h i k E$ , and in the time the point  $C$  describes the still larger circle  $C' l m n C$ , which is in a month; and in that time, the Moon goes round her orbit  $O o$ .

The Moon's attraction at the Earth's center  $E$  exactly balances the Earth's centrifugal force at  $E$ ; and consequently retains the center  $E$  in the orbit  $E h i k E$ . But her attraction at  $A$  is greater than at  $E$ , and less at  $C$  than at  $E$ . So that where the Moon's attraction is greatest, as at  $A$ , the centrifugal force is least; and therefore, the excess of attraction causeth the water to rise, as from  $A$  to  $a$ , on the side of the Earth which is at any time nearest the Moon  $M$ . But, at  $C$  (the side which is then farthest from the Moon) the attraction is least, and the centrifugal force greatest: and therefore, the waters will rise as high from  $C$  to  $c$ , by the excess of the centrifugal force there, as they rise on the opposite side from  $A$  to  $a$  by the excess of the Moon's attraction. Are you satisfied now, *Eudisia*?

E. I.

E. I was sadly afraid, that the rising of the tides on the side of the Earth which (at any time, by its motion on its axis) is turned away from the Moon, would be very difficult to account for. But you have made it just as plain, that they must rise as high on the side of the Earth which is opposite to the Moon, as they do on the side which is under the Moon. Did you ever see this confirmed by an experiment?

N. Yes; I have seen Mr. *Ferguson* do it, to the satisfaction of every observer, by a plain experiment in one of his machines, called the *Whirling Table*; and he is the first that ever did so. He has given a full account of it in his *Lectures on Mechanics, Hydrostatics, Pneumatics, Optics, with the use of the Globes, and the Art of Dialling*. In that book, there are plates of all his machines for the above purposes. I shall send for it from Mr. *Williams's* shop to-morrow, and make you a present of it, on account of the quick progress you have made in astronomy: and

and then you can by yourself learn a course of experimental philosophy.

*E.* Indeed, brother, you lay me under so many obligations, that I shall never be able to make you any proper return for them. But there is one thing, that I had almost forgot to ask you. Pray what is meant by the *spring* and *neap tides*?

*N.* The Earth is so small in comparison of its distance from the Sun, that the Sun's attractive force is nearly equal on all parts of the Earth: and therefore there can be but little difference between the centrifugal force on the side of it which is next the Sun, and the centrifugal force on the opposite side. But still there is some difference, as the Earth moves on in its orbit. And therefore, if the Earth had no Moon to attend it, there would be *small tides* occasioned by the Sun. Consequently, when the Sun, Moon, and Earth are all in a right line (which they are at the time both of new and full Moon) their joint actions concur: and so, raise the tides

D d

higher

higher at these times than at any other : and those are called the *Spring Tides*. But, when the Moon is in her quarters, her action on the tides is *cross-wise* to the Sun's ; for then the Sun is in a line with the *low water*, and his action keeps the tides from falling so low there, and consequently from rising so high under and opposite to the Moon, as they would do by the action of the Moon, if the Sun did not disturb them at all ; and these are called *the neap Tides*.

*E.* I understand you very well ; and do see plainly, that a straight line, drawn from the Moon's center through the Earth's center, would be in the highest part of the tides on both sides of the Earth.

*N.* You are a little mistaken in that point, *Eudisia* ; which may be owing to its being so represented in the figures. But, I am sure you would not have been so, if you had remembered what I told you in our first dialogue ; namely, that all bodies which are put into a state of motion will persevere in that motion till

till something stops their course. If you put water into a basin, and give it a little shake, and then settle the basin suddenly; the water will rise a little further, on the side to which you gave it the motion. after the basin is settled again, than it did in the instant when you settled it. Pray, have you forgot your fall in the boat, when it struck against the bank of the river?

*E.* I have not, brother; and the inference is plain.

*N.* It is: and therefore you know, that when the waters are put into a rising state of motion by the action of the Moon; they would rise a little higher, if the Moon were annihilated at the instant of her being on the meridian, even of a place where she was directly over head. But you are still to consider farther; that, although the Moon's attraction at any place is greatest when she is on the meridian of that place, because she is then the nearest that she can be to the place on that day, yet her attraction at the place does not then cease, but continues for some

time after she has past the meridian: and this continuance of attraction, though weaker, will cause the waters to keep on in their rising state, till the attraction just balances the tendency of the waters to fall back again.

*E.* I thank you, brother, for setting me right. But, pray, how long is the Moon past the meridian, when the water is at the highest?

*N.* If the Earth was covered all over with water, so as the two eminences of the tides at *a* and *c* might regularly follow the Moon; she would always be three hours past the meridian of any given place, when the tide was at the highest at that place. But as the Earth is not all covered with water, and the different capes and corners of the land run out all manner of ways into the oceans and seas, the regular course of the tides is much interrupted thereby; and also by their running through shoals and channels. So that, at different places, the tides are highest at very different distances of the Moon from the meridian. But, at whatever distance the Moon is from the meridian,

meridian, on any given day, *at any place*, when the tide is at its height *there*, it will be so again on the next day, much about the time when the Moon is at the like distance from the meridian again.

*E.* You have quite satisfied me about the tides: and now I will go to my room, and study *Ferguson's* method of calculating the time of new and full Moons.

DIALOGUE

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DIALOGUE IX.

*On the fixed STARS, and SOLAR and SIDERAL TIME.*

*Neander.*

**W**HAT is the matter, fister?—Surely you could not have gone to your room and returned, since you left me.

*Eudisia.* I had scarce gone out of *this* room, when something came into my mind, which was, that you promised me, some days ago, to demonstrate that all the Stars are at rest——And lest I should forget it again, I now beg leave to remind you of it, if you have leisure at present.

N. For

N. For *that*, I refer you to *Ferguson's* astronomy: and, before you have read the first three chapters, you will not only be convinced that all the Stars are at rest; but also that they are Suns to innumerable systems of planetary worlds, as our Sun is to its own system of planets.

E. What? other Suns, and planetary worlds belonging to them! You amaze me!

N. The Deity is infinite in all his perfections: and as he has power enough to create and place Suns and worlds throughout the whole infinitude of space, so he has goodness enough to induce him to do it. But now, if you please, I will tell you of something which I did not think of before; namely, to inform you of the difference between *Solar* and *Sideral* time.

E. You speak too learnedly for me just now, brother; and it is the first time you ever did so.

N. *Solar* time is the time measured by the Sun's apparent motion round the Earth; and *Sideral* time is the time measured

measured by the Stars in *their* apparent motion round it.

*E.* Now I understand you: and have often observed, that if any Star be seen just, as if it were, over a neighbouring chimney, at any hour in the night; in a week afterward, the same Star is sooner seen over the same chimney.

*N.* True: and in 365 days, the stars seem to have made 366 revolutions about the Earth; so that they gain one hour every 24th part of the year upon the time shewn by a well regulated clock. And therefore, every Star comes almost four minutes sooner to the meridian, every succeeding day or night, than it did on the day or night before. The real difference is 3 minutes, 55 seconds, and 54 sixtieth parts of a second. So that, if one clock should be so well regulated as to shew the time to be XII at noon this day, and on the 365th day afterward, and another clock should be so regulated as to shew the time to be XII every day or night when any given Star is on the meridian; the latter clock would gain 3 minutes 55 seconds

55 seconds, and 54 fixtieth parts of a second upon the former, in each revolution of the same Star to the meridian.

*E.* What is the reason of *this* ?

*N.* Much the same as *that* of the Moon's going round her orbit in less time than she goes round from change to change, or from between the Earth and the Sun to the same position again: as I explained to you, by *Fig. 1.* of PLATE V. last Monday morning, in our Seventh Dialogue: And we may make the same figure do for the present subject. You remember I told you that the whole diameter of the Earth's orbit is but as a point, in comparison to the distance of the Stars; which is the same as to say, that a globe of 190 millions of miles in diameter, which would fill the Earth's orbit, would appear no bigger than a dimensionless point, if it were seen from any of the Stars: and the present subject will prove this to be true.

*E.* I am far from doubting the truth

E e

of

of your word; but I should be very glad to see the demonstration.

N .Then here it is. Let the Earth be in what part of its orbit it will, we always find the interval of time (by the best clocks that are made) between any Star's revolving from the meridian to the meridian again, to be equal throughout the whole year: which it could not be, if the Earth's changing its place by a whole diameter of its orbit, bore any sensible proportion to the distance of the Stars. For then, if the hour and minute-hands of a clock should revolve exactly 366 times from XII to XII again (there being supposed to be 24 hours on the dial-plate) in the time of the Star's making 366 revolutions from the meridian to the meridian again; and the hands be set to the uppermost XII, when any given Star is to the meridian on the 21st of December; then on the 20th of March afterward, when the hands were at the same XII as before, the same Star would be a little on the East side of the

the

the meridian, if the Earth's orbit were of any sensible bigness in proportion to the distance of the Star; and a little on the west side of the meridian, when the hands were at XII on the 23d of September; but we never find any such difference.

*E.* To me your demonstration is self-evident.

*N.* Then, you are convinced, that when the meridian of any place has revolved from any Star to the same Star again, the Earth has turned *absolutely* once round its axis; because the same meridian has revolved so, as to be again parallel to any fixed plane, to which it was parallel before, when the same Star was upon it?

*E.* I am.

*N.* Very well, sister.—Now, in *Fig. 1.* of PLATE V. let *S* be the Sun, *A B C D E F G* one half of the Earth's orbit; let the circle *h i k l k* be the Earth (at the top of the figure) and *a h* the meridian of London, which we shall suppose to be at *h*.

Let the straight line *a h S* be produced

*E e 2*

onward,

onward, to five or six miles beyond the Sun  $S$ , as seen from  $h$ ; and let a Star be placed at the farthest end of that line—Then, the distance of the Star from the Sun will be so great, that the Earth's orbit  $A B C$ , &c. will bear no sensible proportion thereto, if it were viewed from the Star; and therefore, to an observer on the Earth at  $h$ , the Star will appear as even with the line  $d h$ , when the Earth has got a quarter round its orbit from  $a$  to  $d$  and the meridian  $d h$  parallel to the position it had at  $a h$ , as when the Earth was at  $a$  in its orbit: So that, let the Earth be in what part of its orbit it will, the Star will always be upon the meridian of the place  $h$ , when *that* meridian has revolved to the same parallel position again; which it will always do in the time of the Earth's turning *absolutely* round its axis.

*E.* Undoubtedly it will.

*N.* Now, suppose the Earth to advance in its orbit from  $a$  to  $b$ , in the time that it turns once round its axis; and then, the *same* meridian  $b h$  will be parallel

parallel to the position it had at  $a h$ , when the Sun and Star were *both* even with it; or, as we say, upon it.

Then it is plain, that when the Earth is at  $b$ , and the meridian  $b h$  has revolved from the Star to the Star again, it must revolve further on, from  $b$  to  $m$ , before it can go round from the Sun to the Sun again at  $S$ . And the arc, or part  $h m$ , of the Earth's circumference bears the same proportion to the Earth's whole circumference, that the arc, or part  $a h$ , of the circumference of the Earth's orbit bears to *its* whole circumference.

When the Earth is at  $c$  in its orbit, and the same meridian  $c h$  comes even with the Star the second time, the meridian must revolve from  $h$  to  $n$  before it can be even with the Sun again, or the Sun be upon it the second time.

When the Earth is at  $d$ , a quarter round its orbit from  $a$ , and the meridian  $d h$  is even with the star; the meridian will want six hours of being even with the Sun in the right line  $d o S$ , and the place

place  $h$  must revolve 6 hours, or through the arc  $h o$  of 90 degrees, before the Sun can be on its meridian  $d h$ .

And consequently, when the Earth has gone half round its orbit, the same meridian will be even with the Star 12 hours before it revolves to the Sun; and when the Earth has gone three quarters round its orbit, the meridian will be even with the Star 18 hours before it comes to be even with the Sun.

And lastly, when the Earth has gone quite round its orbit, its rotation on its axis will have brought the same meridian once more round from the Star to the Star again, than from the Sun to the Sun again.—So that, let that year contain how many days it will, as measured by the apparent revolutions of the Sun from the meridian to the meridian again, it will contain one day more, as measured by the apparent revolutions of the Stars.

*E.* By this I find, that one absolute turn of the Earth round its axis is lost in a year with respect to the number of solar days in the year, because the Earth's motion on its axis is the same way as its  
motion

motion round the Sun. For to bring any meridian round from the Sun to the Sun again, the Earth must turn as much more than quite round its axis, as bears a proportion to the space it moves in its orbit in 24 solar hours. And therefore, to make the year contain 365 solar days and nights, the Earth must turn 366 times round its axis.

*N.* You are right, *Eudisia*.—Now go to your astronomical tables and precepts; and try whether you can calculate the time of new Moon in July 1748 old stile.—If you find any difficulty, come and tell me of it.

*E.* I thank you brother; and make no doubt but that I must soon see you again.

## DIALOGUE X.

*On the PROJECTION of SOLAR ECLIPSES: to which ANSWERS  
to some ASTRONOMICAL QUESTIONS are subjoined.*

*Neander.*

**W**ELL, sister;——you kept quite alone, all the time yesterday after you left me: and as you did not return this morning before breakfast, as usual, I sent to enquire about your health, and the maid told me that you were very well; but so much engaged with your book and pen, that she was almost afraid to speak, for fear of disturbing you; as you took no notice of her when she came into your room.

*Eudisia.*

*Eudisia.* Indeed, brother, I have been very much engaged; and scarce took time to eat either dinner or supper.

*N.* So I observed: and now, pray, what have you been doing?

*E.* After looking a little at *Ferguson's* tables for calculating the true times of new and full Moons, and finding some expressions in the titles of the tables which I did not understand, namely, the *mean Anomalies* of the Sun and Moon; I read the former part of the 19th chapter of his book, in which I not only found *these terms* explained to my satisfaction; but also the *principles* on which the tables are constructed: and, on account of what you have already told me about the attractions of the Sun, Moon, and Earth, I think I understand the principles tolerably well.

*N.* I can very easily take your word for that, *Eudisia.*

*E.* Having read the *precepts*, and compared them with the tables and *examples of calculation*, I then tried to calculate the true times of some new and full moons

which are exemplified in the precepts; and finding my calculations to agree very nearly with *Ferguson's* examples, I tried to calculate the true time of new Moon in July 1748, old stile, as you desired me; of which Mr. *Ferguson* has given no example.—And finding that the Sun must have been eclipsed at the time of *that* new Moon, I even *attempted* to take out the *elements* for projecting that eclipse.

N. Then, indeed, you must have done a great deal of work for the time you have been about it.—Pray, shew me your calculations.

E. I am almost afraid to do it:—but, here they are.

	day	h.	m.	s.
1. The apparent time of new Moon at Greenwich, July in the Forenoon.	14	11	15	3
2. The semi-diameter of the Earth's disc at that time, as seen from the Moon.	0	1	11	
3. The angle of the Moon's visible path with the ecliptic	0	53	32	
4. The Moon's latitude, North descending	5	35	0	
5. The Moon's horary motion from the Sun	0	28	6	
6. The Sun's distance from the nearest solstice	0	27	17	
7. The Sun's distance from the nearest solstice	32	42	40	
8. The Sun's declination, North	19	35	21	
9. The Sun's distance at noon from the vertex of London	31	54	39	
10. The Sun's semidiameter	0	15	50	
11. The Moon's semidiameter	0	14	53	
12. The semidiameter of the Penumbra	0	30	43	

N. Well done, *Eudisia*.——I calculated  
the

the same elements before I gave you the book; and now we will compare the calculations together.—All right—for, do you see,—we have not differed three seconds in any part.—And I did not tell you till now, that I had made any such calculation.

*E.* This gives me great pleasure, indeed.—But upon reading the method of projecting eclipses, I often find mention made of a *Sector*, which I take to be a mathematical instrument, and, as you know that I am entirely unacquainted with any of these instruments, I am afraid I can proceed no further, unless you will shew me a *Sector*, and teach me how to use it.

*N.* It is true, that by means of a *Sector*, those kinds of projections may be much sooner made than without it—But, as I know you are yet totally unacquainted with mathematical instruments, I will now shew you how to project an eclipse of the Sun, only by means of a pair of compasses and a common ruler: And then, you will be at no loss about projecting any eclipse

of the Moon; which is much easier to be done than to project an eclipse of the Sun. —I will first tell you some things, by which you will understand the reason why all the different parts of the construction of a solar eclipse must be as we lay them down; and then proceed to construct the Sun's eclipse which fell on the 14th of July 1748, as it appeared at London. You know, it is but a few days since you covered one of the panes of glass in the window of your room with gum water; and, when it was dry, you placed yourself about a foot from the glass; and, keeping your head steady, you delineated a landscape on the glass, with your black lead pencil, of all the distant objects which you saw through the glass, drawing them on those parts of the glass which were just between them and your eye; as if the pencil had touched the objects themselves.

*E.* I have often done so: then drawn them with ink (which the gum water causes to stick) and then laid a paper over

over them on the glafs, and traced them thereon with the black lead pencil.

N. Now, fuppofe the Equator to be a vifible circle on the Earth, and that a circle is drawn through any place (as fuppofe London) parallel to the Equator: that the Earth had an axis put through it, projecting out a good way from its furface at each pole; and that there was a vifible line drawn perpendicular to the plane of the ecliptic or Earth's orbit, which line would be called the axis of the ecliptic.

Imagine all thefe things would be vifible to an obferver at the Sun; and fuppofe yourfelf to be there, holding a pane of glafs between you and the Earth, and delineating the figure of the Earth thereon, with its axis, Equator, the circle parallel to the Equator paffing through London, and the axis of the ecliptic. Then,

As the Earth turns round its axis from weft to eaft, the places on its furface would appear to you to move as from your left hand toward your right; and  
you

you would see London as moving over the Earth in the circle which is drawn through it, parallel to the Equator. And, when the Moon is new, and eclipseth the Sun from any part of the Earth, you would see her between you and the Earth, as passing over it from left to right hand, the same way as it turns on its axis: and you would see a great part of the Moon's penumbra or partial shadow, all around her (as it were) like a dark brownish ring travelling with her over the Earth.

As the Sun shines round the North pole of the Earth from the 20th of March to the 23d of September, you would see *that* pole all the while in the enlightened part of the Earth's disc (or flat round surface, as it would appear to you; like as the Sun and Moon do to us): and from the 22d of September to the 20th of March, the same pole would be hid from your eye-sight, behind the visible and illuminated disc of the Earth; because it is in the dark all that time.

If

If a straight walking stick be placed at a distance from you, and inclining either directly toward you or from you, it will appear to you to be upright: but, if it inclines either toward your right or left hand, you will perceive it to do so. Therefore, when the Earth's axis inclines either directly toward you or from you at the Sun, it will appear to you to be perpendicular to the plane of the Earth's orbit or ecliptic; and to coincide with the axis of that plane. But, when the Earth's axis inclines more or less sidewise to the Sun, the northern half of it will appear to you to incline from the axis of the ecliptic, toward your right or left hand; and the southern half to incline the contrary way from the axis of the ecliptic: for then, these two axis will seem to cross each other in the middle point of the Earth's axis.

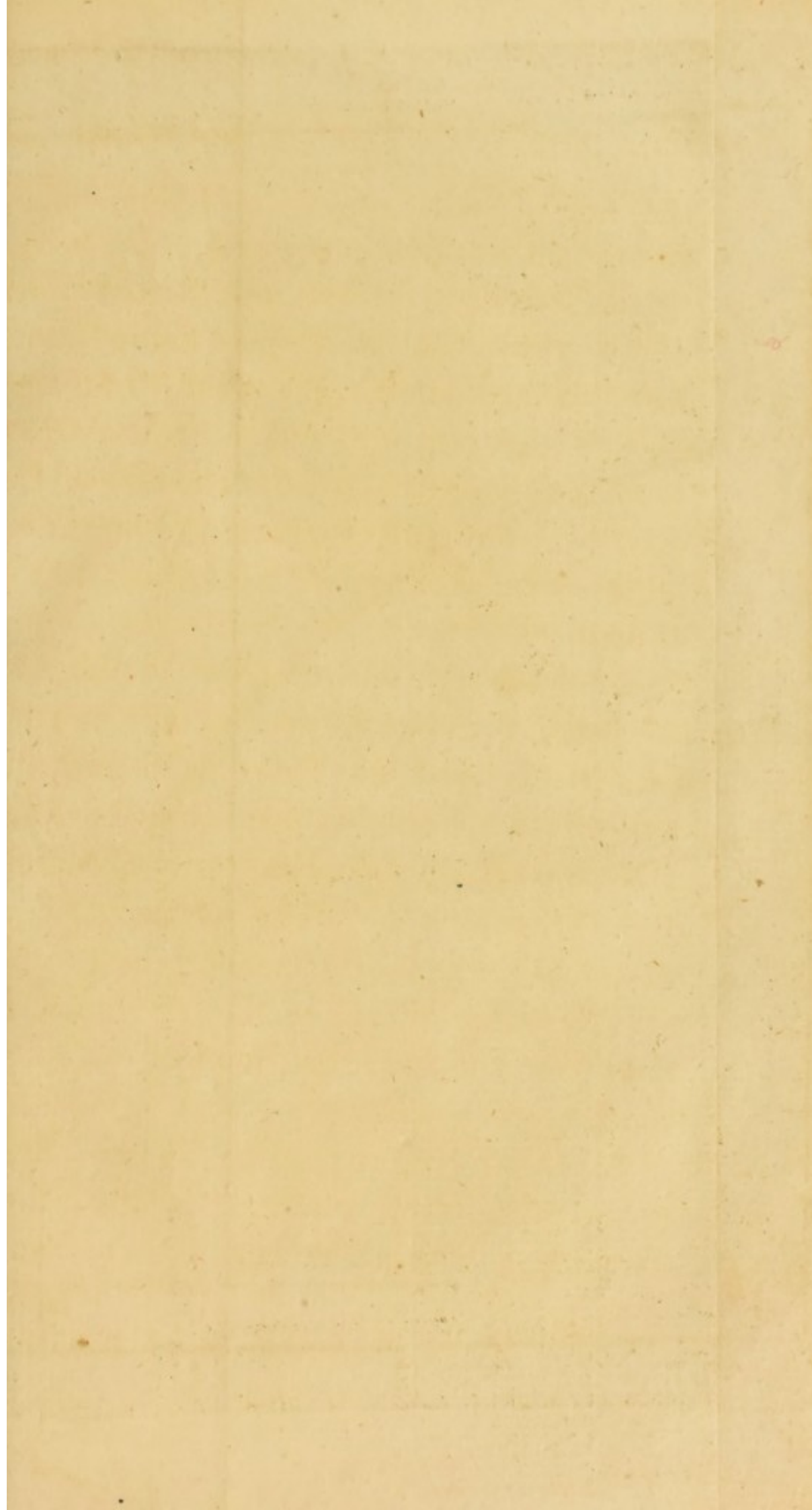
Now, as the Earth's axis really inclines  $23\frac{1}{2}$  degrees from a perpendicular to the plane of the Earth's orbit, and always keeps inclining to one and the same side of the Heavens, in the Earth's whole course round  
the

the Sun: it will appear in different positions of inclination to the axis of the ecliptic, as seen from the Sun, at different times of the year; the North pole being sometimes toward your right hand from the axis of the ecliptic, and at other times toward your left hand from the axis of the ecliptic; constantly varying the apparent angle of its inclination, according to the time of the year.

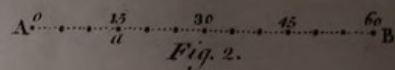
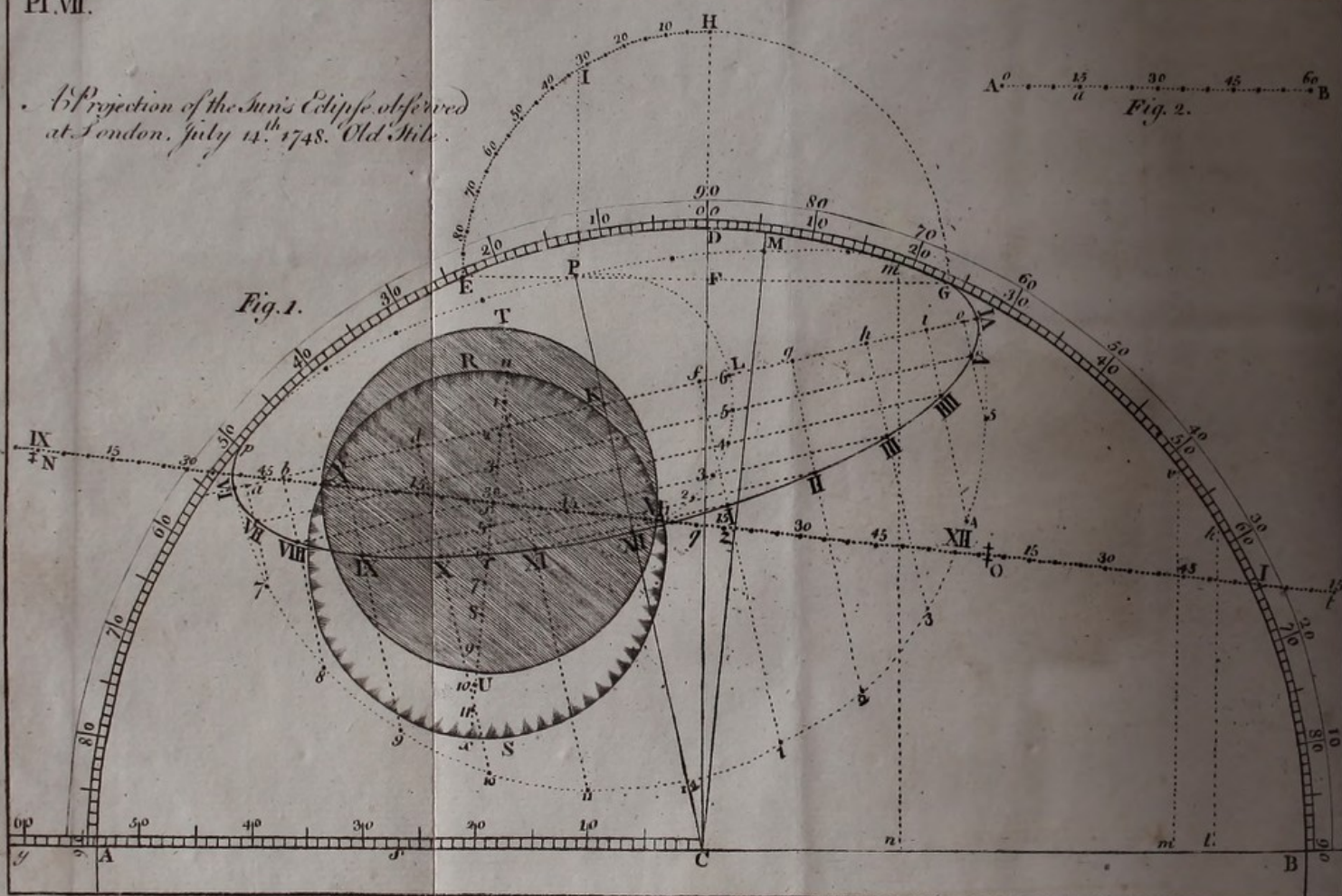
From the 21st of December to the 21st of June, the North pole of the Earth's axis lies toward the right hand from the axis of the ecliptic, as seen from the Sun; and most of all so on the 20th of March. From the 21st of June to the 21st of December, the North pole of the Earth's axis lies more or less to the left hand, as seen from the Sun; and most of all so on the 23th of September.

*E.* I wish you would be so good as to write down these matters for me when you are at leisure; because I am afraid I shall forget them.

*N.* You



• Projection of the Sun's Eclipse observed  
at London, July 14.<sup>th</sup> 1748. Old Style.



*N.* You may depend upon it that I will; especially as they are the very principles on which we are now about to construct an eclipse of the Sun: which is, in the first place, by delineating a figure of the Earth, with its axis, equator, &c. according to their positions as supposed to be seen from the Sun (or from the Moon just between the Earth and the Sun) at the time of the eclipse. Now, we will go to work, according to your calculated elements.

Make a scale, as *y A C* (PLATE VII. *Fig. 1.*) almost half the length of the paper intended for your projection, and divide it into 60 equal parts at least, reckoning each part to be one minute, or a sixtieth part of a degree.—Then, take the semidiameter of the Earth's disc, 53 minutes, 32 seconds, (or  $53\frac{1}{2}$ ) from the scale, in your compasses; and with that extent, set one foot in the end *C* of the scale, as a center; and with the other foot describe the semicircle *A B D*, for the circumference of the northern half of the

G g

Earth's

Earth's illuminated disc or surface, because we live on the North side of the Equator: and continue the line  $y A C$  on to  $B$ ; so  $A B C$  shall be a portion of the Ecliptic equal to the diameter of the Earth, as seen from the Sun or Moon at that time.

From the center  $C$  raise the line  $C D H$ , perpendicular to  $A C B$ ; and call the line  $C D H$  the axis of the ecliptic.

Divide the quadrants  $A D$  and  $D B$  each into 90 equal parts for degrees, beginning at  $D$ . Then connect the points  $E$  and  $G$  (which are  $23\frac{1}{2}$  degrees on each side of  $D$ ) with the straight line  $E F G$ ; in which line, the North pole  $P$  of the Earth's disc will always be found.

Set one foot of the compasses in the point  $F$ , where the line  $E F G$  intersects the axis of the Ecliptic  $C D H$ ; and having extended the other foot from  $F$  to  $E$ , or from  $F$  to  $G$ , describe the semicircle  $E H G$ , and divide its quadrant  $H E$  into 90 equal parts for degrees, because the Earth's axis lies to the left hand from the axis of the Ecliptic, as seen from the Sun in the month of July.—If the Earth's  
axis

axis had lain to the right hand from the axis of the Ecliptic, the quadrant  $H G$  must have been divided into 90 degrees, and not the quadrant  $H E$ .

As the Sun is 32 degrees, 42 minutes, 40 seconds (which may be estimated 32 degrees and four-sixths, or two-thirds, of a degree) from the nearest (or summer) solstice, which is the first point of Cancer, on the noon of the 14th July 1748, draw the right line  $I P$ , parallel to  $H D$ , from  $32\frac{1}{2}$  degrees of the quadrant  $H E$  till it meets the line  $E F G$  at  $P$ : then, from  $P$  to  $C$  draw the right line  $P C$ ; so  $P C$  shall be the northern half of the Earth's axis, and  $P$  the North pole.

As the Sun is on the North side of the Equator in July, and consequently nearer the point of the Heaven just over London (or the vertex of London) than the Equator is; subtract his declination, 9 degrees, 35 minutes (neglecting the 21 seconds) from the Latitude of London, 51 degrees, 30 minutes, and the remainder will be 31 de-

grees, 55 minutes, for the Sun's distance from the vertex of London on the noon of July the 14th.

From the point *k* (in the right hand side of the semicircle *A D B*) at 31 degrees, 55 minutes, counted upward from *B*, draw the right line *k l* parallel to *C D*: and, taking the extent *k l* in your compasses, set it from *C* to XII on the Earth's axis *C P*. So, the point XII shall be the place of London on the Earth's disc, as seen from the Sun, at the instant when it was noon at London on the 14th of July 1748.

Add the Sun's declination,  $19^{\circ} 35'$ , to the Latitude of London  $51^{\circ} 30'$ , and the sum will be 71 degrees, 5 minutes, for the Sun's distance from the vertex of London on the 14th of July at midnight. Therefore,

From  $71^{\circ} 5'$ , counted upward in the right hand side of the semicircle *A D B* from *B* to *m*, draw the right line *m n* parallel to *C D*. Then, taking the extent *m n* in your compasses, set it from *C* towards or beyond *P* on the Earth's axis *C P*, as it happens to reach short of *P* or

*P* or beyond it: but in the present case, it reaches so little above *P*, that we may reckon *C P* to be its whole extent; and so, the point *P* shall represent the place or situation of London at midnight, beyond the illuminated part of the Earth's disc, as seen from the Sun; and consequently in the dark part thereof.

Divide the part of the Earth's axis between *XII* and *P* into two equal parts, *XII K* and *P K*: then, through the point *K* draw the right line *VI K VI* perpendicular to the Earth's axis *C XII K P*.

Subtract the Latitude of London,  $51^{\circ} 30'$ , from  $90^{\circ} 00'$ ; and there will remain  $38\frac{1}{2}$  for its Co-latitude.—Then, from  $38\frac{1}{2}$ , counted upward from *B* to *v* in the semicircle *A D B*, draw the right line *vw*; and, having taken its length in your compasses, set off that length both ways from *K* in the Earth's axis to *VI* and *VI*, in the line *VI K VI*.

Now, to draw the parallel of Latitude of London, or its path on the Earth's disc, as seen from the Sun, from the  
time

time of Sun-rise till the time of Sun-set at London, proceed as follows :

The compaffes being opened from *K* to *VI*, fet one foot in *K*, and with the other foot describe the femicircle *VI* 7 8 9 10 11 12 1 2 3 4 5 *VI*, and divide it into twelve equal parts. Then, from the divifion-points (7 8 9, &c.) draw the right lines 7*a* 8*b* 9*c* 10*d*, &c. all parallel to the Earth's axis *C P*, as in the figure.

Set one foot of the compaffes in *K*, and with the other foot describe the femicircle *PL* XII, and divide its quadrant XII *L* into fix equal parts, as at the points 1, 2, 3, 4, 5, 6,; becaufe the Sun is on the North fide of the Equator. If he had been on the South fide of it, the quadrant *P L* (and not the quadrant XII *L*) muft have been fo divided.

Through the faid divifion-points of the quadrant XII *L*, draw the right lines XI 1 I, X 2 II, IX 3 III VIII, 4 IV, and VII 5 V, all parallel to the right line VI *K VI*; and, through the points where thefe lines meet the former parallel

parallel lines *7a*, *8b*, *9c*, *10d*, &c. draw the elliptical curve VI VII VIII IX X XI XII I II III IV V VI; which may be done by hand, from point to point; and set the hour-letters to those points where the right lines meet in the curve, as in the figure. The curve shall represent the parallel of Latitude of London, or, the path which London (by the Earth's motion on its axis) appears to describe on the earth's disc, as seen from the Sun on the 14th of July, from VI in the morning till VI at night: and the points VI, VII, VIII, IX, &c. in the curve shall be the points of the disc where London would be at each of these hours respectively, as seen from the Sun. If the Sun's declination had been as far South as it was North, the dotted curve VI *P M* VI would have been the path of London; which must have been found by dividing the quadrant *P L*, into six equal parts, and drawing lines parallel to VI *K VI* between that line and the pole *P*, and continuing the lines *7a*, *8b*, *9c*, &c. till they met the foresaid parallel lines drawn  
through

through the division-points of the quadrant  $P L$ .—The points  $p$  and  $G$ , where the elliptical curve touches the circumference of the disc, denote the instants of the Sun's rising and setting at London: for, when London is at  $p$ , it will be just entering into the enlightened part of the Earth; and going into the dark, when it is at  $G$ .

From the point  $M$ , viz. 5 degrees, 35 minutes to the right hand of the axis of the Ecliptic  $C D$ , draw the right line  $M C$  for the axis of the Moon's orbit, as seen from the Sun, because the Moon's Latitude is *North descending*, on the 14th of July 1748.—If her Latitude had been *North ascending*, the axis of her orbit must have been drawn 5 degrees 35 minutes on the left hand side of the axis of the Ecliptic.

Take the Moon's Latitude,  $28' 6''$ , from  $C$  to  $s$ , with your compasses, in the scale  $A C$ , and set that extent from  $C$  to  $q$  on the axis ( $C D$ ) of the Ecliptic.—Then, through the point  $q$ , draw the right line  $N q O t$ , perpendicular to the axis of  
the

the Moon's orbit  $C \approx M$ : and  $N q O t$  shall be the path of the center of the Moon's shadow over the Earth; and will represent as much of the Moon's orbit, seen from the Sun, as she moves through, during the time that her shadow or penumbra is going over the Earth.

From  $C$ , on the scale  $A C$ , take the Moon's horary motion from the Sun,  $27' 17''$  in your compasses; and make the line  $A B$  (*Fig. 2.*) equal in length to *that* extent: and divide the said line into 60 equal parts for so many minutes of time.—Then, as the time of new Moon, on the 14th of July 1748, was at 15 minutes, 3 seconds after XI o'clock, take 15 minutes (neglecting the three seconds) from  $A$  to  $a$  on the line  $A B$  in your compasses, and set them off, in *Fig. 1.* from the *middle point* between  $q$  and  $z$ , in the right line  $N q \approx O$ , to XI in that line; because the tabular time of new Moon is mid-way between the point  $q$ , where the axis  $C D$  of the Ecciptic and the axis  $C M$  of the Moon's orbit

H h

cuts

cuts the line or path of the penumbra's center on the Earth.

Take the whole length of the line *AB* (*Fig. 2.*) in your compasses; and, with that extent, make marks along the line *NO* (*Fig. 1.*) both ways from *XI*; and set the hour-letters to these marks, as in the figure.—Then, divide each space from mark to mark into sixty equal parts or horary minutes, which shall shew the points of the Earth's disc where the center of the penumbra falls, at every hour and minute, during its transit over the Earth.

Apply one side of a square to the line of the penumbra's path *NO*, and move the square forward or backward till the other side cuts the same hour and minute, as at *s* and *r*, both in the path of the penumbra's center and the path of London: and the *minute*, which the square cuts at the same instant in both these paths, is the *instant* of the visible conjunction of the Sun and Moon at London: and consequently, of the greatest obscuration of the Sun by the Moon; which, according to the

the projection, is at 30 minutes past X o'clock in the morning.

Take the Sun's semidiameter,  $15' 50''$  in your compasses from the scale, and setting one foot at  $r$  as a center, in the path of London, with the other foot describe the circle  $RS$  for the Sun, as seen from London at the time of greatest obscuration. Then take the Moon's semidiameter,  $14' 53''$ , in your compasses from the scale; and setting one foot in the Moon's path at  $s$ , with the other foot describe the circle  $TU$  for the Moon, as seen from London, when she obscures most of all of the Sun, during the eclipse: which may be measured by a diameter line  $usrx$  drawn across the Sun through the points  $s$  and  $r$ , and divided into 12 equal parts for digits of the Sun's diameter: of which, according to the present projection, there are  $9\frac{2}{3}$  digits eclipsed.

Take the semidiameter of the penumbra  $0', 43'$ , from the scale in your compasses: and setting one foot in the path of the

H h 2

penumbra's

penumbra's center, direct the other foot to the path of London among the morning hours at the left hand; and carry that extent backwards and forwards, till both the points of the compasses fall into the same instant in both the paths; which instants will denote the time when the eclipse began at London. Then, do the like among the afternoon hours; and where the points of the compasses fall into the same instant in both the paths, they will shew at what time the eclipse ended at London.—These trials shew that the beginning of the eclipse was just at IX o'clock in the morning, and its ending at 7 minutes after XII o'clock at noon, as the compasses reach just from IX in the path of London to IX in the path of the penumbra's center; and from 7 minutes after XII in the path of London to 7 minutes after XII in the path of the penumbra's center.—Thus, we have, at last, finished the projection, and found what was wanted to be known from it.

E. The

*E.* The whole process is very pleasant, but, I think, it is somewhat tedious.

*N.* That is, because we have been obliged to divide the semicircle  $A D B$  and the quadrant  $E H$  with a pair of compasses.—If the Sector had been used, the labour would have been much shortened, because we could have taken off all the measures directly from it; and so have avoided all the trouble of dividing, not only of the semicircle and quadrant, but also even of the scale.

*E.* I wish you would teach me how to use the Sector.

*N.* I will send to my mathematical instrument-maker, Mr. *Bennet*, in Crown-Court, near St. Ann's Church, Soho, for a complete case of mathematical instruments; and will make you a present of it, and instruct you how to use them before I leave this place. In the mean time, I will ask you a few questions relative to the subjects we have been upon: and, if you can answer them cleverly, I shall not scruple to tell you, that

that you have made a very extraordinary progress.

*E.* I thank you, Sir, for your intended present and future instructions: and will answer your questions as well as I can\*.

*N.* What would be the consequence, if the earth were fixed in any point of its orbit, so as to have no progressive motion therein; and to turn round its axis with its present velocity, having its axis perpendicular to the plane of the Ecliptic?

*E.* The solar, or natural day would be of the same length with the sydereal day; which is equal to 23 hours, 56 minutes, 4 seconds of the time now measured by a well regulated clock. The Sun would constantly appear to revolve in the Equator, days and nights would always be of an equal length at all places, either near the poles or far from

\* The substance of what is here put down, by way of question and answer, was given by the author some time ago to a gentleman who has since published it, not without the author's leave, at the end of a printed book.

them. And consequently, there would be no different seasons.

N. What would be the consequence, if the Moon's distance from the Earth was such, as that she should appear to be of the same magnitude with the Sun; that her orbit were circular, and lay in the plane of the Ecliptic; and that she moved round the Earth in her orbit with her present velocity?

E. The Moon would always revolve in the plane of the Equator; and (supposing the Earth had no progressive motion in its orbit) the Moon would go round from change to change in the time she now goes round her orbit, which is, in 27 days, 7 hours, 43 minutes, 5 seconds. The diameters of the Sun and Moon would always appear to be equal. The Moon would eclipse the Sun totally, for an instant of time, at all those places over which the center of her shadow passed, which would be directly along the Equator. The eclipses would be only partial on different sides of the Equator, and never visible at  
more

more than 2350 miles from it. The Moon would be totally eclipsed in the Earth's shadow at every time she was full; and the durations of all her eclipses would be equal.

*N.* What would be the consequence, if the Moon's orbit acquired an elliptical form, such as it is now of: that it continued in the plane of the Ecliptic, and the Earth had no progressive motion, but only turned round its axis as before?

*E.* The lengths of days and nights would be the same as above, and the times between the new or full Moons would remain the same. The Sun would be eclipsed (as above) at every change, and the Moon at every full; and the center of the Moon's shadow, when the Moon is new, would always pass along the Equator. If the changes fell in that part of the Moon's orbit which is furthest from the Earth, the Sun would never be totally eclipsed; but would appear like a fine luminous ring all round the dark body of the Moon,

Moon, at these places on the Equator where the Moon was directly over head at the instant of the change. If the changes fell in that part of the Moon's orbit which is nearest the Earth, all the eclipses of the Sun would be total at the Equator, for about four minutes of time: But if they fell in either of the two parts of the Moon's orbit, which are at a mean between those parts which are at the greatest and least distance from the Earth, the eclipses of the Sun would be just total for an instant of time at the Equator, and no where else. All the Moon's eclipses would be total with continuance, as above.

*N.* Suppose now, that the Earth should revolve about the Sun, with its present velocity, in the plane of the Ecliptic, its axis keeping always perpendicular thereto: that the Moon should revolve as above, with her present velocity; and that her orbit should remain always in the plane of the Ecliptic?

*E.* In that case, the days and nights would always continue (as above) of

equal length; only the 24 solar hours would be 3 minutes, 56 seconds longer than the 24 sydereal hours, as they now are; but there would be no different seasons. The Moon would go round her orbit in 27 days, 7 hours, 43 minutes, 5 seconds; and round from the Sun to the Sun again, or from change to change, in 29 days, 12 hours, 44 minutes, 3 seconds; as she now does. The Sun would be eclipsed (as above) at every change, and the Moon at every full; and all the Sun's eclipses would be central only at the Equator; but they would sometimes be total there for four minutes, sometimes total only for an instant, and at other times annular; according to the distance of the moon from the Earth in different parts of her elliptical orbit at these times.

N. With the above circumstances, relating to the Earth's progressive motion in its orbit, and the Moon's motion in her orbit; what would be the consequence if the Earth's axis should become inclined to the Ecliptic, as it now is; and the Earth  
turn

turn round its axis with its present velocity ?

*E.* We should have all the variety of seasons we now enjoy. The times between the new and full Moons would be the same as in the last answer above, and the eclipses of the Sun and Moon the same. Only, the Sun's central eclipses would not fall always at the Equator, but sometimes on one side of it, and sometimes on the other; that is, between the Equator and *that* pole of the Earth which was inclined toward the Sun at the time of the eclipse. In our Spring, the center of the Moon's shadow would go obliquely over the Earth, from the southern tropic to the northern. In summer, the shadow would begin to take the Earth at the Equator, and thence bend its course to the northern tropic, and from that tropic to the Equator again, where it would leave the Earth. In our autumn, the center of the Moon's shadow would go obliquely over the Earth, from the northern tropic to the southern. — And in winter, it would take the Earth at the

Equator, from which it would bend its course to the southern tropic, and go on obliquely from that tropic to the Equator, where it would leave the Earth. And, in each of these four cases, the Sun's eclipses would be central to all the parts of the Earth over which the center of the Moon's shadow passed; sometimes total only for an instant, sometimes total for four minutes, and at other times only annular.—The eclipses of the Moon would be as above.

*N.* Supposing now, that the Moon's orbit should become inclined to the Ecliptic, as it is at present, but that her nodes should have no motion therein; and every other circumstance should remain as in the last question?

*E.* Then, the Sun would never be eclipsed at more than 17 degrees from either of the nodes, at the time of any new Moon whatever; nor would the Moon be eclipsed at more than 12 degrees from either of the nodes at any time whatever  
of

of being full. So that we should have but few eclipses (as is now the case) in comparison of the number of our new and full Moons. And the eclipses would be confined to the same seasons of the year; for there would be half a year between those which happened about one node and about the other, because there would be just half a year between the conjunctions of the Sun with one node and with the other.

N. Every thing remaining as above, excepting the stability of the nodes, and of those two points of the Moon's orbit which are most and least distant from the Earth: what would be the consequence if these points acquired a direct or forward motion in the Moon's orbit, and her nodes a backward or retrograde motion; as they now have?

E. I believe every circumstance would be as it now is: and therefore, we should have all the variety of eclipses that now exists in nature.

N. Well done, *Eudisia*!—You have answered all my questions to my mind:  
which

which you could not possibly have done, unless you had very well remembered the subjects we have been upon, in all our Ten Dialogues. This, I think, may be our last on Astronomy; because your applying to books will supersede all necessity of our having any more.

*E.* But I am extremely sorry, brother, to have heard yesterday, that you are to set out for Italy in a few days, which is much sooner than was expected. I shall miss you sadly;—and as you will probably be gone before I can read *Ferguson's* Astronomy quite through, I should be glad to know whether you would have me to read any other book upon the like subject afterward.

*N.* By all means——Here is Doctor *Long's* Astronomy:—take it and keep it; for it will afford you a great deal of entertaining and pleasing knowledge, especially in the historical part.—You may skip over those parts which are geometrical, as I shall not now have time to instruct you in that branch of science. 'Tis true, the volume is large; but I  
will

will answer for it, that by the time you have got to the end, you will wish it had been much larger, and that the Doctor would finish his second volume.

*E.* Permit me, dear brother, to thank you most sincerely for this valuable present.

*F I N I S.*

24  
LADY'S ASTRONOMY  
will answer for it, that by the time you  
have got to the end, you will wish it had  
been much longer, and that the Doctor  
would finish his second volume.  
Permit me, dear brother, to thank  
you most sincerely for this valuable present.  
I am, dear brother, your obedient servant,  
J. M. S.

MS. A. 9. 2. 15  
J. M. S.  
JANUARY 1841

THE  
DESCRIPTION AND USE  
OF THE  
G L O B E S,  
AND  
ARMILLARY SPHERE.

THE  
DESCRIPTION AND USE

OF THE  
GLOBES

AND  
ARMILLARY SPHERE

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THE  
DESCRIPTION AND USE  
OF THE  
GLOBES, &c.

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*The description and use of the Globes, and  
Armillary Sphere.*

IF a map of the world be accurately delineated on a spherical ball, The terrestrial globe. the surface thereof will represent the surface of the earth: for the highest hills are so inconsiderable with respect to the bulk of the earth, that they take off no more from its roundness, than grains of sand do from the roundness of a common globe; for the diameter of the earth is 8000 miles, in

round numbers, and no known hill upon it is three miles in perpendicular height.

Proof of  
the earth's  
being glo-  
bular.

That the earth is spherical, or round like a globe, appears, 1. from its casting a round shadow upon the moon, whatever side be turned towards her when she is eclipsed. 2. From its having been sailed round by several persons. 3. From our seeing the farther, the higher we stand. 4. From our seeing the masts of a ship, whilst the hull is hid by the convexity of the water.

And that  
it may be  
peopled  
on all sides  
without  
any one's  
being in  
danger of  
falling  
away from  
it.

The attractive power of the earth draws all terrestrial bodies towards its center; as is evident from the descent of bodies in lines perpendicular to the earth's surface, at the places whereon they fall; even when they are thrown off from the earth on opposite sides, and consequently, in opposite directions. So that the earth may be compared to a great magnet rolled in filings of steel, which attracts and keeps them equally fast to its surface on all sides. Hence as all terrestrial bodies are attracted towards the earth's center, they can be in no danger of falling from any side  
of

of the earth, more than from any other.

The heaven or sky furrounds the whole earth: and when we speak of *up* or *down*, we mean only with regard to ourselves; for no point, either in the heaven, or on the surface of the earth, is *above* or *below*, but only with respect to ourselves. And let us be upon what part of the earth we will, we stand with our feet towards its center, and our heads towards the sky: and so we say, it is *up* to the sky, and *down* towards the center of the earth.

To an observer placed any where in the indefinite space, where there is nothing to limit his view, all remote objects appear equally distant from him; and seem to be placed in a vast concave sphere, of which his eye is the center. Every astronomer can demonstrate, that the moon is much nearer to us than the sun is; that some of the planets are sometimes nearer to us, and sometimes farther from us, than the sun; that others of them never come so near us as the sun always is; that the remotest planet in our system is beyond comparison nearer to us than any of the fixed stars are; and that it is highly probable some stars are, in a manner,

*Up and  
down,  
what.*

*All ob-  
jects in  
the heaven  
appear e-  
qually dis-  
tant.*

The face  
of the hea-  
ven and  
earth re-  
presented  
in a ma-  
chine.

manner, infinitely more distant from us than others. And yet all these celestial objects appear equally distant from us. Therefore, if we imagine a large hollow sphere of glass to have as many bright studs fixed to its inside as there are stars visible in the heaven, and these studs to be of different magnitudes, and placed at the same angular distances from each other as the stars are; the sphere will be a true representation of the starry heaven, to an eye supposed to be in its center and viewing it all around. And if a small globe, with a map of the Earth upon it, be placed on an axis in the center of this starry sphere, and the sphere be made to turn round on this axis, it will represent the apparent motion of the heavens round the earth.

The equi-  
noctial.

If a great circle be so drawn upon this sphere, as to divide it into two equal parts, or hemispheres, and the plane of the circle be perpendicular to the axis of the sphere, this circle will represent the *equinoctial*, which divides the heaven into two equal parts, called the *northern* and the *southern hemispheres*; and every point of that circle will be equally distant from  
the

the *poles*, or ends of the axis in *Poles*. the sphere. That pole which is in the middle of the northern hemisphere will be called the *north pole of the sphere*, and that which is in the middle of the southern hemisphere, the *south pole*.

If another great circle be drawn upon the sphere, in such a manner as to cut the equinoctial at an angle of  $23\frac{1}{2}$  degrees in two opposite points, it will represent the *ecliptic*, or circle of the *The ecliptic*. sun's apparent annual motion: one half of which is on the north side of the equinoctial, and the other half on the south.

If a large stud be made to move eastward in this ecliptic, in such a manner as to go quite round it in the time that the sphere is turned round westward 366 times upon its axis; this stud will represent the *sun*, changing *The sun*. his place every day a 365th part of the ecliptic; and going round westward, the same way as the stars do; but with a motion so much slower than the motion of the stars, that they will make 366 revolutions about the axis of the sphere, in the time that the sun makes only 365. During one half of these revolutions, the sun will be  
on

on the north side of the equinoctial; during the other half, on the south; and at the end of each half, in the equinoctial.

*The earth.*

*The apparent motion of the heavens.*

If we suppose the terrestrial globe in this machine to be about one inch in diameter, and the diameter of the starry sphere to be about five or six feet, a small insect on the globe would see only a very little portion of its surface; but it would see one half of the starry sphere; the convexity of the globe hiding the other half from its view. If the sphere be turned westward round the globe, and the insect could judge of the appearances which arise from that motion, it would see some stars rising to its view on the eastern side of the sphere, whilst others were setting on the western: but, as all the stars are fixed to the sphere, the same stars would always rise in the same points of view on the east side, and set in the same points of view on the west side. With the sun it would be otherwise, because the sun is not fixed to any point of the sphere, but moves slowly along an oblique circle in it. And if the insect should look towards the south, and call that point of the globe, where  
the

the equinoctial in the sphere seems to cut it on the left side, the *east point*; and where it cuts the globe on the right side, the *west point*; the little animal would see the sun rise north of the east, and set north of the west, for  $182\frac{1}{2}$  revolutions; after which, for as many more, the sun would rise south of the east, and set south of the west. And in the whole 365 revolutions, the sun would rise only twice in the east point, and set twice in the west. All these appearances would be the same, if the starry sphere stood still (the sun only moving in the ecliptic) and the earthly globe were turned round the axis of the sphere eastward. For, as the insect would be carried round with the globe, he would be quite insensible of its motion; and the sun and stars would appear to move westward.

*We* are but very small beings when compared with our earthly globe; and *the globe itself* is but a dimensionless point compared with the magnitude of the starry heavens. Whether the earth be at rest and the heaven turns round it, or the heaven be at rest and the earth turns round, the appearance

to us will be exactly the same. And because the heaven is so immensely large in comparison of the earth, we see one half of the heaven as well from the earth's surface, as we could do from its center, if the limits of our view are not intercepted by hills.

*Circles of  
the sphere.*

We may imagine as many circles described upon the earth as we please; and we may imagine the plane of any circle described upon the earth to be continued, until it marks a circle in the concave sphere of the heavens.

*The hori-  
zon.*

The *horizon* is either *sensible* or *rational*. The *sensible* horizon is that circle, which a man, standing upon a large plane, observes to terminate his view all round, where the heaven and earth seem to meet. The plane of our sensible horizon, continued to the heaven, divides it into two hemispheres; one visible to us, the other hid by the convexity of the earth.

The plane of the *rational horizon* is supposed parallel to the plane of the sensible; to pass through the center of the earth, and to be continued to the heavens. And although the plane of the sensible horizon touches the earth in the place of the observer, yet

yet *this* plane and *that* of the rational horizon, will seem to coincide in the heaven, because the whole earth is but a point compared to the sphere of the heaven.

The earth being a spherical body, the horizon, or limit of our view, must change as we change our place.

The *poles of the earth* are those two *Poles.* points on its surface in which its axis terminates. The one is called the *north pole*, and the other the *south pole*.

The *poles of the heaven* are those two points in which the earth's axis produced terminates in the heaven: so that the *north pole* of the heaven is directly over the north pole of the earth; and the *south pole* of the heaven is directly over the south pole of the earth.

The *equator* is a great circle upon *Equator.* the earth, every part of which is equally distant from either of the poles. It divides the earth in two equal parts, called the *northern* and *southern hemispheres*. If we suppose the plane of this circle to be extended to the heaven, it will mark the *equinoctial* therein, and will divide the heaven into two equal parts,

parts, called the *northern* and *southern* hemispheres of the heaven.

*Meridian.*

The *meridian* of any place is a great circle passing through that place and the poles of the earth. We may imagine as many such meridians as we please, because any place, that is ever so little to the east or west of any other place, has a different meridian from that place; for no one circle can pass through any two such places and the poles of the earth.

The *meridian* of any place is divided by the poles into two semicircles; that which passes through the place is called the *geographical*, or *upper meridian*; and that which passes through the opposite place is called the *lower meridian*.

*Noon and  
Midnight.*

When the rotation of the earth brings the plane of the geographical meridian to the sun, it is *noon* or *mid-day* to that place; and when the lower meridian comes to the sun, it is *midnight*.

All places lying under the same geographical meridian have their noon at the same time, and consequently all the other hours. All those places are said to have the same *longitude*, because no one of them lies either eastward or westward from any of the rest.

If

If we imagine 24 semicircles, one of <sup>Hour cir-</sup>  
 which is the geographical meridian of <sup>cles.</sup>  
 a given place, to meet at the poles, and  
 to divide the equator into 24 equal  
 parts, each of these meridians will  
 come round to the sun in 24 hours, by  
 the sun's equable motion round its  
 axis in that time. And, as the equator  
 contains 360 degrees, there will be 15  
 degrees contained between any two of  
 these meridians which are nearest to  
 one another: for 24 times 15 are 360.  
 And as the earth's motion is eastward,  
 the sun's apparent motion will be west-  
 ward, at the rate of 15 degrees each  
 hour: Therefore,

They whose geographical meridian <sup>Longitude.</sup>  
 is 15 degrees eastward from us, have  
 noon, and every other hour, an hour  
 sooner than we have. They whose  
 meridian is fifteen degrees westward  
 from us, have noon, and every other  
 hour, an hour later than we have: and  
 so on in proportion, reckoning one hour  
 for every fifteen degrees.

As the earth turns round its axis  
 once in 24 hours, and shews itself all  
 round to the sun in that time, so it  
 goes round the sun once a year in a  
 great circle called the *ecliptic*, which <sup>Ecliptic.</sup>  
 crosses

crosses the equinoctial in two opposite points, making an angle of  $23\frac{1}{2}$  degrees with the equinoctial on each side. So that one half of the ecliptic is in the northern hemisphere, and the other in the southern. It contains 360 equal parts, called degrees (as all other circles do, whether great or small) and as the earth goes round it every year, the sun will appear to do the same, changing his place almost a degree, at a mean rate, every 24 hours. So that whatever place, or degree of the ecliptic, the earth is in at any time, the sun will then appear in the opposite. And as one half of the ecliptic is on the north side of the equinoctial, and the other half on the south, the sun, as seen from the earth, will be half a year on the south side of the equinoctial, and half a year on the north: and twice a year in the equinoctial itself.

*Signs and  
degrees.*

The ecliptic is divided by astronomers into 12 equal parts, called *signs*, each sign into 30 *degrees*, and each degree into 60 *minutes*: but, in using the globes, we seldom want the sun's place nearer than half a degree of the truth.

The names and characters of the 12 signs are as follow; beginning at that  
point

point of the ecliptic where it crosses the equinoctial to the northward, and reckoning eastward round to the same point again; and the days of the months on which the sun now enters the signs are set down below them:

<i>Aries,</i>	<i>Taurus,</i>	<i>Gemini,</i>	<i>Cancer,</i>
♈	♉	♊	♋
March	April	May	June
20	20	21	21

<i>Leo,</i>	<i>Virgo,</i>	<i>Libra,</i>	<i>Scorpio,</i>
♌	♍	♎	♏
July	August	September	October
23	23	23	23

<i>Sagittarius,</i>	<i>Capricorn,</i>	<i>Aquarius,</i>	<i>Pisces,</i>
♐	♑	♒	♓
November	December	January	February
22	21	20	18

By remembering on what day the sun enters any particular sign, we may easily find his place any day afterward, whilst he is in that sign, by reckoning a degree for each day; which will occasion no error of consequence in using the globes.

When

When the sun is at the beginning of *Aries*, he is in the equinoctial; and from that time he declines northward every day, until he comes to the beginning of *Cancer*, which is  $23\frac{1}{2}$  degrees from the equinoctial: from thence he recedes southward every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of *Libra*, and at the end of that half year, he is at his greatest south declination, in the beginning of *Capricorn*, which is also  $23\frac{1}{2}$  degrees from the equinoctial. Then, he returns northward from *Capricorn* every day, for half a year; in the middle of which half, he crosses the equinoctial at the beginning of *Aries*, and at the end of it he arrives at *Cancer*.

The sun's motion in the ecliptic is not perfectly equable, for he continues eight days longer in the northern half of the ecliptic, than in the southern; so that the summer half year in the northern hemisphere is eight days longer than the winter half year; and the contrary in the southern hemisphere.

*Tropicks.*

The *tropicks* are lesser circles in the heaven, parrallel to the equinoctial;  
one

one on each side of it, touching the ecliptic in the points of its greatest declination; so that each tropic is  $23\frac{1}{2}$  degrees from the equinoctial, one on the north side of it, and the other on the south. The northern tropic touches the ecliptic at the beginning of *Cancer*, the southern at the beginning of *Capricorn*; for which reason the former is called the *tropic of Cancer*, and the latter the *tropic of Capricorn*.

The *polar circles* in the heaven are each  $23\frac{1}{2}$  degrees from the poles, all around. That which goes round the north pole is called the *Arctic circle*, from *ἄρκτος* which signifies a *bear*; there being a constellation or group of stars near the north pole, which goes by that name. The south polar circle is called the *antarctic circle*, from its being opposite to the arctic.

The ecliptic, tropics, and polar circles are drawn upon the terrestrial globe, as well as upon the celestial. But the ecliptic, being a great fixed circle in the heavens, cannot properly be said to belong to the terrestrial globe; and is laid down upon it only for the conveniency of solving some problems. So that, if this circle on the terrestrial

C

globe

globe was properly divided into the months and days of the year, it would not only suit the globe better, but would also make the problems thereon much easier.

In order to form a true idea of the earth's motion round its axis every 24 hours, which is the cause of day and night; and of its motion in the ecliptic round the sun every year, which is the cause of the different lengths of days and nights, and of the vicissitude of seasons; take the following method, which will be both easy and pleasant.

An idea of  
the sea-  
sons.

Let a small terrestrial globe, of about three inches diameter, be suspended by a long thread of twisted silk, fixt to its north pole: then, having placed a lighted candle on a table, to represent the sun, in the center of a hoop of a large cask, which may represent the ecliptic, the hoop making an angle of  $23\frac{1}{2}$  degrees with the plane of the table; hang the globe within the hoop near to it; and, if the table be level, the equator of that globe will be parallel to the table, and the plane of the hoop will cut the equator at an angle of  $23\frac{1}{2}$  degrees; so that one half of the equator will be above the hoop, and the other half

half below it: and the candle will enlighten one half of the globe, as the sun enlightens one half of the earth, whilst the other half is in the dark.

Things being thus prepared, twist the thread towards the left hand, that it may turn the globe the same way by untwisting; that is, from west, by south, to east. As the globe turns round its axis or thread, the different places of its surface will go regularly through the light and dark; and have, as it were, an alternate return of day and night in each rotation. As the globe continues to turn round, and to shew itself all around to the candle, carry it slowly round the hoop by the thread, from west, by south, to east; which is the way that the earth moves round the sun, once a year, in the ecliptic. and you will see that, whilst the globe continues in the lower part of the hoop, the candle (being then north of the equator) will constantly shine round the north pole; and all the northern places which go through any part of the dark will go through a less portion of it than they do of the light; and the more so, the farther they are from the equator; consequently, their days

are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the highest and lowest points, the candle will be directly over the equator, and will enlighten the globe just from pole to pole; and then, every place on the globe will go through equal portions of light and darkness, as it turns round its axis; and, consequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, towards the highest part of the hoop, the candle will be on the south side of the equator, shining farther and farther round the south pole, as the globe rises higher and higher in the hoop; leaving the north pole as much in darkness as the south pole is then in the light, and making long days and short nights on the south side of the equator, and the contrary on the north side, whilst the globe continues in the northern or higher side of the hoop: and when it comes to the highest point, the days will be at the longest, and the nights at the shortest, in the southern hemisphere; and the reverse in the northern. As the globe advances and descends in the hoop, the  
light

light will gradually recede from the south pole, and approach towards the north pole, which will cause the northern days to lengthen, and the southern days to shorten in the same proportion. When the globe comes to the middle point, between the highest and lowest points of the hoop, the candle will be over the equator, enlightening the globe just from pole to pole; when every place of the earth (except the poles) will go through equal portions of light and darkness; and, consequently, the day and night will be then equal all over the globe.

And thus, at a very small expense, one may have a delightful and demonstrative view of the cause of days and nights, with their gradual increase and decrease in length, through the whole year together, with the vicissitudes of spring, summer, autumn, and winter, in each annual course of the earth round the sun.

If the hoop be divided into 12 equal parts, and the signs be marked in order upon it, beginning with *Cancer* at the highest point of the hoop, and reckoning eastward (or contrary to the apparent motion of the sun) you will see how  
the

the sun appears to change his place every day in the ecliptic, as the globe advances eastward along the hoop, and turns round its own axis: and that when the earth is in a low sign, as at *Capricorn*, the sun must appear in a high sign, as at *Cancer*, opposite to the earth's real place: and that whilst the earth is in the southern half of the ecliptic, the sun appears in the northern half, and *vice versa*: that the farther any place is from the equator, between it and the polar circle, the greater is the difference between the longest and shortest day at that place; and that the poles have but one day and one night in the whole year.

The terrestrial globe described.

These things premised, we shall proceed to the description and use of the terrestrial globe, and explain the geographical terms as they occur in the problems.

This globe has the boundaries of land and water laid down upon it, the countries and kingdoms divided by dots, and coloured to distinguish them, the islands properly situated, the rivers and principal towns inserted, as they have been ascertained upon the earth by measurement and observation.

The

The equator, ecliptic, tropics, polar circles, and meridians, are laid down upon the globe in the manner already described. The ecliptic is divided into 12 signs, and each sign into 30 degrees, which are generally subdivided into halves, and into quarters, if the globe is large. Each tropic is  $23\frac{1}{2}$  degrees from the equator; and each polar circle  $23\frac{1}{2}$  degrees from its respective pole. Circles are drawn parallel to the equator, at every ten degrees distance from it, on each side to the poles: these circles are called *parallels of latitude*. On large globes there are circles drawn perpendicularly through every tenth degree of the equator, intersecting each other at the poles: but on globes of or under a foot diameter, they are only drawn through every fifteenth degree of the equator; these circles are generally called *meridians*, sometimes *circles of longitude*, and at othertimes *hour-circles*.

The globe is hung in a brass ring, called the *brassen meridian*; and turns upon a wire in each pole sunk half its thickness into one side of the meridian ring; by which means, *that* side of the ring divides the globe into two equal parts,

parts, called the *eastern* and *western hemispheres*; as the equator divides it into two equal parts, called the *northern* and *southern hemispheres*. This ring is divided into 360 equal parts or degrees, on the side wherein the axis of the globe turns. One half of these degrees are numbered, and reckoned, from the equator to the poles, where they end at 90: their use is to shew the latitudes of places. The degrees on the other half of the meridian ring are numbered from the poles to the equator, where they end at 90: their use is to shew how to elevate either the north or south pole above the horizon, according to the latitude of any given place, as it is north or south of the equator.

The brasen meridian is let into two notches made in a broad flat ring, called the *wooden horizon*, the upper surface of which divides the globe into equal parts, called the *upper* and *lower hemispheres*. One notch is in the north point of the horizon, and the other in the south. On this horizon are several concentric circles, which contain the months and days of the year, the signs and degrees answering to the sun's

sun's place for each month and day, and the 32 points of the compass.— The graduated side of the brass meridian lies towards the east side of the horizon, and should be generally kept toward the person who works problems by the globes.

There is a small *horary circle*, so fixed to the north part of the brazen meridian, that the wire in the north pole of the globe is in the center of that circle; and on the wire is an *index*, which goes over all the 24 hours of the circle, as the globe is turned round its axis. Sometimes there are two horary circles, one between each pole of the globe and the brazen meridian; which is the contrivance of the ingenious Mr. Joseph Harris, master of the assay-office in the Tower of London; and makes it very convenient for putting the poles of the globe through the horizon, and for elevating the pole to small latitudes and declinations of the sun: which cannot be done where there is only one horary circle fixed to the outer edge of the brazen meridian.

There is a thin slip of brass, called the *quadrant of altitude*, which is divided

ed into 90 equal parts or degrees, answering exactly to so many degrees of the equator. It is occasionally fixed to the uppermost point of the brazen meridian by a nut and screw. The divisions end at the nut, and the quadrant is turned round upon it.

As the globe has been seen by most people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expressed, we judge it would signify very little to refer to a figure of it; and shall therefore only give some directions how to choose a globe, and then describe its use.

Directions  
for  
choosing  
globes.

1. See that the papers be well and neatly pasted on the globes, which you may know, if the lines and circles thereon meet exactly, and continue all the way even and whole; the circles not breaking into several arches, nor the papers either coming short, or lapping over one another.

2. See that the colours be transparent, and not laid too thick upon the globe to hide the names of places.

3 See that the globe hang evenly between the brazen meridian and the wooden

wooden horizon; not inclining either to one side or to the other.

4. See that the globe be as close to the horizon and meridian as it conveniently may; otherwise, you will be too much puzzled to find against what part of the globe any degree of the meridian or horizon is.

5. See that the equinoctial line be even with the horizon all around, when the north or south pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the east and west points in all elevations of the poles from 0 to 90 degrees.

7. See that the degree of the brazen meridian marked with 0 be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the brazen meridian above the horizon; which you may know, if you bring any of the decimal divisions on the meridian to the north point of the horizon, and find their complement to 90 in the south point.

9. See that when the quadrant of altitude is placed as far from the equator, on the brazen meridian, as the pole is elevated above the horizon, the beginning

ginning of the degrees of the quadrant reaches juſt to the plane ſurface of the horizon.

10. See that whilſt the index of the hour-circle (by the motion of the globe) paſſes from one hour to another, 15 degrees of the equator paſs under the graduated edge of the braſen meridian.

11. See that the wooden horizon be made ſubſtantial and ſtrong; it being generally obſerved, that, in moſt globes, the horizon is the firſt part that fails, on account of its having been made too flight.

Directi-  
ons for  
uſing  
them.

In uſing the globes, keep the eaſt ſide of the horizon towards you (unleſs your problem requires the turning of it,) which ſide you may know by the word Eaſt upon the horizon; for then you have the graduated ſide of the meridian towards you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated ſide of the meridian.

In working ſome problems, it will be neceſſary to turn the whole globe and horizon about, that you may look on the weſt ſide thereof; which turning will be apt to jog the ball ſo as to ſhift away that degree of the globe which  
was

was before set to the horizon or meridian: to avoid which inconvenience, you may thrust in the feather-end of a quill between the ball of the globe and the brazen meridian; which, without hurting the ball, will keep it from turning in the meridian, whilst you turn the west side of the horizon towards you.

### PROBLEM I.

*To find the \* latitude and † longitude of any given place upon the globe.*

Turn the globe on its axis, until the given place comes exactly under that graduated side of the brazen meridian,

\* The latitude of a place is its distance from the equator, and is north or south, as the place is north or south of the equator. Those who live at the equator have no latitude, because it is there that the latitude begins.

† The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the said place is distant from the meridian of any other place from which we reckon, either eastward or westward, for 180 degrees, or half round the globe. The English reckon the longitude from the meridian of London, and the French now reckon it from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called the *first meridian*. The places upon this meridian have no longitude, because it is there that the longitude begins.

meridian, on which the degrees are numbered from the equator; and observe what degree of the meridian the place then lies under; which is its latitude, north or south, as the place is north or south of the equator.

The globe remaining in this position, the degree of the equator, which is under the brazen meridian, is the longitude of the place (from the meridian of *London* on the *English* globes) which is east or west, as the place lies on the east or west side of the first meridian of the globe.—All the *Atlantic Ocean*, and *America*, is on the west side of the meridian of *London*; and the greatest part of *Europe*, and of *Africa*, together with all *Asia*, is on the east side of the meridian of *London*, which is reckoned the *first meridian* of the globe by the *English* geographers and astronomers.

## PROBLEM II.

*The longitude and latitude of a place being given, to find that place on the globe.*

Look for the given longitude in the equator, counting it eastward or westward from the first meridian, as it is mentioned

mentioned to be east or west; and bring the point of longitude in the equator to the brazen meridian, on that side which is above the south point of the horizon: then count from the equator on the brazen meridian to the degree of the given latitude, towards the north or south pole, according as the latitude is north or south; and under that degree of latitude on the meridian you will have the place required.

### PROBLEM III.

*To find the difference of longitude, or difference of latitude, between any two given places.*

Bring each of these places to the brazen meridian, and see what its latitude is: the lesser latitude subtracted from the greater, if both places are on the same side of the equator, or both latitudes added together, if they are on different sides of it, will give the difference of latitude required. And the number of degrees contained between these places, reckoned on the equator, when

when they are brought separately under the braſen meridian, is their difference of longitude; if it be leſs than 180: but if more, let it be ſubtracted from 360, and the remainder is the difference of longitude required. Or,

Having brought one of the places to the braſen meridian, and ſet the hour-index to XII, turn the globe until the other place comes to the braſen meridian, and the number of hours and parts of an hour paſt over by the index, will give the longitude in time; which may be eaſily reduced to degrees, by allowing 15 degrees for every hour, and one degree for every four minutes.

*N. B.* When we ſpeak of bringing any place to the braſen meridian, it is the graduated ſide of the meridian that is meant.

#### PROBLEM. IV.

*Any place being given, to find all thoſe places that have the ſame longitude or latitude with it.*

Bring the given place to the braſen meridian, then all thoſe places which  
lie

lie under that side of the meridian, from pole to pole, have the same longitude with the given place. Turn the globe round its axis, and all those places which pass under the same degree of the meridian that the given place does, have the same latitude with that place.

Since all latitudes are reckoned from the equator, and all longitudes are reckoned from the first meridian, it is evident, that the point of the equator which is cut by the first meridian has neither latitude nor longitude.—The greatest latitude is 90 degrees, because no place is more than 90 degrees from the equator: and the greatest longitude is 180 degrees, because no place is more than 180 degrees from the first meridian.

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PROBLEM

## PROBLEM V.

To find the \* antæci, † periæci, and  
‡ antipodes, of any given place.

Bring the given place to the brazen meridian, and, having found its latitude, keep the globe in that situation, and count

\* The *antæci* are those people who live on the same meridian, and in equal latitudes, on different sides of the equator. Being on the same meridian, they have the same hours; that is, when it is noon to the one it is also noon to the other; and when it is mid-night to the one, it is also mid-night to the other, &c. Being on different sides of the equator, they have different or opposite seasons at the same time; the length of any day to the one is equal to the length of the night of that day to the other; and they have equal elevations of the different poles.

† The *periæci* are those people who live on the same parallel of latitude, but on opposite meridians: so that though their latitude be the same, their longitude differs 180 degrees. By being in the same latitude, they have equal elevations of the same pole (for the elevation of the pole is always equal to the latitude of the place), the same length of days or nights, and the same seasons. But being on opposite meridians, when it is noon to the one, it is mid-night to the other.

‡ The *antipodes* are those who live diametrically opposite to one another upon the globe, standing with feet towards feet, on opposite meridians and parallels. Being on opposite sides of the equator they have opposite seasons, winter to one when it is summer to the other; being equally distant from the equator, they have the contrary poles equally elevated above the horizon; being on opposite meridians, when it is noon to the one, it must be midnight to the other; and as the sun recedes from the one when he approaches to the other, the length of the day to one must be equal to the length of the night at the same time to the other.

count the same number of degrees of latitude from the equator towards the contrary pole, and where the reckoning ends, you have the *antæci* of the given place upon the globe. Those who live at the equator have no *antæci*.

The globe remaining in the same position, set the hour-index to the upper XII on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the same latitude with the given place, is the *periæci* required. Those who live at the poles have no *periæci*.

As the globe now stands (with the index at the lower XII) the *antipodes* of the given place will be under the same point of the brazen meridian where its *antæci* stood before. Every place upon the globe has its *antipodes*.

## PROBLEM. VI.

*To find the distance between any two places on the globe.*

Lay the graduated edge of the quadrant of altitude over both the places, and count the number of degrees intercepted between them on the quadrant;

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then

then multiply these degrees by 60, and the product will give the distance in geographical miles: but to find the distance in English miles, multiply the degrees by  $69\frac{1}{2}$ , and the product will be the number of miles required. Or take the distance betwixt any two places with a pair of compasses, and apply that extent to the equator; the number of degrees intercepted between the points of the compasses is the distance in degrees of a great circle\*; which may be reduced either to geographical miles, or to English miles, as above.

*Great  
circle.*

*Lesser  
circle.*

\* Any circle that divides the globe into two equal parts is called a *great circle*, as the equator or meridian. Any circle that divides the globe into two unequal parts (which every parallel of latitude does) is called a *lesser circle*. Now as every circle, whether great or small contains 360 degrees, and a degree upon the equator or meridian contains 60 geographical miles, it is evident, that a degree of longitude upon the equator is longer than a degree of longitude upon any parallel of latitude, and must therefore contain a greater number of miles. So that although all the degrees of latitude are equally long upon an artificial globe (though not precisely so upon the earth itself), yet the degrees of longitude decrease in length as the latitude increases, but not in the same proportion. The following table shews the length of a degree of longitude, in geographical miles, and hundredth parts of a mile, for every degree of latitude, from the equator to the poles; a degree on the equator being 60 geographical miles.

*A Table*

*A Table shewing the number of miles in a degree of longitude, and in any given degree of latitude.*

Deg.	Parts. Miles.	Deg.	Parts. Miles.	Deg.	Parts. Miles.	Deg.	Parts. Miles.	Deg.	Parts. Miles.
1	59.99	19	56.73	37	47.92	55	34.41	73	17.54
2	59.96	20	56.38	38	47.28	56	33.55	74	16.53
3	59.92	21	56.02	39	46.63	57	32.68	75	15.52
4	59.85	22	55.63	40	45.97	58	31.79	76	14.31
5	59.77	23	55.23	41	45.28	59	30.90	77	13.50
6	59.67	24	54.81	42	44.59	60	30.00	78	12.48
7	59.56	25	54.38	43	44.88	61	29.09	79	11.45
8	59.42	26	53.93	44	43.16	62	28.17	80	10.42
9	59.26	27	53.46	45	42.43	63	27.24	81	9.38
10	59.09	28	52.96	46	41.68	64	26.30	82	8.35
11	58.89	29	52.47	47	40.92	65	25.36	83	7.32
12	58.69	30	51.96	48	40.15	66	24.41	84	6.28
13	58.46	31	51.43	49	39.36	67	23.44	85	5.24
14	58.22	32	50.88	50	38.57	68	22.48	86	4.20
15	57.95	33	50.32	51	37.76	69	21.50	87	3.15
16	57.67	34	49.74	52	36.94	70	20.52	88	2.10
17	57.38	35	49.15	53	36.11	71	19.53	89	1.05
18	57.06	36	48.54	54	35.27	72	18.54	90	0.00

## PROBLEM VII.

*A place on the globe being given, and its distance from any other place, to find all the other places upon the globe which are at the same distance from the given place.*

Bring the given place to the brazen meridian, and screw the quadrant to the

the meridian directly over that place; then keeping the globe in that position, turn the quadrant quite round upon it, and the degree of the quadrant that touches the second place, will pass over all the other places which are equally distant with it from the given place.

This is the same as if one foot of a pair of compasses was set in the given place, and the other foot extended to the second place, whose distance is known; for if the compasses be then turned round the first place as a center, the moving foot will go over all those places which are at the same distance with the second from it.

### PROBLEM VIII.

*The hour of the day at any place being given, to find all those places where it is noon at that time.*

Bring the given place to the brazen meridian, and set the index to the given hour; this done, turn the globe until the index points to the upper  
XII.

XII, and then, all the places that lie under the brazen meridian have noon at that time.

N. B. The upper XII always stands for noon; and when the bringing of any place to the brazen meridian is mentioned, the side of that meridian on which the degrees are reckoned from the equator is meant, unless the contrary side be mentioned.

#### PROBLEM IX.

*The hour of the day at any place being given, to find what o'clock it then is at any other place.*

Bring the given place to the brazen meridian, and set the index to the given hour; then turn the globe, until the place where the hour is required comes to the meridian, and the index will point out the hour at that place.

#### PROBLEM

## PROBLEM X.

*To find the sun's place in the ecliptic, and his \* declination for any given day of the year.*

Look on the horizon for the given day, and right against it you have the degree of the sign in which the sun is (or his place) on that day at noon. Find the same degree of that sign in the ecliptic line upon the globe, and, having brought it to the brazen meridian, observe what degree of the meridian stands over it; for that is the sun's declination, reckoned from the equator.

## PROBLEM XI.

*The day of the month being given, to find all those places of the earth over which the sun will pass vertically on that day.*

Find the sun's place in the ecliptic for the given day, and, having brought it

\* The sun's declination is his distance from the equinoctial in degrees, and is north or south, as the sun is between the equinoctial and the north or south pole.

it to the brazen meridian, observe what point of the meridian is over it; then, turning the globe round its axis, all those places which pass under that point of the meridian, are the places required: for, as their latitude is equal, in degrees and parts of a degree, to the sun's declination, the sun must be directly over head to each of them at its respective noon.

## PROBLEM XII.

*A place being given in the \* torrid zone, to find those two days of the year, on which the Sun shall 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;

\* The globe is divided into five zones; one torrid, two temperate, and two frigid. The *torrid zone* lies between the two tropics, and is 47 degrees in breadth, or 23h on each side of the equator: the *temperate zones* lie between the tropics and polar-circles, or from 23h degrees of latitude to 66h, on each side of the equator; and are each 43 degrees in breadth: the *frigid zones* are the spaces included within the polar circles, which being each 23h degrees from their respective poles, the breadth of each of these zones is 47 degrees. As the sun never goes without the tropics, he must every moment be vertical to some place or other in the torrid zone.

ridian; then turn the globe round its axis, and observe the two degrees of the ecliptic which pass exactly under that degree of latitude: lastly, find on the wooden horizon the two days of the year in which the sun is in those 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, and consequently, he will then be vertical to it at noon.

### PROBLEM XIII.

*To find all those places of the north frigid zone, where the sun begins to shine constantly without setting, on any given day, from the 21st of March to the 23d of September.*

On these two days, the sun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and so make equal day and night to all places of the earth. But as the sun declines from the equator towards either pole, he will  
shine.

shine just as many degrees round that pole, as are equal to his declination from the equator; so that no place within that distance of the pole will then go through any part of the dark, and consequently the sun will not set to it. Now, as the sun's declination is northward from the 21st of March to the 23d of September, he must constantly shine round the north pole all that time; and on the day that he is in the northern tropic, he shines upon the whole north frigid zone; so that no place within the north polar circle goes through any part of the dark on that day. Therefore,

Having brought the sun's place for the given day to the brazen meridian, and found his declination (by Prob. IX.), count as many degrees on the meridian, from the north pole, as are equal to the sun's declination from the equator, and mark that degree from the pole where the reckoning ends: then, turning the globe round its axis, observe what places in the north frigid zone pass directly under that mark; for they are the places required.

The like may be done for the south frigid zone, from the 23d of September

to the 21<sup>st</sup> of March, during which time the sun shines constantly on the south pole.

#### PROBLEM XIV.

*To find the place over which the sun is vertical, at any hour of a given day.*

Having found the sun's declination for the given day (by Prob. IX.), mark it with chalk on the brazen meridian: then bring the place where you are (suppose London) to the brazen meridian, and set the index to the given hour; which done, turn the globe on its axis, until the index points to XII at noon, and the place on the globe, which is then directly under the point of the sun's declination marked upon the meridian, has the sun that moment in the zenith, or directly over head.

#### PROBLEM

PROBLEM XV.

*The day and hour at any place being given, to find all those places where the sun is then rising, or setting, or on the meridian; consequently, all those places which are enlightened at that time, and those which are in the dark :*

This problem cannot be solved by any globe fitted up in the common way, with the hour-circle fixed upon the brass meridian; unless the sun be on or near some of the tropics on the given day. But by a globe fitted up according to Mr. *Joseph Harris's* invention (already mentioned) where the hour-circle lies on the surface of the globe, below the meridian, it may be solved for any day of the year, according to his method; which is as follows :

Having found the place to which the sun is vertical at the given hour, if the place be in the northern hemisphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place  
be

be in the southern hemisphere, elevate the south pole accordingly, and bring the said place to the brazen meridian. Then, all those places which are in the western semicircle of the horizon have the sun rising to them at that time; and those in the eastern semicircle have it setting: to those under the upper semicircle of the brass meridian it is noon; and to those under the lower semicircle it is mid-night. All those places which are above the horizon are enlightened by the sun, and have the sun just as many degrees above them, as they themselves are above the horizon; and this height may be known, by fixing the quadrant of altitude on the brazen meridian over the place to which the sun is vertical; and then, laying it over any other place, observe what number of degrees on the quadrant are intercepted between the said place and the horizon. In all those places that are 18 degrees below the western semicircle of the horizon, the morning twilight is just beginning; in all those places that are 18 degrees below the eastern semicircle of the horizon, the evening twilight is ending; and all those places that

that are lower than 18 degrees, have dark night.

If any place be brought to the upper semicircle of the brazen meridian, and the hour-index be set to the upper XII or noon, and then the globe be turned round eastward on its axis; when the place comes to the western semicircle of the horizon, the index will shew the time of sun-rising at that place; and when the same place comes to the eastern semicircle of the horizon, the index will shew the time of sun-set.

To those places which do not go under the horizon, the sun sets not on that day: and to those which do not come above it, the sun does not rise.

#### PROBLEM XVI.

*The day and hour of a lunar eclipse being given, to find all those places of the earth to which it will be visible.*

The moon is never eclipsed but when she is full, and so directly opposite to the sun, that the earth's shadow falls upon her. Therefore, whatever place of the earth the sun is vertical to at that time, the moon must be vertical  
to

to the antipodes of that place; so that the sun will be then visible to one half of the earth, and the moon to the other.

Find the place to which the sun is vertical at the given hour (by Prob. XIV.), elevate the pole to the latitude of that place, and bring the place to the upper part of the brazen meridian, as in the former problem: then, as the sun will be visible to all those parts of the globe which are above the horizon, the moon will be visible to all those parts of the globe which are below it, at the time of her greatest obscuration.

But with regard to an eclipse of the sun, there is no such thing as shewing to what places it will be visible, with any degree of certainty, by a common globe; because the moon's shadow covers but a small portion of the earth's surface; and her latitude, or declination from the ecliptic, throws her shadow so variously upon the earth, that, to determine the places on which it falls, recourse must be had to long calculations.

PROBLEM XVII.

*To rectify the globe for the latitude, the \*  
zenith, and the sun's place.*

Find the latitude of the place (by Prob. 1.) and if the place be in the northern hemisphere, raise the north pole above the north point of the horizon, as many degrees (counted from the pole upon the brazen meridian) as are equal to the latitude of the place. If the place be in the southern hemisphere, raise the south pole above the south point of the horizon, as many degrees as are equal to the latitude. Then, turn the globe till the place comes under its latitude on the brazen meridian, and fasten the quadrant of altitude so, that the chamfered edge of its nut (which is even with the graduated edge) may be joined to the zenith, or point of latitude. This done, bring the sun's place in the ecliptic for the given day (found by Prob. X.) to the graduated side of the brazen meridian,  
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\* The *zenith*, in this sense, is the highest point of the brazen meridian above the horizon; but in the proper sense, it is that point of the heaven which is directly vertical to any given place, at any given instant of time.

and set the hour-index to XII at noon, which is the uppermost XII on the hour-circle; and the globe will be rectified.

*Remark.*

The latitude of any place is equal to the elevation of the nearest pole of the heaven above the horizon of that place; and the poles of the heaven are directly over the poles of the earth, each 90 degrees from the equinoctial line. Let us be upon what place of the earth we will, if the limits of our view be not intercepted by hills, we shall see one half of the heaven, or 90 degrees every way round, from that point which is over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view: if we go from the equator, towards either pole of the earth, we shall see the corresponding pole of the heaven rising gradually above our horizon, just as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the corresponding pole of the heaven would be directly over our head. Consequently, the elevation or height of the pole in degrees above the horizon, is equal to the number of degrees that the place is from the equator.

PROBLEM

PROBLEM XVIII.

*The latitude of any place, not exceeding  
\*  $66\frac{1}{2}$  degrees, and the day of the  
month being given to find the time of  
sun rising and setting, and consequently  
the length of the day and night.*

Having rectified the globe for the latitude, and for the sun's place on the given day (as directed in the preceding problem) bring the sun's place in the ecliptic to the eastern side of the horizon, and the hour-index will shew the time of sun rising; then turn the globe on its axis, until the sun's place comes to the western side of the horizon, and the index will shew the time of sun-setting.

The hour of sun-setting doubled, gives the length of the day; and the hour of sun-rising doubled, gives the length of the night.

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PROBLEM

\* All places whose latitude is more than  $66\frac{1}{2}$  degrees are in the frigid zones; and to those places the sun does not set in summer for a certain number of diurnal revolutions, which occasions this limitation of latitude.

## PROBLEM XIX.

*The latitude of any place, and the day of the month, being given; to find when the morning twilight begins, and the evening twilight ends, at that place.*

This problem is often limited: for, when the sun does not go 18 degrees below the horizon, the twilight continues the whole night; and for several nights together in summer, between 49 and  $66\frac{1}{2}$  degrees of latitude: and the nearer to  $66\frac{1}{2}$  the greater is the number of these nights. But when it does begin and end, the following method will shew the time for any given day.

Rectify the globe, and bring the sun's place in the ecliptic to the eastern side of the horizon; then mark that point of the ecliptic with chalk which is in the western side of the horizon, it being the point opposite to the sun's place: this done, lay the quadrant of altitude over the said point, and turn the globe eastward, keeping the quadrant at the chalk-mark, until it be just 18 degrees high on the quadrant; and the index will point out the time when

when the morning twilight begins: for the sun's place will then be 18 degrees below the eastern side of the horizon. To find the time when the evening twilight ends, bring the sun's place to the western side of the horizon, and the point opposite to it, which was marked with the chalk, will be rising in the east: then, bring the quadrant over that point, and, keeping it thereon, turn the globe westward, until the said point be 18 degrees above the horizon on the quadrant, and the index will shew the time when the evening twilight ends; the sun's place being then 18 degrees below the western side of the horizon.

#### PROBLEM XX.

*To find on what day of the year the sun begins to shine constantly without setting, on any given place in the north frigid zone; and how long he continues to do so.*

Rectify the globe to the latitude of the place, and turn it about until some point of the ecliptic, between *Aries* and *Cancer*, coincides with the north point of the horizon where the bra-  
fen

fen meridian cuts it: then find, on the wooden horizon, what day of the year the sun is in that point of the ecliptic; for that is the day on which the sun begins to shine constantly on the given place, without setting. This done, turn the globe until some point of the ecliptic, between *Cancer* and *Libra*, coincides with the north point of the horizon, where the brazen meridian cuts it; and find, on the wooden horizon, on what day the sun is in that point of the ecliptic; which is the day that the sun leaves off constantly shining on the said place, and rises and sets to it as to other places on the globe. The number of natural days, or complete revolutions of the sun about the earth, between the two days above found, is the time that the sun keeps constantly above the horizon without setting: for all that portion of the ecliptic, which lies between the two points which intersect the horizon in the very north, never sets below it: and there is just as much of the opposite part of the ecliptic that never rises; therefore, the sun will keep as long constantly below the horizon in winter, as above it in summer.

Whoever

Whoever considers the globe will find, that all places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the opposite season.

### PROBLEM XXI.

*To find in what latitude the sun shines constantly without setting, for any length of time less than \*  $182\frac{1}{2}$  of our days and nights.*

Find a point in the ecliptic half as many degrees from the beginning of *Cancer* (either toward *Aries* or *Libra*) as there are † natural days in the time given; and bring that point to the north side of the brazen meridian, on which

\* The reason of this limitation is, that 182½ of our days and nights make half a year, which is the longest time that the sun shines without setting, even at the poles of the earth.

† A natural day contains the whole 24 hours; an artificial day, the time that the sun is above the horizon.

which the degrees are numbered from the pole towards the equator: then, keep the globe from turning on its axis, and slide the meridian up or down until the foresaid point of the ecliptic comes to the north point of the horizon, and then, the elevation of the pole will be equal to the latitude required.

### PROBLEM XXII.

*The latitude of a place, not exceeding  $66\frac{1}{2}$  degrees, and the day of the month being given; to find the sun's amplitude, or point of the compass on which he rises or sets.*

Rectify the globe, and bring the sun's place to the eastern side of the horizon; then observe what point of the compass on the horizon stands right against the sun's place, for that is his amplitude at rising. This done, turn the globe westward, until the sun's place comes to the western side of the horizon, and it will cut the point of his amplitude at setting. Or, you may count the rising amplitude in degrees, from the east point of the horizon, to that point where the sun's place

place cuts it; and the setting amplitude, from the west point of the horizon, to the sun's place at setting.

### PROBLEM XXIII.

*The latitude, the sun's place, and his \* altitude being given; to find the hour of the day, and the sun's azimuth, or number of degrees that he is distant from the meridian.*

Rectify the globe, and bring the sun's place to the given height upon the quadrant of altitude; on the eastern side of the horizon, if the time be in the forenoon; or the western side, if it be in the afternoon; then, the index will shew the hour: and the number of degrees in the horizon, intercepted between the quadrant of altitude and the south point, will be the sun's true azimuth at that time.

*N. B.* Always when the quadrant of altitude is mentioned in working any problem, the graduated edge of it is meant.

If this be done at sea, and compared with the sun's azimuth, as shewn by

h

the

\* The sun's altitude, at any time, is his height above the horizon at that time.

the compaffes, if they agree, the compafs has no variation in that place: but if they differ, the compafs does vary; and the variation is equal to this difference.

#### PROBLEM XXIV.

*The latitude, hour of the day, and the sun's place, being given; to find the sun's altitude and azimuth.*

Rectify the globe, and turn it until the index points to the given hour; then lay the quadrant of altitude over the fun's place in the ecliptic, and the degree of the quadrant cut by the fun's place is his altitude at that time above the horizon; and the degree of the horizon cut by the quadrant is the fun's azimuth, reckoned from the fouth.

#### PROBLEM XXV.

*The latitude, the sun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and hour of the day, though they had all been lost.*

Rectify the globe for the latitude and  
\* zenith,

\* zenith, and set the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the sun's place; and the day of the month answering thereto, will be found over the like place of the sun on the wooden horizon. Keep the quadrant of altitude in that position, and having brought the sun's place to the brasen meridian, and the hour-index to XII at noon, turn back the globe, until the sun's place cuts the quadrant of altitude again, and the index will shew the hour.

Any two points of the ecliptic, which are equi-distant from the beginning of *Cancer* or of *Capricorn*, will have the same altitude and azimuth at the same hour, though the months be different; and therefore it requires some care in this problem, not to mistake both the month, and the day of the month; to avoid which, observe, that from the 20th of March to the 21st of June, that part of the ecliptic which is  
h 2 between

• By rectifying the globe for the zenith, is meant screwing the quadrant of altitude to the given latitude on the brass meridian.

between the beginning of *Aries* and beginning of *Cancer* is to be used : from the 21<sup>st</sup> of June to the 23<sup>d</sup> of September, between the beginning of *Cancer* and beginning of *Libra* : from the 23<sup>d</sup> of September to the 21<sup>st</sup> of December, between the beginning of *Libra* and the beginning of *Capricorn* ; and from the 21<sup>st</sup> of December to the 20<sup>th</sup> of March, between the beginning of *Capricorn* and beginning of *Aries*. And as one can never be at a loss to know in what quarter of the year he takes the sun's altitude and azimuth, the above caution with regard to the quarters of the ecliptic, will keep him right as to the month and day thereof.

### PROBLEM XXVI.

*To find the length of the longest day at any given place.*

If the place be on the north side of the equator (find its latitude by Prob. I. and elevate the north to that latitude); then, bring the beginning of *Cancer* to the brazen meridian, and set the hour-index to XII at noon. But if the given place be on the south side of the equator, elevate the south pole to its latitude, and

and bring the beginning of *Capricorn* to the brass meridian, and the hour-index to XII. This done, turn the globe westward, until the beginning of *Cancer* or *Capricorn* (as the latitude is north or south) comes to the horizon; and the index will then point out the time of sun-setting, for it will have gone over all the afternoon hours, between mid-day and sun-set; which length of time being doubled, will give the whole length of the day, from sun-rising to sun-setting. For, in all latitudes, the sun rises as long before mid-day, as he sets after it.

### PROBLEM XXVII.

*To find in what latitude the longest day is of any given length less than 24 hours.*

If the latitude be north, bring the beginning of *Cancer* to the brazen meridian, and elevate the north pole to about  $66\frac{1}{2}$  degrees; but if the latitude be south, bring the beginning of *Capricorn* to the meridian, and elevate the south pole to about  $66\frac{1}{2}$  degrees, because the longest day in north latitude is

is when the sun is in the first point of *Cancer*; and in south latitude, when he is in the first point of *Capricorn*. Then set the our-index to XII at noon, and turn the globe westward, until the index points at half the number of hours given; which done, keep the globe from turning on its axis, and slide the meridian down in the notches, until the afore-said point of the ecliptic (*viz. Cancer or Capricorn*) comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

### PROBLEM XXVIII.

*The latitude of any place, not exceeding  $66\frac{1}{2}$  degrees, being given; to find in what \* climate the place is.*

Find the length of the longest day at the given place by Prob. XXVI.  
and

\* A *Climate*, from the equator to either of the polar circles, is a tract of the earth's surface, included between two such parallels of latitude, that the length of the longest day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the sun keeps long above the horizon without setting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and six from each polar circle to its respective pole.

and whatever be the number of hours whereby it exceedeth twelve, double that number, and the sun will give the climate in which the place is.

PROBLEM XXIX.

*The latitude, and the day of the month, being given ; to find the hour of the day when the sun shines.*

Set the wooden horizon truly level, and the brazen meridian due north and south by a mariner's compass : then, having rectified the globe, stick a small sewing-needle into the sun's place in the ecliptic, perpendicular to that part of the surface of the globe : this done, turn the globe on its axis, until the needle comes to the brazen meridian, and set the hour-index to XII at noon ; then, turn the globe on its axis until the needle points exactly towards the sun (which it will do when it casts no shadow on the globe) and the index will shew the hour of the day.

PROBLEM

## PROBLEM XXX.

*A pleasant way of shewing all those places of the earth which are enlightened by the sun, and also the time of the day when the sun shines.*

Take the terrestrial ball out of the wooden horizon, and also out of the brazen meridian; then set it upon a pedestal in sun-shine, in such a manner, that its north pole may point directly towards the north pole of the heaven, and the meridian of the place where you are be directly towards the south. Then, the sun will shine upon all the like places of the globe, that he does on the real earth, rising to some when he is setting to others; as you may perceive by that part where the enlightened half of the globe is divided from the half in the shade, by the boundary of the light and darkness: all those places, on which the sun shines, at any time, having day; and all those, on which he does not shine, having night.

IF a narrow slip of paper be put round the equator, and divided into  
24 equal

24 equal parts, beginning at the meridian of your place, and the hours be set to those divisions in such a manner, that one of the VI's may be upon your meridian; the sun being upon that meridian at noon, will then shine exactly to the two XII's; and at one o'clock to the two I's, &c. So that the place, where the enlightened half of the globe is parted from the shaded half, in this circle of hours, will shew the hour of the day.

We shall here add the following observations on the Terrestrial globe, and then proceed to the Use of the Celestial Globe, &c.

1. The latitude of any place is equal to the elevation of the pole above the horizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the latitude wants of 90 degrees.

2. Those places which lie on the equator have no latitude, it being there that the latitude begins; and those places which lie on the first meridian have no longitude, it being there that the longitude

gitude begins. Consequently, that particular place of the earth where the first meridian intersects the equator has neither longitude nor latitude.

3. In all places of the earth, except the poles, all the points of the compass may be distinguished in the horizon; but from the north pole, every place is south, and from the south pole, every place is north. Therefore, as the sun is constantly above the horizon of each pole for half a year in its turn, he cannot be said to depart from the meridian of either pole for half a year together. Consequently, at the north pole it may be said to be noon every moment for half a year; and let the winds blow from what part they will, they must always blow from the south; and at the south pole, from the north.

4. Because one half of the ecliptic is above the horizon of the pole, and the sun, moon and planets, move in (or nearly in) the ecliptic; they will rise and set to the poles. But, because the stars never change their declinations from the equator (at least not sensibly in one age) those which are once above the horizon  
of

of either pole, never set below it; and those which are once below it, never rise.

5. All places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it.

6. All places upon the equator have their days and nights equally long, that is 12 hours each, at all times of the year. For although the sun declines alternately, from the equator towards the north and towards the south, yet, as the horizon of the equator cuts all the parallels of latitude and declination in halves, the sun must always continue above the horizon for one half of a diurnal revolution about the earth, and for the other half below it.

7. When the sun's declination is greater than the latitude of any place, upon either side of the equator, the sun will come twice to the azimuth or point of the compass in the forenoon at that place; and twice to a like azimuth in the afternoon; that is, he will go twice back every day, whilst his declination continues to be greater than the latitude. Thus suppose the globe rectified to the

i 2 latitude

latitude of Barbadoes, which is 13 degrees north; and the sun to be any where in the ecliptic, between the middle of Taurus and middle of Leo; if the quadrant of altitude be set about \* 18 degrees north of the east in the horizon, the sun's place be marked with a chalk upon the ecliptic, and the globe be then turned westward on its axis, the said mark will rise in the horizon a little to the north of the quadrant, and thence ascending, it will cross the quadrant towards the south; but before it arrives at the meridian, it will cross the quadrant again, and pass over the meridian northward of Barbadoes. And if the quadrant be set about 18 degrees north of the west, the sun's place will cross it twice, as it descends from the meridian towards the horizon, in the afternoon.

8. In all places of the earth between the equator and the poles, the days and nights are equally long, viz. 12 hours each, when the sun is in the equinoctial; for in all elevations of the pole, short of 90 degrees (which is the greatest) one half of the equator or equinoctial will be  
above

\* From the middle of Gemini to the middle of Cancer, the quadrant may be set 20 degrees.

above the horizon, and the other half below it.

9. The days and nights are never of an equal length at any place between the equator and the polar circles, but when the sun enters the signs ♈ Aries and ♎ Libra. For in every other part of the ecliptic, the circle of the sun's daily motion is divided into two unequal parts by the horizon.

10. The nearer that any place is to the equator, the less is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the sun describes in the heaven every 24 hours being cut more nearly equal in the former case, and more unequally in the latter.

11. In all places lying upon any given parallel of latitude, however long or short the day or night be at any one of these places, at any time of the year, it is then of the same length at all the rest; for in turning the globe round its axis (when rectified according to the sun's declination) all these places will keep equally

equally long above or below the horizon.

12. The sun is vertical twice a year to every place between the tropics; to those under the tropics, once a year, but never any where else. For, there can be no place between the tropics, but that there will be two points in the ecliptic, whose declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the sun never goes without the tropics, he can never be vertical to any place that lies without them.

13. To all places in the \* torrid zone, the duration of the twilight is least, because the sun's daily motion is the most perpendicular to the horizon; in the frigid † zones, greatest; because the sun's daily motion is nearly parallel to the horizon; and therefore he is the longer in getting 18 degrees below it (till which time the twilight always continues.) And  
in

\* Between the tropics.

† Between the polar circles and poles.

in the \* temperate zones it is at a medium between the two, because the obliquity of the sun's daily motion is so.

14. In all places lying exactly under the polar circles, the sun, when he is in the nearest tropic, continues 24 hours above the horizon without setting; because no part of that tropic is below their horizon. And when the sun is in the farthest tropic, he is for the same length of time without rising; because no part of that tropic is above their horizon. But, at all other times of the year, he rises and sets there, as in other places; because all the circles that can be drawn parallel to the equator, between the tropics, are more or less cut by the horizon, as they are farther from, or nearer to, that tropic which is all above the horizon: and when the sun is not in either of the tropics, his diurnal course must be in one or other of these circles.

15. To all places in the northern hemisphere, from the equator to the polar circle, the longest day and shortest night is when the sun is in the northern tropic; and the shortest day and longest night is when the sun is in the southern tropic; because no circle of the sun's daily

\* Between the tropics and polar circles.

daily motion is so much above the horizon, and so little below it, as the northern tropic; and none so little above it, and so much below it as the southern. In the southern hemisphere the contrary.

16. In all places between the polar circles and poles, the sun appears for some number of days (or rather diurnal revolutions) without setting; and at the opposite time of the year without rising; because some part of the ecliptic never sets in the former case, and as much of the opposite part never rises in the latter. And the nearer unto, or the more remote from the pole, these places are, the longer or shorter is the sun's continual presence or absence.

17. If a ship sets out from any port, and sails round the earth eastward to the same port again, let her take what time she will to do it in, the people in that ship, in reckoning their time, will gain one complete day at their return, or count one day more than those who reside at the same port; because, by going contrary to the sun's diurnal motion, and being forwarder every evening than they were in the morning, their  
horizon

horizon will get so much the sooner above the setting sun, than if they had stopt for a whole day at any particular place. And thus, by cutting off a part proportionable to their own motion from the length of every day, they will gain one complet day of that sort at their return; without gaining one moment of absolute time more than is elapsed during their course, to the people at the port. If they sail westward, they will reckon one day less than the people do who reside at the said port, because, by gradually following the apparent diurnal motion of the sun, they will keep him each particular day so much longer above their horizon, as answers to that day's course; and by that means, they cut off a whole day in reckoning at their return, without losing one moment of absolute time.

Hence, if two ships should set out at the same time from any port, and sail round the globe, one eastward and the other westward, so as to meet at the same port on any day whatever, they will differ two days in reckoning their time at their return. If they sail twice round they earth, they will differ four days; if thrice, then six &c.



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THE USE OF THE

# CELESTIAL GLOBE,

A N D

## ARMILLARY SPHERE.

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**H**AVING done for the present with the terrestrial globe, we shall proceed to the use of the celestial; first premising, that as the equator, ecliptic, tropics, polar circles, horizon, and brazen meridian, are exactly alike on both globes, all the former problems concerning the sun are solved the same way by both globes. The method also of rectifying the celestial globe is the same as rectifying the terrestrial, viz. Elevate the pole according to the latitude of your place, then screw the quadrant of altitude to the zenith, on the brass meridian; bring the sun's place in the ecliptic to the graduated edge of the brass meridian, on the side which is

*The celestial globe.*

*To rectify it.*

k 2                      above

above the south point of the wooden horizon, and set the hour index to the uppermost XII, which stands for noon.

N. B. The sun's place for any day of the year stands directly over that day on the horizon of the celestial globe, as it does on that of the terrestrial.

*Latitude  
and longi-  
tude of the  
stars.*

The *latitude* and *longitude* of the stars, or of all other celestial phenomena, are reckoned in a very different manner from the latitude and longitude of places on the earth: for terrestrial latitudes are reckoned from the equator, and longitudes from the meridian of some remarkable place, as of London by the English, and of Paris by the French; though most of the French maps begin their longitude at the meridian of the island *Ferro*.—But the astronomers of all nations agree in reckoning the *latitudes* of the moon, stars, planets, and comets, from the *ecliptic*; and their *longitudes* from the  
\* *equinoctial colure*, in that semicircle  
of

*Colures.*

\* The great circle that passes through the *equinoctial points* at the beginning of ♈, and ♎, and through the poles of the world (which are two opposite points, each 90 degrees from the equinoctial) is called the *equinoctial colure*: and the great circle that passes through the beginning of ♈ and ♎ and

of it which cuts the ecliptic at the beginning of *Aries*  $\gamma$ ; and thence eastward, quite round, to the same semicircle again. Consequently, those stars which lie between the equinoctial and the northern half of the ecliptic have north declination and south latitude; those which lie between the equinoctial and the southern half of the ecliptic have south declination and north latitude; and all those which lie between the tropics and poles have their declinations and latitudes of the same denomination.

There are six great circles on the celestial globe, which cut the ecliptic perpendicularly, and meet in two opposite points in the polar circles; which points are each ninety degrees from the ecliptic, and are called its poles. These polar points divide those circles into twelve semicircles; which cut the ecliptic at the beginnings of the 12 signs. They resemble so many meridians on the terrestrial globe; and as all places which lie under any particular meridian semicircle on that globe

and also through the poles of the ecliptic, and poles of the world, is called the *solstitial colure*.

globe have the same longitude, so all those points of the heaven, through which any one of the above semicircles are drawn, have the same longitude.— And as the greatest latitudes on the earth are at the north and south poles of the earth, so the greatest latitudes in the heaven are at the north and south poles of the ecliptic.

In order to distinguish the stars, with regard to their situations and positions in the heaven, the antients divided the whole visible firmament of stars into particular systems, which they called *constellations*; and digested them into the forms of such animals as are delineated upon the celestial globe. And those stars which lie between the figures of those imaginary animals, and could not be brought within the compass of any of them, were called *unformed stars*.

Because the moon and all the planets were observed to move in circles or orbits which cross the ecliptic (or line of the sun's path) at small angles, and to be on the north side of the ecliptic for one half of their course round the heaven of stars, and on the south side of it for the other half, but never to

go quite 8 degrees from it on either side, the ancients distinguished that space by two lesser circles, parallel to the ecliptic (one on each side) at 8 degrees distance from it. And the space included between these circles they called the *zodiac*, because most of the 12 constellations placed therein resemble some living creature.—These con-  
 stellations are, 1. *Aries* ♈, the ram; 2. *Taurus* ♉, the bull; 3. *Gemini* ♊, the twins; 4. *Cancer* ♋, the crab; 5. *Leo* ♌, the lion; 6. *Virgo* ♍, the virgin; 7. *Libra* ♎, the balance; 8. *Scorpio* ♏, the scorpion; 9. *Sagittarius* ♐, the archer; 10. *Capricornus* ♑, the goat; 11. *Aquarius* ♒, the water bearer; and 12. *Pisces* ♓, the fishes.

Its signs  
or divisi-  
ons.

It is to be observed, that in the  
 infancy of astronomy these twelve  
 constellations stood at or near the  
 places of the ecliptic, where the above  
 characteristics are marked upon the  
 globe: but now, each constellation  
 has got a whole sign forwarder, on  
 account of the recession of the equi-  
 noctial points from their former places.  
 So that the constellation of *Aries* is  
 now got into the former place of *Taurus*;  
 that of *Taurus*, into the former place  
 of *Gemini*; and so on.

Remark,

The

The stars appear of different magnitudes to the eye; probably because they are at different distances from us. Those which appear brightest and largest are called *stars of the first magnitude*; the next to them in size and lustre, are called *stars of the second magnitude*; and so on to the *sixth*, which are the smallest that can be discerned by the bare eye.

Some of the most remarkable stars have names given them, as *Castor* and *Pollux* in the heads of the *Twins*, *Sirius* in the mouth of the *Great Dog*, *Procyon* in the side of the *Little Dog*, *Rigel* in the left foot of *Orion*, *Arcturus* near the right thigh of *Bootes*, &c.

These things being premised, which I think are all that the young *Tyro* need be acquainted with before he begins to work any problem by this globe, we shall now proceed to the most useful of those problems, omitting several which are of little or no consequence.

#### PROBLEM

PROBLEM I.

*To find the \* right ascension and † declination of the sun, or any fixed star.*

Bring the sun's place in the ecliptic to the brazen meridian, then that degree in the equinoctial which is cut by the meridian is the sun's *right ascension*; and that degree of the meridian which is over the sun's place is his *declination*. Bring any fixed star to the meridian, and its *right ascension* will be cut by the meridian, in the equinoctial; and the degree of the meridian that stands over it is its *declination*.

So that *right ascension* and *declination*, on the celestial globe are found in the same manner as *longitude* and *latitude* on the terrestrial.

\* The degree of the equinoctial, reckoned from the beginning of *Aries*, that comes to the meridian with the sun or star, is its *right ascension*.

† The distance of the sun or star in degrees from the equinoctial towards either of the poles, north or south, is its *declination*, which is north or south accordingly.

## PROBLEM II.

*To find the latitude and longitude of any star.*

If the given star be on the north side of the ecliptic, place the 90th degree of the quadrant of altitude on the north pole of the ecliptic, where the twelve semicircles meet, which divide the ecliptic into the 12 signs: but if the star be on the south side of the ecliptic, place the 90th degree of the quadrant on the south pole of the ecliptic: keeping the 90th degree of the quadrant on the proper pole, turn the quadrant about, until its graduated edge cuts the star: then, the number of degrees in the quadrant, between the ecliptic and the star, is its latitude; and the degree of the ecliptic cut by the quadrant is the star's longitude, reckoned according to the sign in which the quadrant then is.

PROBLEM

## PROBLEM III.

*To represent the face of the starry firmament, as seen from any given place of the earth, at any hour of the night.*

Rectify the celestial globe for the given latitude, the zenith, and sun's place, in every respect, as taught by the 17th problem for the terrestrial; and turn it about, until the index points to the given hour: then, the upper hemisphere of the globe will represent the visible half of the heaven for that time: all the stars upon the globe being then in such situations, as exactly correspond to those in the heaven. And if the globe be placed duly north and south, by means of a small sea-compass, every star on the globe will point toward the like star in the heaven: by which means, the constellations and remarkable stars may be easily known. All those stars which are in the eastern side of the heaven are rising in the eastern side; all in the western are setting in the western side; and all those under the upper part of the brazen meridian,

between the south point of the horizon and the north poles, are at their greatest altitude, if the latitude of the place be north: but if the latitude be south, those stars which lie under the upper part of the meridian, between the north point of the horizon and the south pole, are at their greatest altitude.

#### PROBLEM IV.

*The latitude of the place, and day of the month, being given; to find the time when any known star will rise, or be upon the meridian, or set.*

Having rectified the globe, turn it about until the given star comes to the eastern side of the horizon, and the index will shew the time of the star's rising; then turn the globe westward, and when the star comes to the brazen meridian, the index will shew the time of the star's coming to the meridian of your place; lastly, turn on, until the star comes to the western side of the horizon, and the index will shew the time of the star's setting.

N. B. In

N. B. In northern latitudes, those stars which are less distant from the north pole than the quantity of its elevation above the north point of the horizon, never set; and those which are less distant from the south pole than the number of degrees by which it is depressed below the horizon, never rise: and *vice versa* in southern latitudes.

#### PROBLEM V.

*To find at what time of the year a given star will be upon the meridian, at a given hour of the night.*

Bring the given star to the upper semicircle of the brass meridian, and set the index to the given hour; then turn the globe, until the index points to XII at noon, and the upper semicircle of the meridian will then cut the sun's place, answering to the day of the year sought; which day may be easily found against the like place of the sun among the signs on the wooden horizon.

#### PROBLEM

## PROBLEM VI.

*The latitude, day of the month, and \* azimuth of any known star being given; to find the hour of the night.*

Having rectified the globe for the latitude, zenith, and sun's place, lay the quadrant of altitude to the given degree of azimuth in the horizon; then turn the globe on its axis, until the star comes to the graduated edge of the quadrant; and when it does, the index will point out the hour of the night.

## PROBLEM VII.

*The latitude of the place, the day of the month, and altitude † of any known star, being given; to find the hour of the night.*

Rectify the globe as in the former problem, guess at the hour of the night,

\* The number of degrees that the sun, moon, or any star is from the meridian, either to the east or west, is called, its *azimuth*.

† The number of degrees that the star is above the horizon, as observed by means of a common quadrant, is called its *altitude*.

night, and turn the globe until the index points at the supposed hour; then lay the graduated edge of the quadrant of altitude over the known star; and if the degree of the star's height in the quadrant upon the globe answers exactly to the degree of the observed altitude in the heaven, you have guessed exactly: but if the star on the globe is higher or lower than it was observed to be in the heaven, turn the globe backwards or forwards, keeping the edge of the quadrant upon the star, until its center comes to the observed altitude in the quadrant; and then the index will shew the true time of the night.

### PROBLEM VIII.

*An easy method for finding the hour of the night by any known stars, without knowing either their altitude or azimuth; and then, of finding both their altitude and azimuth, and thereby the true meridian.*

Tie one end of a thread to a common musket bullet; and, having rectified the globe as above, hold the  
other

other end of the thread in your hand, and carry it slowly round betwixt your eye and the starry heaven, until you find it cuts any two known stars at once. Then, guessing at the hour of the night, turn the globe until the index points to that time in the hour-circle; which done, lay the graduated edge of the quadrant over any one of these two stars on the globe, which the thread cut in the heaven. If the said edge of the quadrant cuts the other star also, you have guessed the time exactly; but if it does not, turn the globe slowly backwards or forwards, until the quadrant (kept upon either star) cuts them both through their centers; and then, the index will point out the exact time of the night: the degree of the horizon, cut by the quadrant, will be the true azimuth of both these stars from the south; and the stars themselves will cut their true altitude in the quadrant. At which moment, if a common azimuth compass be set upon a floor or level pavement, that these stars in the heaven may have the same bearing upon it (allowing for the variation of the needle) as the quadrant of  
altitude

altitude has in the wooden horizon of the globe, a thread extended over the north and south points of that compass will be directly in the plane of the meridian: and if a line be drawn upon the floor or pavement, along the course of the thread, and an upright wire be placed in the southmost end of the line, the shadow of the wire will fall upon that line, when the sun is on the meridian, and shines upon the pavement.

#### PROBLEM IX.

*To find the place of the moon, or of any planet, and thereby to shew the time of its rising, southing, and setting.*

See in *Parker's* or *Weaver's* Ephemeris the \* geocentric place of the moon or planet in the ecliptic, for the given day of the month; and according to its longitude and latitude, as shewn by the Ephemeris, mark the same with a chalk upon the globe. Then, having rectified the globe, turn it round its axis westward, and as the

m                      said

\* The place of the Moon or planet, as seen from the earth, is called its geocentric place.

said mark comes to the eastern side of the horizon, to the brazen meridian, and to the western side of the horizon, the index will shew at what time the planet rises, comes to the meridian, and sets, in the same manner as it would do for a fixed star.

### PROBLEM X.

*To explain the phænomena of the harvest moon.*

In order to do this, we must premise the following things. 1. That as the sun goes only once a year round the ecliptic, he can be but once a year in any particular point of it: and that his motion is almost a degree every 24 hours at a mean rate. 2. That as the moon goes round the ecliptic once in 27 days and 8 hours, she advances  $13\frac{1}{2}$  degrees in it, every day at a mean rate. 3. That as the sun goes through part of the ecliptic in the time the moon goes round it, the moon cannot at any time be either in conjunction with the sun, or opposite to him, in that part of the ecliptic where she was so the last time before; but must travel as  
much

much forwarder, as the sun has advanced in the said time; which being  $29\frac{1}{2}$  days, make almost a whole sign. Therefore, 4. The moon can be but once a year opposite to the sun, in any particular part of the ecliptic. 5. That the moon is never full but when she is opposite to the sun, because at no other time can we see all that half of her which the sun enlightens. 6. That when any point of the ecliptic rises, the opposite point sets. Therefore when the moon is opposite to the sun, she must rise at\* sun set. 7. That the different signs of the ecliptic rise at very different angles or degrees of obliquity with the horizon, especially in considerable latitudes; and that the smaller this angle is, the greater is the portion of the ecliptic that rises in any small part of time; and *vice versa*. 8. That, in northern latitudes, no part of the ecliptic rises at so small an angle with the horizon, as *Pisces* and *Aries* do; therefore, a greater portion of the ecliptic rises in one hour, about these signs, than  
m 2 about

\* This is not always strictly true, because the moon does not keep in the ecliptic, but crosses it twice every month. However the difference need not be regarded in a general explanation.

about any of the rest. 9. That the moon can never be full in *Pisces* and *Aries* but in our autumnal months, for at no other time of the year is the sun in the opposite signs of *Virgo* and *Libra*.

These things premised, take 13 degrees of the ecliptic in your compasses, and, beginning at *Pisces*, carry that extent all round the ecliptic, marking the places with a chalk where the points of the compasses successively fall. So you will have the moon's daily motion marked out for one complete revolution in the ecliptic (according to § 2 of the last paragraph.)

Rectify the globe for any considerable northern latitude, (as suppose that of London) and then, turning the globe round its axis, observe how much of the hour-circle the index has gone over at the rising of each particular mark on the ecliptic; and you will find that seven of the marks (which take in as much of the ecliptic as the moon goes through in a week) will all rise successively about *Pisces* and *Aries*, in the time that the index goes over two hours. Therefore, whilst the moon is in *Pisces* and *Aries*, she will not differ in general above two hours in  
her

her rising for a whole week. But if you take notice of the marks on the opposite signs, *Virgo* and *Libra*, you will find that seven of them take nine hours to rise; which shews, that when the moon is in these two signs, she differs nine hours in her rising within the compass of a week. And so much later as every mark is rising than the one that rose next before it, so much later will the moon be of rising any day, than she was on the day before, in the corresponding part of the heaven. The marks about *Cancer* and *Capricorn* rise with a mean difference of time between those about *Aries* and *Libra*.

Now, although the moon is in *Pisces* and *Aries* every month, and therefore must rise in those signs within the space of two hours later for a whole week, or only about 17 minutes later every day than she did on the former; yet she is never full in these signs, but in our autumnal months *August* and *September*, when the sun is in *Virgo* and *Libra*. Therefore, no full moon in the year will continue to rise so near the time of sun-set for a week or so, as these two full moons do, which fall in the time of harvest.

In

In the winter months, the moon is in *Pisces* and *Aries* about her first quarter; and as these signs rise about noon in winter, the moon's rising in them passes unobserved. In the spring months, the moon changes in these signs, and consequently rises at the same time with the sun; so that it is impossible to see her at that time. In the summer months she is in these signs about her third quarter, and rises not until mid-night, when her rising is but very little taken notice of; especially as she is on the decrease. But in the harvest months she is at the full when in these signs, and, being opposite to the sun, she rises when the sun sets (or soon after) and shines all the night.

In southern latitudes, *Virgo* and *Libra* rise at as small angles with the horizon as *Pisces* and *Aries* do in the northern; and as our spring is at the time of their harvest, it is plain their harvest full moons must be in *Virgo* and *Libra*; and will therefore rise with as little difference of time as ours do in *Pisces* and *Aries*.

For a fuller account of this matter, I must refer the reader to my *Astronomy*, in which it is described at large.

PROBLEM

PROBLEM XI.

*To explain the equation of time, or difference of time between well regulated clocks and true sun-dials.*

The earth's motion on its axis being perfectly equable, and thereby causing an apparent equable motion of the starry heaven round the same axis, produced to the poles of the heaven; it is plain that equal portions of the celestial equator pass over the meridian in equal parts of time, because the axis of the world is perpendicular to the plane of the equator. And therefore, if the sun kept his annual course in the celestial equator, he would always revolve from the meridian to the meridian again in 24 hours exactly, as shewn by a well-regulated clock.

But as the sun moves in the ecliptic, which is oblique both to the plane of the equator and axis of the world, he cannot always revolve from the meridian to the meridian again in 24 equal hours; but sometimes a little sooner, and at other times a little later, because

cause equal portions of the ecliptic pass over the meridian in unequal parts of time, on account of its obliquity. And this difference is the same in all latitudes.

To shew this by a globe, make chalk-marks all round the equator and ecliptic, at equal distances from one another (suppose 10 degrees) beginning at *Aries* or at *Libra*, where these two circles intersect each other. Then turn the globe round its axis, and you will see that all the marks in the first quadrant of the ecliptic, or from the beginning of *Aries* to the beginning of *Cancer*, come sooner to the brazen meridian than their corresponding marks do on the equator: those in the second quadrant, or from the beginning of *Cancer* to the beginning of *Libra*, come later: those in the third quadrant, from *Libra* to *Capricorn*, sooner; and those in the fourth, from *Capricorn* to *Aries*, later. But those at the beginning of each quadrant come to the meridian at the same time with their corresponding marks on the equator.

Therefore, whilst the sun is in the first and third quadrants of the ecliptic,

tic, he comes sooner to the meridian every day than he would do if he kept in the equator; and consequently he is faster than a well-regulated clock, which always keeps equable or equatorial time: and whilst he is in the second and fourth quadrants, he comes later to the meridian every day than he would do if he kept in the equator; and is therefore slower than the clock. But at the beginning of each quadrant, the sun and clock are equal.

And thus, if the sun moved equally in the ecliptic, he would be equal with the clock on four days of the year, which would have equal intervals of time between them. But as he moves faster at some times than at others (being eight days longer in the northern half of the ecliptic than in the southern) this will cause a second inequality; which, combined with the former, arising from the obliquity of the ecliptic to the equator, makes up that difference, which is shewn by the common equation tables to be between good clocks and true sun-dials.



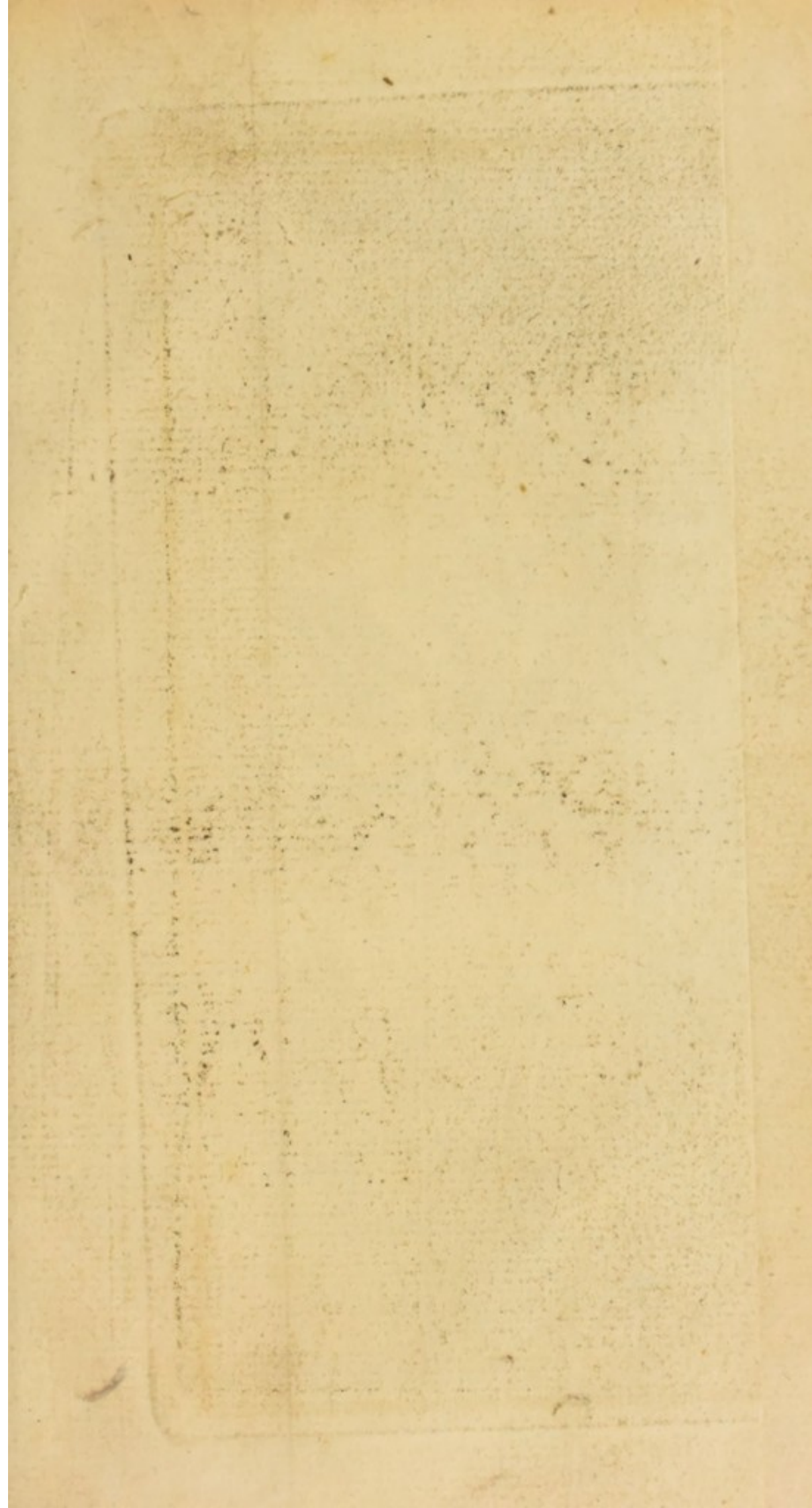


PLATE VIII.

Fig. 1.

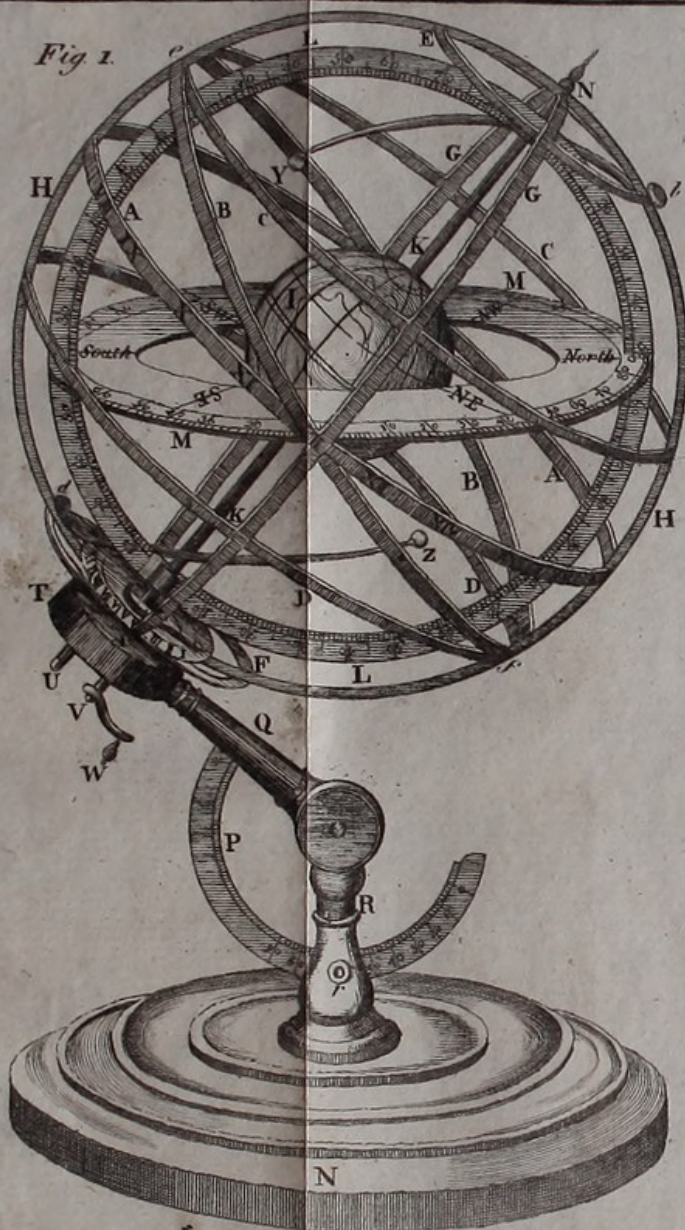


Fig. 2.

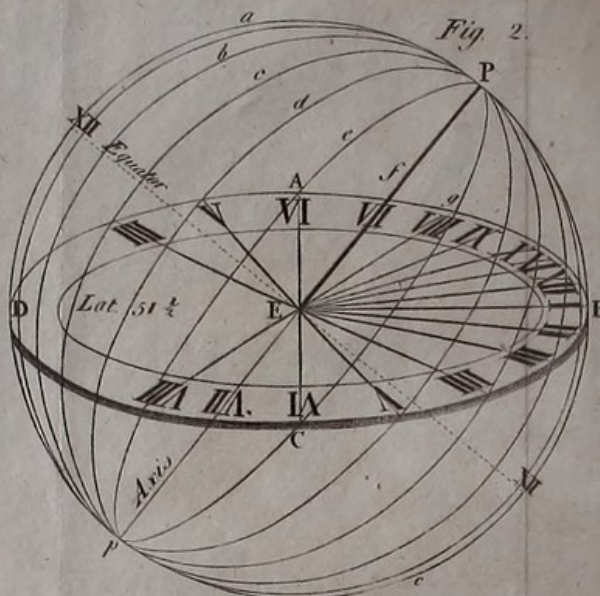
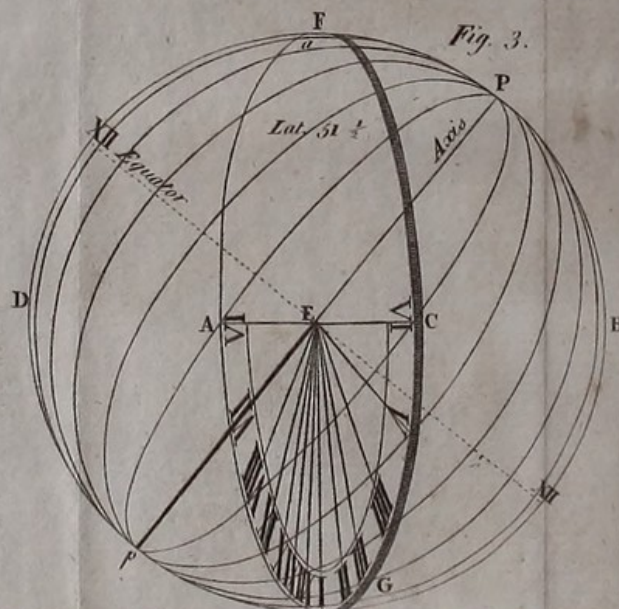


Fig. 3.



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THE  
DESCRIPTION AND USE  
OF THE  
ARMILLARY SPHERE.

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WHOEVER has seen a common *armillary sphere*, and understands how to use it, must be sensible that the machine here referred to is of a very different, and much more advantageous construction. And whoever has seen the curious glass sphere invented by Dr LONG, or the figure of it in his *Astronomy*, must know that the furniture of the terrestrial globe in this machine, the form of the pedestal, and the manner of turning either the earthly globe, or the circles which surround it, are all copied from the Doctor's glass sphere; and that the only difference is, a parcel of rings instead of a glass celestial globe; and all the additions are, a moon within the sphere, and a semicircle upon the pedestal.

The exterior parts of this machine are a compages of brass rings, which represent the principal circles of the heaven, viz. 1. The equinoctial *AA*, which is divided into 360 degrees (beginning at its intersection with the ecliptic in *Aries*) for shewing the sun's right ascension in degrees; and also in 24 hours, for shewing his right ascension in time. 2. The ecliptic *BB*, which is divided into 12 signs, and each sign into 30 degrees, and also into the months and days of the year; in such a manner, that the degree or point of the ecliptic in which the sun is, on any given day, stands over that day in the circle of months. 3. The tropic of *Cancer* *CC*, touching the ecliptic at the beginning of *Cancer* in *e*, and the tropic of *Capricorn* *DD*, touching the ecliptic at the beginning of *Capricorn* in *f*; each  $23\frac{1}{2}$  degrees from the equinoctial circle. 4. The arctic circle *E*, and the antarctic circle *F*, each  $23\frac{1}{2}$  degrees from its respective pole at *N* and *S*. 5. The equinoctial colure *GG*, passing through the north and south poles of the heaven at *N* and *S*, and through the equinoctial points *Aries* and *Libra*, in the

the ecliptic. 6. The solstitial colure *HH*, passing through the poles of the heaven, and through the solstitial points *Cancer* and *Capricorn*, in the ecliptic. Each quarter of the former of these colures is divided into 90 degrees, from the equinoctial to the poles of the world, for shewing the declination of the sun, moon and stars: and each quarter of the latter, from the ecliptic at *e* and *f*, to its poles *b* and *d*, for shewing the latitudes of the stars.

In the north pole of the ecliptic is a nut *b*, to which is fixed one end of a quadrantal wire, and to the other end a small sun *Y*, which is carried round the ecliptic *BB*, by turning the nut: and in the south pole of the ecliptic is a pin at *d*, on which is another quadrantal wire, with a small moon, *Z* upon it, which may be moved round by hand: but there is a particular contrivance for causing the moon to move in an orbit which crosses the ecliptic at an angle of  $5\frac{1}{2}$  degrees, in two opposite points called the *moon's nodes*; and also for shifting these points backward in the ecliptic, as the *moon's nodes* shift in the heaven.

Within

Within these circular rings is a small terrestrial globe *I*, fixed on an axis *K K*, which extends from the north and south poles of the globe at *n* and *s*, to those of the celestial sphere at *N* and *S*. On this axis is fixed the flat celestial meridian *L L*, which may be set directly over the meridian of any place on the globe, and then turned round with the globe, so as to keep over the same meridian upon it: This flat meridian is graduated the same way as the brass meridian of a common globe, and its use is much the same. To this globe is fitted the moveable horizon *M M*, so as to turn upon two strong wires proceeding from its east and west points to the globe, and entering the globe at opposite points of its equator, which is a moveable brass ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, so as to place any given meridian upon it, directly under the celestial meridian *L L*. The horizon is divided into 360 degrees all round its outermost edge, within which are the points of the compass, for shewing the amplitude of the sun and moon, both in degrees and points.

The

The celestial meridian *L L*, passes through two notches in the north and south points of the horizon, as in a common globe: but here, if the globe be turned round, the horizon and meridian turn with it. At the south pole of the sphere is a circle of 24 hours, fixt to the rings, and on the axis is an index which goes round that circle, if the globe be turned round its axis.

The whole fabric is supported on a pedestal *N*, and may be elevated or depressed upon the joint *O*, to any number of degrees from 0 to 90, by means of the arc *P*, which is fixed into a strong brass arm *Q* and slides in the upright piece *R*, in which is a screw at *r*, to fix it at any proper elevation.

In the box *T* are two wheels (as in Dr. *Long's* sphere) and two pinions, whose axis come out at *V* and *U*; either of which may be turned by the small winch *W*. When the winch is put upon the axis *V*, and turned backward, the terrestrial globe, with its horizon and celestial meridian, keep at rest; and the whole sphere of circles turns round from east, by south, to west, carrying

carrying the sun *Y*, and moon *Z*, round the same way, and causing them to rise above and set below the horizon. But when the winch is put upon the axis *U*, and turned forward, the sphere with the sun and moon kept at rest; and the earth, with its horizon and meridian, turn round from west, by south, to east; and bring the same points of the horizon to the sun and moon, to which these bodies came when the earth kept at rest, and they were carried round it; shewing that they rise and set in the same points of the horizon, and at the same times in the hour-circles, whether the motion be in the earth or in the heaven. If the earthly globe be turned, the hour-index goes round its hour-circle; but if the sphere be turned, the hour-circle goes round below the index.

And so, by this construction, the machine is equally fitted to shew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the sphere for use, first slacken the screw *r* in the upright stem *R*, and taking hold of the arm *Q*, move it up or down until the given degree of latitude for any place be at the side  
of

of the stem *R*; and then the axis of the sphere will be properly elevated, so as to stand parallel to the axis of the world, if the machine be set north and south by a small compass: this done, count the latitude from the north pole, upon the celestial meridian *L L*, down towards the north notch of the horizon, and set the horizon to that latitude; then, turn the nut *b* until the sun *Y* comes to the given day of the year in the ecliptic, and the sun will be at its proper place for that day: find the place of the moon's ascending node, and also the place of the moon, by an Ephemeris, and set them right accordingly: lastly, turn the winch *W*, until either the sun comes to the meridian *L L*, or until the meridian comes to the sun (according as you want the sphere or earth to move) and set the hour-index to the XII, marked noon, and the whole machine will be rectified.—Then turn the winch, and observe when the sun or moon rise and set in the horizon, and the hour-index will shew the times thereof for the given day.

As those who understand the use of the globes will be at no loss to work many other problems by this sphere, it is needless to enlarge any farther upon it.

T H E E N D.

*A LIST of the APPARATUS on which Mr. Ferguson reads his Course of Twelve Lectures on Machines, Hydrostatics, Hydraulics, Pneumatics, Electricity, Dialing, and Astronomy.*

(The numbers relate to the lectures read on the Machinery, to which they are prefixed.)

I.

**S**IMPLE machines for demonstrating the power of the Lever, the Wheel and Axle, the Inclined Plane, the Pullies, the Wedge, and the Screw.

A compound Engine, in which all these powers work together.

A working model of the great Crane at *Bristol*, which is reckoned to be the best Crane in Europe,

A working model of a Crane that has four different powers, to be adapted to the different weight intended to be raised: invented by Mr. *Ferguson*.

A Pyrometer that makes the expansion of metals by heat visible to the ninety thousandth part of an inch.

II.

Simple machines for shewing the center of gravity of bodies, and how much a tower may incline without danger of falling.

A double Cone that seemingly rolls up-hill of itself, whilst it is actually descending.

A machine made in the figure of a man, that tumbles backward by continually oversetting the center of gravity.

Models of wheel-carriages; some with broad wheels, others with narrow; some with large wheels, others with small: for proving experimentally which sort is the best.

A machine for shewing what degree of power is sufficient to draw a loaded cart or waggon up hill; when the quantity of weight to be drawn up and the angle of the hill's height are known.

A model of a most curious Silk-reel, invented by Mr. Verrier near Wrington in Somersetshire.

A large working model of a water-mill for sawing timber.

A model of a hand-mill for grinding corn.

A model of a water-mill for winnowing and grinding corn, drawing up the sacks, and boulting the flour.

A machine for demonstrating that the power of the wind on wind-mill sails is as the square of the velocity of the wind.

A working model of the Engine by which the piles were driven for a foundation to the piers of Westminster Bridge.

### III.

A machine for shewing that fluids weigh as much in their own Elements as they do in Air.

A machine for shewing that, on equal bottoms, the pressure of fluids is in proportion to their perpendicular

perpendicular heights, be their quantities ever so great or ever so small.

A machine for shewing that fluids press equally in all manner of directions.

A machine for shewing how an ounce of water in a tube may be made to raise sixteen pounds weight of lead.

A machine for shewing, that, at equal heights, the smallest quantity of water will balance the greatest quantity whatever, if the columns join at bottom.

A machine for shewing how solid lead may be made to swim in water, and the lightest wood to sink therein.

Machines for demonstrating the Hydrostatical Paradox.

A machine for demonstrating that the quantity of water displaced by a ship is equal to the whole weight of the ship and cargo.

Machines for shewing the working of Syphons, and the Tantalus' cup.

A large machine for shewing the cause and phenomena of ebbing and flowing wells, and of intermitting and reciprocating springs.

#### IV.

Machines for shewing that when solid bodies are immersed and suspended in fluids, the solid loses as much of its weight as its bulk of the fluid weighs; and that the weight lost by the solid is imparted to the fluid.

A hydrostatic balance for shewing the specific gravities of bodies, and detecting counterfeit gold or silver.

A working

A working model of Archimedes's spiral pump.

Glass models for shewing the structure and operations of sucking, forcing, and lifting pumps.

A working model of a quadruple pump-mill, for raising water by means of water turning a wheel.

A working model of the Persian wheel for raising water; and one of Mr. Blakey's Fire Engines.

A working model of the engine by which water is raised from the Hungarian mines.

A large model of the great engine at London Bridge that goes by the Tides, and raises water by forcing pumps.

#### V, and VI.

An Air-pump with a great apparatus belonging to it, for experiments shewing the weight and spring of the air.

A wind-gun.

#### VII.

An Electrical machine with a large apparatus for shewing many experiments in Electricity.

A simple machine, by which all the principles of dialing are evident to sight.

Several kinds of sun dials.

A model of an astronomical Clock, shewing the apparent motions and times of rising and setting of the Sun, Moon and Stars; with the ages and phases of the Moon at all times.

Another model of a Clock for shewing the apparent motions of the Sun and Stars, with the times

times of their rising and setting, and the Equation of time.

### VIII.

A centripetal and centrifugal machine for explaining and demonstrating the laws by which the planets move and are retained in their orbits; proving the diurnal and annual motions of the Earth; and shewing why the tides rise equally high at the same time on opposite sides of the Earth.

### IX, X, XI, XII.

A machine for shewing the motions of the comets.

An Orrery shewing the real motions of the planets round the Sun, and round their axis: the apparent stations, direct and retrograde motions, of Mercury and Venus, as seen from the Earth: the different lengths of days and nights, and all the vicissitudes of seasons: the motions and various phases of the moon: the harvest Moon: the tides: the causes, times, and returns of all the Eclipses of the Sun and Moon: the Eclipses of Jupiter's satellites, and the phenomena of Saturn's ring.

In London, any number of persons, not less than twenty-five, who will subscribe one guinea each, may have a course of twelve lectures read on the above mentioned machinery, provided they agree to have at least three lectures a week ;  
in

in which, they may appoint the days and hours that are most convenient for themselves.

Within ten miles of London, any number not less than thirty may have a course; each subscriber paying one guinea. And,

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