The young gentleman and lady's astronomy. Familiary explained in ten dialogues between Neander and Eudosia. To which is added, the description and use of the globes and armillary sphere / By James Ferguson.

Contributors

Ferguson, James, 1710-1776.
Neander.
Eudosia.

Publication/Creation

Dublin : Printed for Boulter Grierson, 1768.

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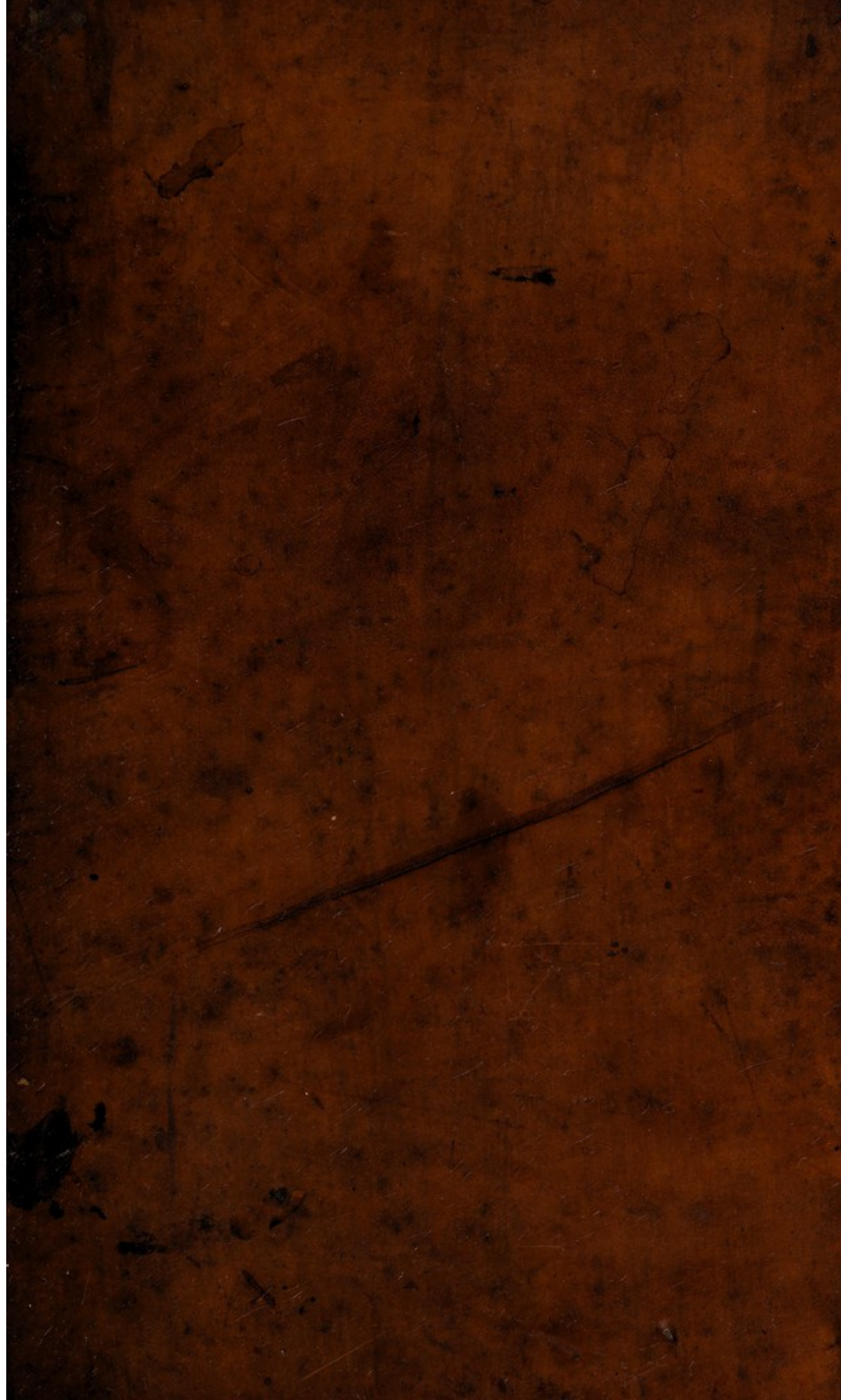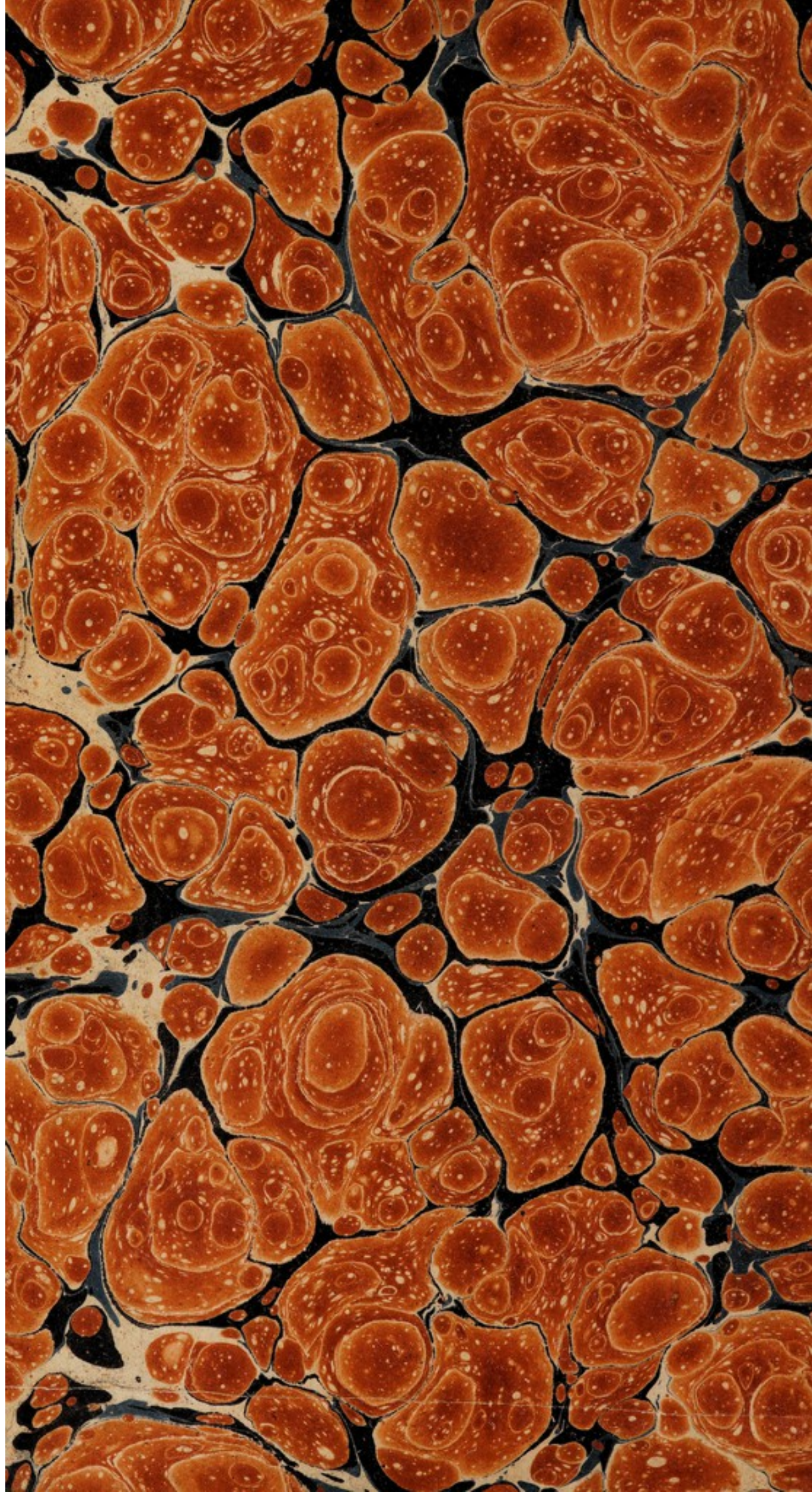
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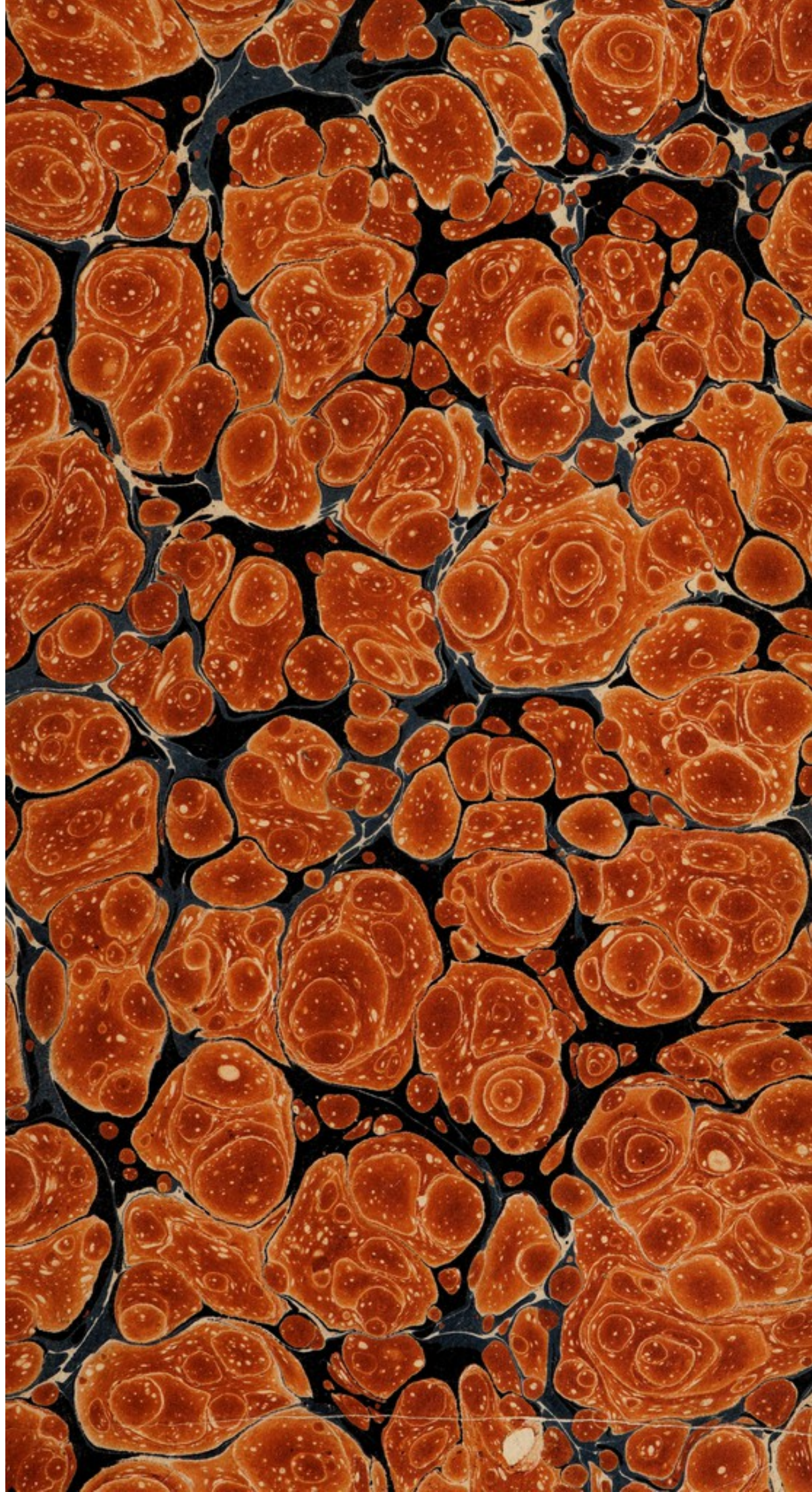
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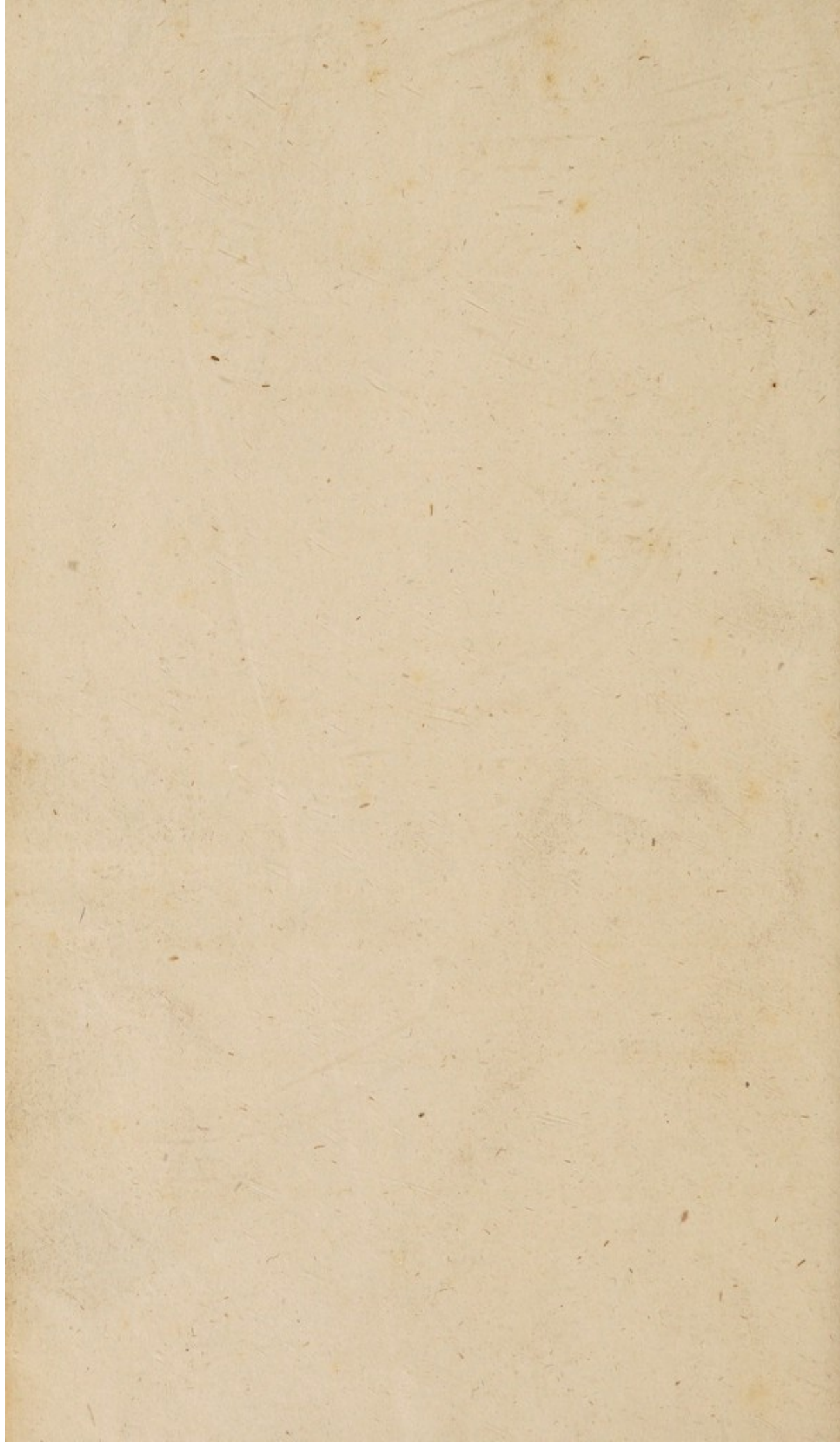
Young GENTLEMAN and LADY's

ASTRONOMY,

FAMILIARLY EXPLAINED

IN TEN DIALOGUES

BETWEEN

NEANDER and EUDOSIA.

To which is added,

The DESCRIPTION and USE of the

GLOBES and ARMILLARY SPHERE.

By JAMES FERGUSON, F.R.S.

The works of the LORD are Great, fought out of all them that have pleafure therein Pfal. CXI. v. 2.

DUBLIN:

Printed by BOULTER GRIERSON, Printer to the King's Moft Excellent Majefty.

M DCC LXVIII.

ADVERTISEMENT.

THE defign of the following Treatife is to fhew, that Young Gentlemen and Ladies may acquire a competent knowledge of Aftronomy, without any previous knowledge of Geometry or Mathematics. How far the Author has fucceeded in this, is left to the judgment and decifion of his impartial Readers ; to whom, if his labours be agreeable and inftructive, the purpofe for which he wrote will be fully anfwered.

which fhone forth with the greateft luftre in the whole of your deportment.——I am ftill the fame as before, excepting the improvement I have made at that famous univerfity ; where, not only the fublime fciences are taught by the greateft mafters, but the truths of the Chriftian religion proved in the lectures which I have conftantly attended.——You know that you and I ufed to converfe familiarly before I went thither : let us do fo ftill.

E. Dear brother, I cannot exprefs how much you oblige me by this behaviour.——I was afraid before to tell you my mind ; but now I will, efpecially as you are to be here for fome confiderable time before you fet 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 fex have no bufinefs with.

N. Pray *Eudofia*, what is that ?

E. It is nothing lefs than to be in fome meafure acquainted with the fublime fcience of Aftronomy ; for I have been told, that, of all others, it is the beft for enlarging our minds, and filling them with the moft noble ideas of the GREAT CREATOR and his works ; and confequently of drawing us nearer to Him, with an humble fenfe of our own meannefs, and of every thing that the greateft art of man can perform.

N. Indeed, fifter, whoever told you fo, told you a great truth ; and I am very glad to find you have an inclination to learn the moft fublime fcience that ever was taught by mankind.

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

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

E. Now,

E. Now, let me fpeak freely.——I have been told, aftronomers pretend that the fun ftands ftill, and that the earth turns round.——What do you fay to this ?——I know you honour the Bible, and it afferts the contrary. Now, I fee fo many things in that Book which appear to me to be above all the powers of human compofition, and carry fuch evident marks of Divinity with them, as are fufficient 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 againft the Bible.

N. Dear fifter, I admire the goodnefs of your heart. ——You may depend upon it, that the ftudy of aftronomy will never have the leaft tendency towards prejudicing your mind againft the Scriptures.——You know that we cannot take every thing there in the ftrict literal fenfe. If we did, we fhould 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 fhould believe, and how we fhould behave, in order to attain and fecure to ourfelves the favour of our Maker here, and our perpetual felicity hereafter ; which are things infinitely more interefting to us than all other knowledge and wealth in the world.——They fpeak according to the common apprehenfions of mankind, in thofe points which are merely fpeculative, and have no direct tendency to influence our morals ; and, as they never were intended to inftruct us in experimental phi- lofophy, or aftronomy, or in any thing elfe that we could acquire by our own induftry without them, nothing that regards thefe fciences can rather be deduced or inferred from them.——One might with as good reafon take up a law-book and expect to find a fyftem of geo- graphy in it, as take up the Bible with a view to find a fyftem of aftronomy therein.

E. What

E. What you have faid is rational and juft; and now, if you pleafe, I fhould be glad to enter upon our intended fubject.——If the fun does not move, pray, to what is he fixed? and what hinders him from falling down to the earth, when he is fo high above it, efpecially at noon in fummer?

N. High and *low* are only relative terms; for, when the fun is at his loweft depreffion with refpect to us, he is directly over-head to fome other part of the earth; for the earth is round like a globe, and on whatever part of its furface a perfon ftands upright, he thinks himfelf to be on the uppermoft fide; and wonders how any one can ftand directly oppofite to him, on the undermoft fide of the earth; or rather, how he can hang to it, with his head downward, and not fall off to the lower fky.

E. That is what I have often wondered at, when I have heard it affirmed that the earth is habitable on all fides; or that, where towns cannot be built, fhips may fail. How comes it to pafs, that the weight of a fhip caufeth it not to fall off from the lower feas; or that thefe fhips and feas do not fall off to the lower fky altogether?

N. What we call *weight* is caufed by *attraction.*—— The earth attracts all bodies on or near its furface, towards its center, equally on all fides, every particle of matter alike; and therefore thofe bodies which contain the greateft number of particles of matter, acquire from this attraction the greateft and moft forcible preffure; and confequently have (what we call) the greateft weight.——The earth may be compared to a great round loadftone rolled in filings of iron, which it attracts equally on all fides; fo that they cannot fall off even from its undermoft fide: nay, it will take them up from a table, if they be within the fphere of its attraction.——

By

By and by, you fhall be fatisfied with refpect to your query about the fun.

E. So far I underftand you very well; but ftill it feems odd to me that people fhould ftand oppofite to us on the earth, with their heads downward.

N. I believe it does; but you know, that either the fun muft go round the earth to give us days and nights, or the earth muft turn round like a globe on its axis to do fo: and will not either of thefe motions anfwer the intended purpofe?

E. Undoubtedly it will.

N. Now, as I have no mind to deceive you, and fhall in due time prove every thing that I advance, even to your own fatisfaction; I do fay, that the fun does not move round the earth every twenty-four hours, but that the earth turns round in twenty-four hours: and as the fun can only enlighten one half the earth at any given inftant of time, and the other half muft then be in the dark; this motion of the earth will caufe the different places on its furface to revolve through the light and the dark in twenty-four hours; in which time, of courfe, they muft have a day and a night: and at the inftant when it is mid-day at one place, it muft be mid-night at the oppofite.——Do you believe what I fay with refpect to the earth's turning round?

E. I do, becaufe I am fully fatisfied that you would not knowingly deceive me; and you have promifed to prove that it does.

N. Then, be pleafed to ftand up for a minute.——It is now feven o'clock in the morning, and you think you are ftanding upright, on the uppermoft fide of the earth.——You will think the fame if you ftand upright at feven o'clock in the evening, when the earth has turned half round, becaufe you will then perceive no difference of pofture: and yet, at that time, you will be very nearly in the fame pofition as a perfon is juft

now,

now, who ftands on the fide of the earth oppofite to us : which perfon being as ftrongly 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 prefent of falling upward.

E. Pardon me, fir, if you had not been at the univerfity, I fhould have thought *falling upward* a very improper expreffion.

N. So it is; and I do affure you that I never heard fuch an expreffion at the univerfity, nor do I remember ever to have ufed 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 fky over our heads; and *down* toward the center of the earth, to which all terreftrial bodies would fall, by the power of the earth's attraction. So that, with regard to open fpace, what is *up* from any given point of the earth's furface, is *down* from the oppofite point thereof. And as the fky furrounds the whole earth, we call it *up* toward the fky over our heads, be where we will; and *down* from our place toward the center of the earth.

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

N. I heard you was at Plymouth laft year; had you not then the curiofity to go aboard fome of the fhips there, or at the Dock?

E. My papa and I went to the Dock, with a fmall party of gentlemen and ladies. Mr. *Falconer*, who was then mafter of the Belleifle happened to be on fhore; and obferving that we were ftrangers, he moft politely invited us to fee his fhip, which was then lying with many others in the Hamoaze. We moft willingly accepted his invitation, and he took us all out in his boat; fhewed us firft into the cabin of the fhip, and, as it was

in

in the afternoon, he genteely treated the gentlemen with wine, and the ladies with tea; after which, he shewed us the whole infide of his ship of war. The way that the different apartments are laid out, especially the powder-magazine, and how 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 wonderous 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 seemed to me as if it moved very slowly toward the right-hand. I

foon loft fight of it, and other objects appeared to my view, and difappeared flowly and gradually ; which could arife from no other caufe than the very flow and gentle turning of the fhip the contrary way.

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

E. Not in the leaft ; and the whole company agreed, that if we had not looked out, we fhould not have thought that the fhip had any motion at that time.

N. And is not *that fingle cafe* fufficient to convince you that the earth may turn round, and carry us all about with it, and we feel nothing of its motion ; efpecially as the motion of the earth is much more re-gular and uniform than the motion of a fhip, or any other machine that human art can contrive.

E. I confefs it is.——But if the earth turns round, how comes it to pafs that a ftone thrown directly upward, falls down again upon the very fame place of the earth from which it was thrown up?——For, confidering how large a globe the earth is, the parts of its furface muft move very faft, to turn round once every twenty-four hours. And if it turns at all, its motion muft be eaftward ; becaufe the fun, moon, and ftars appear to move from Eaft to Weft. Now I fhould imagine, that a ftone or ball thrown directly upward from any place, would fall as far to the weftward, of that place, as the place itfelf has got to the eaftward, whilft the ftone was difengaged from the earth, and rifing and falling in the fame line.

N. Your obfervation is very fenfible.——But you ought to confider, that any body which is put into mo-tion will perfevere in that motion till fome thing or other turns it afide, or ftops its courfe. The ftone partook of the earth's motion before it was difengaged therefrom : the perfon who took it up had the fame motion, by which means it was ftill communicated to the ftone ; and therefore, its motion was as quick eaft-

ward

ward while its was rifing and falling in the open air, as the earth's motion is : fo that it could not mifs falling down again upon the fame part of the earth. And although it would have appeared to a fpectator to afcend and defcend in the fame perpendicular line, yet its real motion was in a curve, and would manifeftly have appeared fo to an obferver at reft in the open air, on whom the earth's motion had no effect.

If a large boat was failing along, near the fhore, two perfons oppofite to one another in the boat might tofs a ball to each other, over and over acrofs the boat, to catch for their diverfion : and they would imagine it to be only going to and fro, from one perfon to the oppofite, always in the fame line : whereas 'tis certain, that the progreffive motion of the ball, going from one fide to the other, would be equal to the progreffive motion of the boat : for if it was not, the oppofite perfon (who had a progreffive motion) could not catch it. And although it would appear to all the people in the boat, to move forward and backward in the fame line, yet, to an obferver on the fhore, who is no way affected by the motion of the boat, the ball would be feen to have a zigzag motion, never returning to either perfon in the fame line in which he toffed it toward the other.

E. You have fully convinced me that there is nothing conclufive in my argument againft the earth's motion.——And, in confirmation of what you faid about a body's being put into motion, that it will naturally perfevere therein, till fome caufe or other turns it afide, or ftops its courfe, I had once the experience thereof ; and very painful it was. For, croffing our river in the boat, I ftood up when it was about half way over ; and as its motion was uniform by the men pulling the rope, I was quite infenfible both of its motion and my own. But when it ftopt fuddenly againft

the

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 perfevered in the motion given me by the boat, I could not have fallen when it was ftopt.

N. Indeed, *Eudofia*, you have given a true philofophical account of the caufe of your falling : and now I think we may, for the prefent, have done talking of this matter.

E. I think fo too; for, fpeaking of the fall makes me almoft imagine I ftill feel it.———But, pray, how do you prove that the earth is round like a globe ?

N. I will prove *that* immediately. The fun fhines in through the window.———

E. What then ?

N. Have patience a minute, and look at *this* fmall globe in my hand, and the flat circular plate that lies on the table.———You fee the globe may be hung by the thread which is faftened to it. I now twift the thread, and hang the globe by it in the beams of the fun ; and the globe cafts a fhadow on *that* upright board behind it. You fee that the globe turns by the untwifting of the thread ; but let it turn how it will, it always cafts as round a fhadow 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 twifted. You fee, that when the broad-fide of the plate faces the fun, it cafts a round fhadow on the board, as the globe did : but as it turns obliquely toward the fun, by the untwifting of the thread, its fhadow is of an oval figure on the board ; and when its edge is turned toward the fun, its fhadow on the board is only a narrow ftraight line.

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

N. The

N. The earth always cafts a fhadow toward that part of the heaven which is oppofite to the fun ; and the moon appears as flat to us as the board on which the fhadow of the fmall globe was projected. When the earth's fhadow falls upon the moon, we fay, *the moon is e-clipfed.* Thefe eclipfes happen at all different times of the twenty four hours ; and, confequently, when all the different fides of the earth are fucceffively turned toward the Sun. But the earth's fhadow on the moon is always bounded by a circular line ; and therefore, it is plain, that the earth muft be of a globular fhape. ——For, if it were fhaped like *this* flat circular plate, its fhadow on the moon could never be circular but when its broad-fide was turned directly toward the fun. At other times, the fhadow would be either of an oval figure, or only a ftreight line, as you have feen on the board. There are feveral other ways of proving that the earth is round ; but I believe you are fatisfied that it is fo, from what I have now fhewn you.

E. I am entirely fatisfied, and therefore more proofs would be fuperfluous. But I fhould now be glad to know how you prove that the earth turns round ; and that the fun does not go round the earth.

N. Before I proceed to the demonftration, I will afk you a very plain queftion, which I hope you will not take amifs, as I have not the leaft defign to affront you.

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

N. Suppofe you put a fmall bird on a fpit, and put it to the fire ; whether it is the beft way to turn the fpit round with the bird, or to let the fpit ftand ftill, and move the fire round about it ?

E. Your queftion almoft furprifes me,——for, not to fpeak of the wifdom of *man,* fure no *woman* of common fenfe could be fo abfurd, as to fet about con-
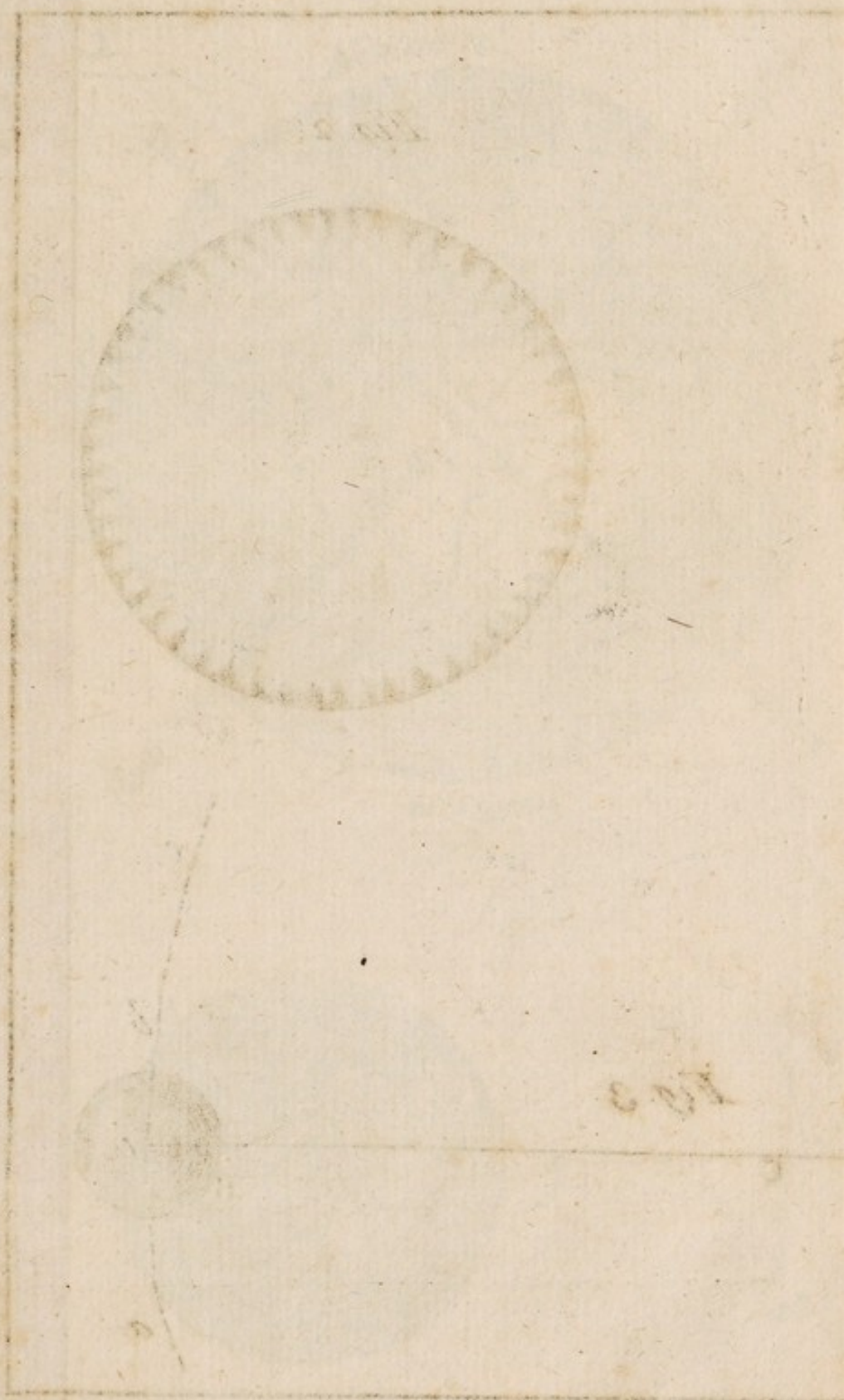
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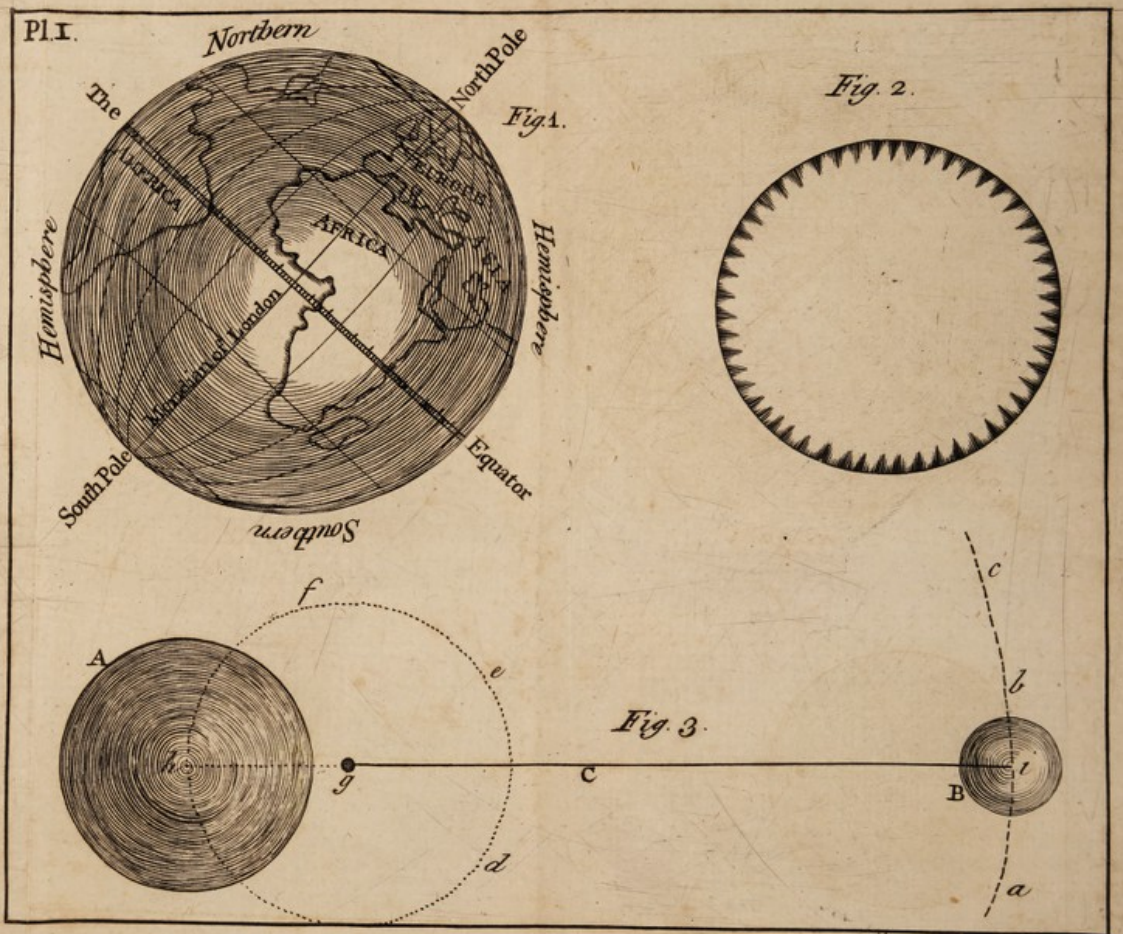triving how to make the large fire and grate be carried round the fpit.

N. True, *Eudofia.*——Now I can affure you, that the fun is, at leaft 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 fmall bird on a fpit.————And as no *man* in his fenfes would go to work on fuch an abfurd attempt, would it not be horrid blafphemy to fuppofe, that the DEITY, who is the very effence of wifdom and perfection, would do fo.

E. Heaven forbid the thought ! the bare mentioning fuch a thing is enough to chill one's blood.—— Were I fure, that the fun could be proved to be a million of times as big as the earth, I fhould afk no further demonftration of the ftability of the fun and the motion of the earth ; becaufe I fhould naturally conclude, that the fun is a million of times more unfit to move than the earth is. And, as the moft fuperlative degree of wifdom and reafon is in the Deity, 'tis impoffible for me to imagine he could do any thing that is irrational.——My belief is, that he always makes ufe of the feweft, moft fimple, and moft rational means, to produce the greateft, moft noble, and moft aftonifhing effects ; fuch as his infinite goodnefs and beneficence to his creatures has rendered conducive to their welfare, in numberlefs inftances.

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 ftraight line within itfelf, paffing through its center, and terminating in its North and South points, which are called its *North* and *South poles*; as an orange would turn round in the open air, if you firft fet it a whirling, and then throw it off your hand in the air.

Water

Pl. I.

Northern

The

North Pole

Fig. 1.

Hemisphere

Hemisphere

EUROPE

AFRICA

ASIA

Meridian of London

South Pole

Equator

Southern

Fig. 2.

Fig. 3.

A

f

e

c

b

h

g

c

t

d

a

B

Water naturally runs downward, all around the earth, from thefe parts which are higheſt, or fartheſt from the center, toward thofe which are loweſt or neareſt to it: and this is caufed 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 fmooth like a poliſhed globe, all the parts of its furface would be equidiſtant from its center; and water could never run upon it. About three-fourth parts of the earth's furface is covered with the feas, 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 caufe the furface of the feas to be of a perfectly round and globular form.

E. Undoubtedly it would: for then, as every particle of the water's furface would be drawn with equal force toward the earth's center, and thefe particles do touch each other; none of them could get nearer the center than their neighbouring ones.

N. Right.— —-And now, fuppofing the earth to be at reſt, and the furface of the oceans and feas to be perfectly globular; what do you think the confequence would be, if the earth fhould begin, and continue to turn round on a line within itfelf, as if it turned on a real axis?

E. Let me think a little.———I have obferved, that when our maid took her mop out of a pail of water, the head of the mop was round: but when fhe began to trundle it on her arm, it immediately became flattened at the parts of the ſtick which were even with its furface; and it fwelled out in the middle———Pray, brother, if I may be allowed to make a very odd fort of a comparifon, 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

you have told me that fuch a line within the earth, from its North to its South poles, is called the axis of the earth?——If fo, feeing 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 furface of the feas about the poles would become flat, and the furface of the feas which are fartheft from the poles would fwell out, all around: and fo, the figure of the earth would be like that of a whirling mop.

N. No philofopher could have made a more apt comparifon, nor have drawn a better conclufion from it. When I told you before, that the earth is round, I did not mean that it is ftrictly fo; although, at the diftance of the moon, it would appear to be round, as its fhadow on the moon does to us. I do not here confider the hills as any thing, becaufe they are fo little in comparifon to the whole bulk of the earth, that they take off no more from its roundnefs in general, than grains of duft do from the roundnefs of *that* fmall three inch globe which you fee 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 furface. The middle line (fee Fig. 1. of PLATE I.) circle, or that is drawn round it, is called the *Equator*, which divides the globe into two equal parts, called the *Northern* and *Southern Hemifpheres*, or half globes. The *North* and *South Poles* are the *middle Points* of the North and South hemifpheres, each pole being a quarter of a circle diftant from each point of the equator, all around: and a ftraight line drawn through the center from pole to pole, is called *the axis* of the globe.

If the thin papers were fcraped off from the poles, and almoft half way round them toward the equator, the globe would be a little flattened at the poles, and comparatively fo much fwelled out about the equator

but

but if it were then viewed from the diftance of fix or feven feet, it would ftill appear to be round.

E. I believe it would :—but what of all this?

N. From actual meafurement and obfervation, the earth is proved to be a little flattened at the poles, and fwelled out about the equator; the equatoreal diameter of the earth being thirty-five miles 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 eafily judge when I tell you, that no lefs than 25,000 Englifh miles would meafure it round : and the higheft 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 feas 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 itfelf would be laid feveral miles under water.

E. This is a very plain cafe : and the not returning of the waters from the feas about the equator, is to me an evident proof of the earth's turning round its axis ; without which, the furface of the waters would become of a general roundnefs, as I faw the head of the mop do when the maid left off trundling it.—— And now it feems plain, that the Almighty muft have made the rigid earth as much higher about the equator, than the land is about thofe places near the poles, as the earth's quick motion about the equatoreal parts would caufe the waters to rife there. For I fee by the globe, that there are great quantities of land about the equator, and many fmall iflands in the feas, which are not overflowed.

N. The more you know of thefe matters, *Eudofia*, ftill the greater reafon you will have to admire the

power

power, and adore the wifdom and goodnefs of the Deity.

E. Indeed, brother, I believe I fhall.——And I already begin to think, that if an atheift would be perfuaded to learn Aftronomy, it would foon cure him of his infidelity.

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

E. I think you told me, that almoft three-fourth parts of the furface of the earth is covered with feas; and by looking on *that* fmall globe, I imagine it may be fo. But you have not yet told me, how it is known, that the earth's circumference is 25,000 Englifh miles; and perhaps I fhould not be able to underftand it if you did.

N. The bulk of the earth is afcertained by (what is called) Geometry, and could not have been known by any other kind of learning. And as you do not yet underftand any part of that fcience, I fhould only confound your head by talking to you on that fubject at prefent.

E. Your faying, " *at prefent,*" gives me fome hopes, that you will endeavour to inftruct me in that branch of fcience afterward.——But can you tell me juft now, how many miles of the earth is land; and how many are covered with the feas?

N. The furface of the earthy part of our great globe is divided into four great tracks or fpaces, called *Europe, Afia, Africa,* and *America*; as you fee them laid out on the fmall three inch globe.

According to meafurement of the beft maps, the feas and unknown parts of land contain 160,522,026 fquare miles: the inhabited parts 38,990,569; *Europe* 4,456,065; *Afia* 10,768,823; *Africa* 9,654,807; *America* 14,110,874. In all, 199,512,595; which is

the

the number of fquare miles on the whole furface of our globe.

E. I admire the prodigious bulk of the earth; but infinitely more fo, the power that muft have fet it in motion at firft.

N. Nothing is great or fmall but in comparifon. We are very big when compared with animals which can be feen only by the help of a microfcope: the earth is big indeed when compared with ourfelves, who live upon it: the planet Jupiter is a thoufand times as big as our earth, and the fun is more than a thoufand times as big as Jupiter.——If you fo juftly admire the power that put our fmall planet the earth into motion, how much more muft you admire the power which put the whole planetary fyftem round us in motion!

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

N. Indeed it might cure any one of pride: and I believe no aftronomer can be either proud or impious. ——But hark!——the bell rings for breakfaft,——I thought to have fatisfied your query about the fun, but muft leave it till the next opportunity. Be fure then to put me in mind of it, and afterwards to talk about the folar fyftem.

E. I believe I fhall have no occafion to re-mind you.
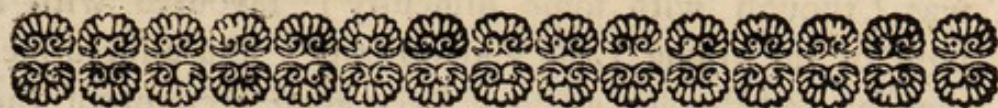
DIALOGUE

DIALOGUE II.

On the BALANCE of NATURE and the SOLAR SYSTEM.

Neander.

WELL, fifter ; what became of you yefterday after breakfaft ? I went to my room immediately after, thinking you would follow me, that we might have a little converfation. But, inftead of *that*, you have left me quite alone ; for I never faw you the whole day afterward, except at dinner and fupper.

Eudofia. Indeed, brother, I was fo much pleafed with what you told me yefterday morning, that I was willing to make the moft and beft of it that I could ; and therefore employed the reft 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, laft year, attended a courfe of lectures on experimental philofophy at Tunbridge Wells ; and always, when fhe went

B 2   home,

home, wrote down what fhe had heard and feen. The perfon who read the lectures informed me, that he was (though with fome difficulty) favoured with a fight of the young Lady's manufcript ; and affured me, that fhe had therein given a very good account of the machinery and experiments. I hope you will not re-fufe to fhew me yours, every day, as we proceed.

E. You fhall always fee it, were it only for this felfifh reafon, that you may correct and amend what is wrong in it ; and then I fhall reap the advantage. I will now repeat my yefterday's query : To what is the fun fixed ? for you have convinced me that he does not move round the earth.

N. The fun is not fixed to any thing at all ; nor is it any way requifite he fhould. I told you that the falling of bodies to the earth is folely caufed by the earth's attraction.

E. I remember it very well ; and it feems plain to me, that their falling toward the earth's center, on all fides of it, is a demonftrative proof of the earth's at-traction. For what elfe could poffibly determine bodies to fall, on oppofite fides of the earth, in directions quite contrary to one another ?

N. Right *Eudofia*, you are a philofopher already : and I fhall have very great pleafure in teaching you, at leaft, the rudiments of Aftronomy.

The tendency of bodies to fall, is called their *Gra-vitation*, and the power which gives them that ten-dency, is called *Attraction*. Now, fuppofing the fun (PLATE I. *Fig.* 2.) to be the only body that exifts in univerfal fpace, and that he is put into any part of open fpace, pray, to what other part of fpace do you think he would fall ?

E. I think he could not fall to any other part of fpace at all, becaufe 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 of 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 toward the sun, as the sun would toward 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 anfwer your queftion by afk-
ing you one.————Did you ever put a pebble into a
fling, 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 fling ?

E. O, yes ! and the moment I let the ftring flip
from my hand, away the pebble flew.————I likewife
remember, that the fafter I whirled the fling, the great-
er was the tendency of the pebble to fly off ; and that
I was obliged to pull the ftring fo much the ftronger
to keep the pebble from doing fo.

N. That obfervation will be of more fervice to you
by and by, than you at prefent think of ; but it would
be too foon to tell you juft now how it will.

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

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

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

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

E. I fee that the earth's motion round the fun is indifpenfibly neceffary, and am therefore fatisfied that it does exift. But I think the fun would require fome motion too, in order to give him a centrifugal force, without which, it feems 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 fling pulled my hand fo ftrongly, although the pebble was fmall, that I could not poffibly keep my hand fteady whilft the pebble was in motion.

N. Well done, fifter.——The fun really moves in an orbit as well as the earth ; and the fun's orbit is as much lefs than the earth's, as his quantity of matter is greater than the earth's. And, as both thefe bodies go round their orbits in the fame period of time, the fun moves as much flower than the earth does, as his quantity of matter is greater than the earth's. So, what is wanting in the velocity or fwiftnefs of the fun'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 fwiftnefs of its motion in its orbit ; on which account, their centrifugal forces are equal to each other's attractions ; and, as thefe attractions keep them from flying out of their orbits by their centrifugal forces, fo thefe 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 is a new light to me, and a moft delightful one it is. But, although I think I underftand it, I wifh you would further explain it by a figure.

N. Here

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 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). Hang 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

ends of a common fteelyard, by which you have feen meat weighed at home, after it was brought from market. The point *g* may reprefent the center or axis of the fteel-yard, which bears the weights that are at both its ends. And, as gravity and weight are fynonymous terms, the point *g*, or center of the fteelyard, is not improperly termed the center of gravity of the weights *A* and *B*.

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

N. And, now, if you twift the thread, by which the wire and balls are fufpended at the point *g*, the untwifting of the thread will caufe them both to go round; the great ball in the fmall 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 reft.

E. From which I infer, that the center of gravity between the fun and the earth is a motionlefs point.

N. And your inference is right.

E. I was juft going to afk you a queftion, but am very glad a lucky thought prevented me; for it would have been quite childifh.

N. Remember what M. *Beaugrand* told you when he began to teach you French; *Never fear, but fpeak 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 queftion was?

E. As we were obliged to hang the wire and balls by a thread, to fupport their center of gravity; I was juft about to afk, what is it that fupports the center of gravity between the earth and the fun?

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

E. I immediately recollected, that we muft fupport the center of gravity between the two balls, becaufe,

otherwife,

otherwife, they would have fallen to the great earth by the power of its attraction. But, as there is no greater body than the fun 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 fupport it.

N. If you had asked the queftion, I fhould have told you the very fame thing.

E. If all the parts of aftronomy are as eafily learnt as thofe which you have already taught me, I fhall have no reafon to be vain, even if I become a tolerable good aftronomer by your inftructions.

N. I dare not fay 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 befides, which go round the fun.

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

E. Then, our fun muft be their fun too.

N. It is really fo ; 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 are inhabited as well as our earth. For, to what purpofe could the fun fhine upon lifelefs 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 axes, as our earth turns round its axis ; for which plain reafon, they have days and nights as our earth has : and the two which are fartheft from the fun, namely, *Jupiter* and *Saturn,* and which, confequently, have much lefs light than our earth has ; have moons to enlighten them, *Jupiter* four, and *Saturn* five.

E. To

E. To me, this is a pofitive proof of their being inhabited ; and is enough to make us think, that we are but a fmall 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 univerfal. GOD loves his creatures, as is manifeft by what he hath done for us, who, perhaps, deferve lefs of his favour than the inhabitants of all the other planets do, taken together. ———It is as eafy to him to take care of thoufands of millions as of one individual, and to liften to all their various requefts.———On account of his omniprefence, nothing can efcape his notice ; and on account of his omnifcience, nothing can efcape his knowledge !

E. And, as his omnipotence may be inferred from his works, fo I have often thought, that his goodnefs may be inferred from his power. For, as he had power enough to make the world, he certainly has power enough to punifh the world : and, confequently, if his goodnefs were not equal to his power, he would punifh us feverely for breaking his laws.

N I believe, fifter, a more juft inference was never made.

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

N. No ; thofe which are neareft the fun go fooneft round him, and thofe which are fartheft from him are longeft in performing their circuits.

E. And do they all move round the center of gravity between the fun and them, as round a fixed point ?

N. They do.

E. Then, as the times of their going round the fun are fo various, I cannot fee how the fun can defcribe any regular circle round the common center of gravity between him and them all. For, in order that the fun fhould move regularly round fuch a circle, I think all

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the planets would need to be joined together in one mafs.

N. 'Tis very true ; and we muft proceed by degrees. What I fhowed you by the figure was only on fuppofition, that there is but one planet belonging to the fun. But as there are fix 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 fyftem ; and defcribes no regular or perfect circle round it, but is fometimes nearer to it, and at other times further from it, according as he is attracted by a greater or fmaller number of planets toward any fide of the heavens.

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

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 fame way, from Weft, by South, to Eaft.

E. And do you know what their diftances from the fun are ?

N. Their comparative diftances from the fun have been known long ago, both by the laws of nature, and by obfervation, and are as follows.——If we fuppofe the earth's diftance from the fun to be divided into 100,000 equal parts, Mercury's diftance from the fun will be equal to 38,710 of thefe parts ; Venus's diftance 72,333 ; Mars's diftance 152,369 ; Jupiter's diftance 520,096 ; and Saturn's diftance 954,006.

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

N. Not fo exactly as we could wifh : yet aftronomers have come much nearer to the knowledge thereof, by the late tranfit of Venus over the fun, on the 6th of June 1761, than ever they were before.——But we

muſt wait with patience till the year 1769, when there will be a much better tranſit of that planet over the ſun, in the evening of the third of June ; by which means, if it be properly obſerved at different places of the earth, the dimenſions of the whole ſyſtem will be very nicely known. And the aſtronomers will do well to embrace *that* opportunity, becauſe there will not be ſuch another in a hundred years afterward. 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 late 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 494,990,976 : and Saturn's diſtance 907,956,130.

E. Theſe diſtances are ſo immenſely great, that I can form no ideas 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 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 !

<div align="right">*N.* Great</div>

N. Great as you think it, (and to be fure great it is) yet fome of the comets go almoft fourteen times as far from the fun as Saturn is : notwithftanding which, they are then nearer to the fun than to any of the ftars. For, if any comet fhould go as near to any ftar as it is to the fun, when fartheft from him, it would be as much attracted by that ftar as it is then by the fun ; and its motion being then toward the ftar, it would go on, and become a comet to that ftar ; and we fhould never hear of it any more.——And now, *Eudofia,* what do you think of the diftance of the ftars ?

E. I am loft in wonder !——But fuppofing there were no comets, pray is there any other way by which we might know that the diftance of the ftars is fo inconceiveably great ?

N. I fhall only tell you of one way.——If we are at a great diftance from two neighbouring houfes, they feem to be fmall, and at a little diftance from one another. But, as we approach nearer and nearer to them, they feem to grow bigger and bigger, and the diftance between them to encreafe. You know this.

E. Very well : pleafe to proceed.

N. The earth goes round the fun every year, in an orbit, which is upwards of 190 millions of miles in diameter.——Hence, we are 190 millions of miles nearer to fome of the ftars juft now, than we were half a year ago, or fhall be half a year hence : and yet, for all that, the fame ftars ftill appear to us of the fame magnitude, and at the fame diftance from each other, not only to the bare eye, but alfo when viewed by the niceft made inftruments.——Which fhews very plainly, that the whole diameter of the earth's orbit is but a dimenfionlefs point in comparifon to the diftance of the ftars.

E. All further proofs of the immenfe (and, I fhould think, almoft infinite) diftance of the ftars, would be

<div align="right">fuperfluous</div>

superfluous. But, as we were talking about the comets, pray, are they not dangerous?———We are always frightened when we hear of their appearing, left their fiery trains fhould burn the world.

N. That is owing to people's not knowing better. The orbits of the planets are all nearly in the fame plane, (as if they were circles drawn on a flat board) but the orbits of the comets are elliptical, and all of them fo oblique to the orbits of the planets, and alfo to each other, that no comet can ever touch a planet. And, as to thofe appearances, which are called the tails of the comets, they are only thin vapours, which arife from the comets, and which could not hurt any planet, if it fhould happen to go through that vapour when the comet is crofing the plane in which the planet's orbit lies. If thefe trains were fire, we could not fee any thing through them that is beyond them. For, if you hold a candle between you and any object, you cannot fee that object through the flame of the candle ; but the fmalleft ftars are feen through the tail of a comet.

E. This is comfortable doctrine indeed.

N. Befides, you know that the world muft be converted to Chriftianity before it be burned ; which, we can hardly believe, will be within the time that you and I can live, according to the ordinary courfe of nature.

E. Alas, brother ! our people who go into thofe remote parts where Chriftianity was never heard of, behave fo unjuftly and cruelly to the poor natives, as might rather frighten them from the chriftian religion, than induce them to embrace it. I confefs I am not at all furprifed, when I hear, that the native Americans rife fometimes in large bodies, and deftroy thofe who call themfelves chriftians, on account of their barbarous ways of ufing 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

E. As it makes me melancholy to think or fpeak of thefe things ; I beg we may refume our intended fubject. Confidering how far the planets are from the fun, and in what times they go round him, they muft move very faft in their orbits. I fhould be glad to know how many miles they move every hour.

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

E. And fo we are carried 68,243 miles every hour, along with the earth in open fpace, without being in the leaft fenfible of that rapid motion.

N. We are indeed, fifter.

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

N. When the diftance of an object is known, there are eafy geometrical rules for deducing its real bulk from its apparent bulk.———According to the fore-mentioned diftances, the fun's diameter is 893,760 miles, (and confequently he is 1,410,200 times as big as the earth) ; Mercury's diameter, 3100 ; Venus's, 9360 , the Earth's, 7970 ; Mars's diameter, 5150 ; Jupiter's, 94,100 ; and Saturn's diameter, 77,990 Englifh miles.

The moon's diftance from the earth's center is 240,000 Englifh miles, her diameter is 2170 ; fhe moves (with refpect to the earth) 2290 miles in her orbit every hour ; and fhe 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 diftances. His firft, or neareft moon, goes round him in 1 day, 18 hours, 36 minutes ; the fecond, in 3 days, 13 hours, 15 minutes ; the third, in 7 days, 3 hours, 59 minutes ; and the fourth, or fartheft moon from him, in 16 days, 18 hours, 30 minutes.

Saturn has five moons, the neareft of which goes round him in 1 day, 21 hours, 19 minutes; the fecond, 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 outermoft, in 79 days, 7 hours, 48 minutes. This planet is encompaffed by a broad thin ring, fet edge-ways round it, and the diftance of the ring from the planet is equal to the breadth of the ring. The fun fhines for almoft 15 of our years together on the northern fide of the ring, then goes off, and fhines as long on the fouthern fide of it: fo there is but one day and one night on each fide of the ring, in the time of Saturn's whole revolution about the fun, which takes up almoft 30 of our years.

E. A long day and night indeed, for the inhabitants of the ring, if any fuch there be. Undoubtedly, if it is inhabited, it muft be by beings very different from us; as we have no reafon 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 axes, as our earth does: do they all turn round the fame way, or eaftward, fo as to caufe the fun and ftars appear to go round weftward; and in what times do they turn round?

N. By viewing them with good telefcopes, we fee fpots upon moft of them, which adhere to their furfaces, and appear and difappear regularly on their oppofite fides. By the motions of thefe fpots, which are all eaftward, 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 fun, or the length of her year; and we fhall 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 axes, becaufe no fpots have

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been

been feen upon them, even by the beft telefcopes.———
The fun turns round his axis in 25 days, 6 hours, from
Weft to Eaft, alfo.

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

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

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

N. Never mind that, *Eudofia*; for I believe I fhall
publifh thefe our converfations, for the fake of other
young ladies; many of whom are, no doubt, willing to
learn Aftronomy, but have no body to teach them. And
then you can have the whole together in print.

E. If you do, Sir, I muft infift upon your not men-
tioning my name.

N. Your defire fhall be complied with: and in con-
cealing your real name, I fhall alfo conceal my own.

DIALOGUE

DIALOGUE III.

On GRAVITY and LIGHT.

Neander.

SO, fifter; I find you are not willing to flip the morning opportunity, when we can be undifturbed, and by ourfelves. Have you made any remarks upon our laft converfation?

Eudofia. Yes, brother.——In the firft 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 obferved likewife, that the further the planets are from the fun, they not only take longer times to go round him, but alfo move flower in every part of their refpective orbits. Can you affign any reafon for this?

N. The nearer that any planet is to the fun, the more ftrongly it is attracted by the fun; the farther any planet is from the fun, the lefs is the force of the fun's

attraction

attraction upon it. And, therefore, those planets which are the nearer to the fun muft move the fafter in their orbits, in order thereby to acquire centrifugal forces equal to the power of the fun's attraction: and thofe which are the farther from the fun muft move the flower, in order that they may not have too great a degree of centrifugal force, for the weaker attraction of the fun at thofe diftances.

E. Then I underftand, that the fun'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 refpective orbits. Is it not fo?

N. Accurately fo.

E. Then, as the power of the Deity is manifeft, in having fet off fuch large bodies as the planets are, with fuch amazing degrees of velocity; fo his great wifdom is confpicuous, in having fo exactly adjufted their velocities, and, confequently, their centrifugal forces, to the different degrees of the fun's attraction at the diftances the planets are from him.———Here is a wonderful balance indeed! Can there be an atheift?——— I am fure no man could be fo, after hearing fuch things as you have told me of.

N. 'Tis faid there are atheifts; but they muft all be ftupid fools.———The Almighty has laid the great book of nature open to our view; fo that, every one that runs may read. Suppofing matter had exifted from eternity, (which, by the bye, is too great a compliment to be paid to matter) I imagine, the greateft atheift in the world could hardly bring himfelf to believe, that ftones could have hewed themfelves, bricks made themfelves, trees fhaped themfelves into beams and boards, and mortar made itfelf; and then, all thefe materials have jumbled themfelves together, fo as to build a houfe. And what is a houfe in comparifon to a planetary fyftem;

Pl. II.

Fig. 1.

Fig. 2.

Fig. 3.
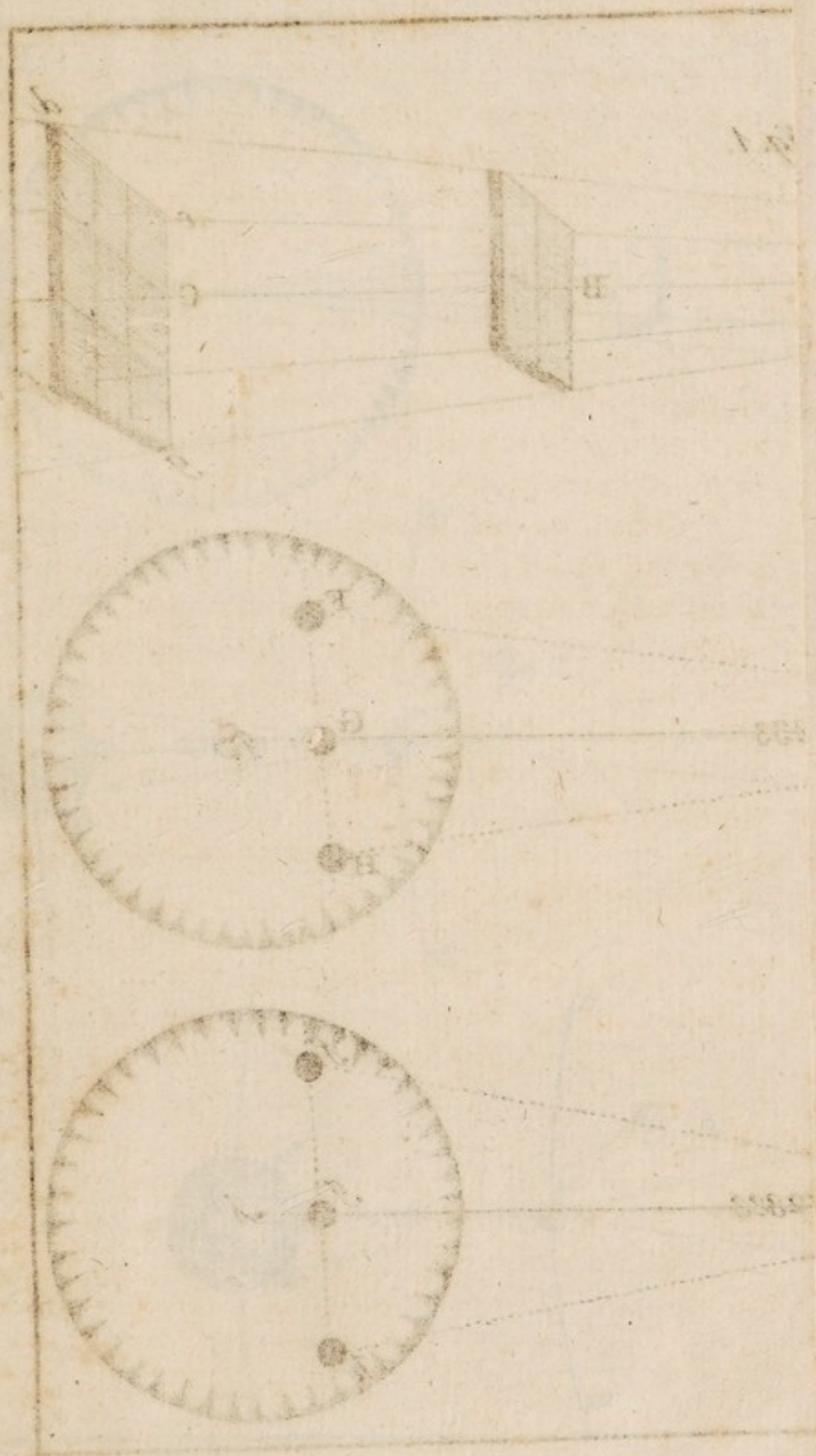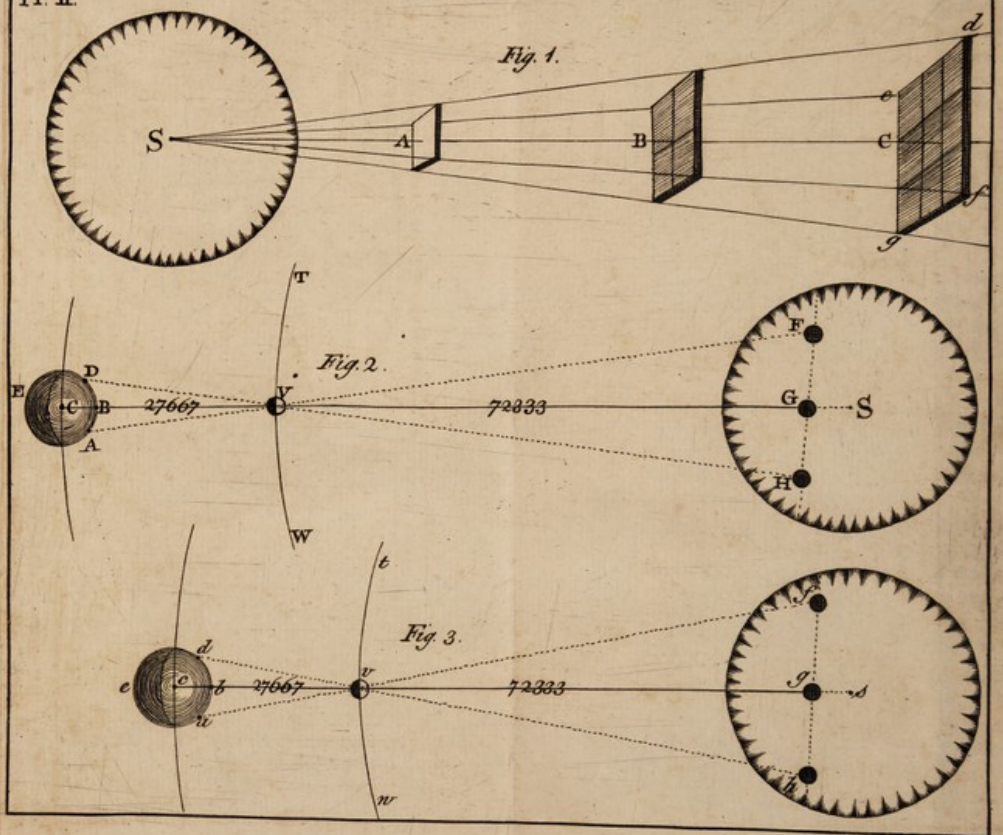
or the fkill required to build it, when compared with the organization of any infect?

E. Nothing at all.———But I am apt to lead you into digreffions. Doth the power of the fun's attraction decreafe in proportion as the diftance from him increafes?

N. No : his attractive force diminifhes in proportion as the fquares of the diftances (that is, as the diftances multiplied by themfelves) from him increafe. So that, at twice the diftance from the fun's center, his attractive force is four times lefs; at thrice the diftance, it is three times three times, or nine times lefs; at four times the diftance, the attraction is four times four times, or fixteen times lefs; and fo on.——And this we find, from the comparative diftances of the planets from the fun, and their different velocities in their orbits: befides, I have often feen this experimentally confirmed by a machine called *The whirling-table.*

E. If I underftand this; fuppofing there are four planets fo placed, as that the diftance of the fecond from the fun is twice as great as the diftance of the firft; the diftance of the third, three times as great; and the diftance of the fourth, four times as great as the diftance of the firft : the fourth will be attracted only with a fixteenth part of the force wherewith the firft is attracted; the third only with a ninth part of the force; and the fecond with only a fourth part of the force that attracts the firft.

N. Exactly fo.

E. I fhould be glad to know the reafon why the fun's attraction decreafes in proportion to the fquares of the diftances from him. Why do you fhake your head?

N. Becaufe you afk me a queftion which Sir Ifaac Newton himfelf could not folve; although he was the prince of philofophers.

E. But

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 furface of the attracted body.

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

N. I have drawn a figure for your infpection (PLATE II. *Fig.* 1.) which indeed is for a quite different purpofe : but it would exactly folve your queftion, if gravity acted as all mechanical caufes do ; only on the furfaces of bodies.

Let *S* be the center of the fun ; and *S d*, *S e*, *S f*, *S g*, be, as it were, lines of attractive force, drawing the three fquare plates *A*, *B*, and *C*, toward *S*. Thefe lines touch only the four corners of the plates ; but we may fuppofe the whole fpace within them to be full of fuch attractive lines, laying hold of all the parts, or points (if you will) of the furface of each plate : and every particle of matter in each plate requiring an equal degree of power to draw it equally faft toward the fun.

Now, let the plate *B* be twice as far from the fun'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 *S d*, *S e*, *S f*, and *S g*, were four cords, equally ftretched, 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 furface as *A* does, and four times as great a quantity of matter, fuppofing 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 furface and matter as *A* does, fuppofing it of an equal thicknefs with *A*.

<div align="right">Suppofe</div>

Suppofe now, that the intermediate lines of attraction, between the four corner lines, are fo clofe together, as that they lay hold of every point of the furface 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 fur-face of *B*, and of every ninth point of the furface of *C*; fo that, the plate *B* will want three fourth parts of the attraction that would be fufficient to draw it toward *S* as faft as the plate *A* is drawn; and *C* will want eight ninth parts of the attraction that would be fufficient to make it move as faft as *A* moves toward *S*.

E. I fee this very well: but, if gravity acts not according to the quantity of furface, pray how does it act?

N. Exactly in proportion to the folid contents of bodies; that is, to the quantities of matter they contain. For, you 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 furface, by which means you would divide it into nine fquare pieces: if you then lay them above one another in the fcale, they will be juft as heavy as they were before, when they lay at each other's edges, all in one piece, in the fcale. Or, if you fuppofe them to be fo cut, and then joined together at each other's backs, and put them at the diftance *S c* from the fun, as before; they will have only a ninth part of the furface toward the fun as before: and yet, the fun's attractive force on them will be juft the fame.

E. Then, it feems, there is no way of accounting for the manner in which gravity acts, but by refolving it into the will of the Deity; feeing that the quantity of furface has nothing to do in the cafe.

N. Indeed there is not. And, therefore, when I henceforth fpeak of gravity, I would have you always underftand, that I do not thereby mean a *Caufe*, but the

effect of a cause, which we do not comprehend. Be-fides, you know, that if gravity acted according to the furfaces, or bulks of bodies, a cork would be as heavy as a piece of lead of the fame bulk as the cork.

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

N. It is to fhew, that the light of the fun, or of any other luminous body, decreafes in proportion as the fquare of the diftance from the luminous body increafes. The rays of the fun's light go out in ftraight lines from all points of the fun's furface : and, confe-quently, the farther they go off from the fun, the more they fpread ; and fo they cover the more of the furfaces of bodies at the greater diftances.

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

N. Becaufe, if we endeavour to look at the fun, or at a candle, through the bore of a bended pipe, we cannot fee it ; but through a ftraight pipe we can.

E. Enough, Brother ; pleafe now to explain the figure.

N. Let *S* be the fun's center, and *S d*, *S e*, *S f*, *S g*, be four rays of light, going out from the fun's furface in ftraight lines (in the fame direction as if they pro-ceeded from his center), and fuppofe the fpace within thefe rays to be filled with others. Take the diftances *S A*, *S B*, *S C*, from the fun's center, fo as *S B* fhall be twice as great as *S A*, and *S C* thrice as great. Then, at the diftance *S A* place the little fquare plate *A*, on which all the rays will fall that fill the above-mentioned fpace at *A*. At the diftance *S B*, place the fquare plate *B* ; which being twice as long and twice as broad as the plate *A*, it contains four times as much furface as *A* does : and if *A* be taken away, all the light that fell

upon

upon it, will fall upon, and cover the whole furface of *B*; which being four times as large in furface as *A* is, and having only as much light upon it as *A* had, every point of the furface of *B* can have no more than a fourth part of the light that fell upon every point of the furface of *A*. And, laftly, at three times the diftance *S A*, place the fquare plate *C*; which being three times as long and three times as broad as the plate *A*, it contains nine times as great a furface : and then, if *B* be taken out of the way, fo as to let all the light that fell upon it go on to the plate *C*, the light will juft cover the furface of that plate ; which being nine times as large as the furface 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 fo ftrong and vivid as it was upon every point of *A*.

E. Nothing can be plainer than this : and it follows of courfe, that at four times the diftance of *A* from the fun, his light is fixteen times weaker than at *A* ; at five times the diftance, it is twenty-five times weaker ; and fo on. I thank you for making this fo plain.

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

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

N. Very eafily.—The fun's light is feven times as great on Mercury as on the Earth ; about twice as great at Venus ; at Mars, it is not half fo great, or ftrong, as we have it on the Earth ; at Jupiter, only a twenty-eight part fo ftrong as at the Earth ; and at Saturn, is but about a ninetieth part fo ftrong as with us.

E. Then,

E. Then, I fhould be almoft tempted to think,—but I cannot—will not indulge fuch a thought as that the Deity is partial : for I cannot imagine the inhabitants of our earth to be better than thofe of the other planets. On the contrary, I would fain hope they have not acted fo abfurdly with refpect to him, as we have done.

N. Tell me freely what the thought was that arofe in your mind, which you are fo willing to fupprefs.— The Deity is no other way a refpecter of perfons than that of properly diftinguifhing between the good and the bad ; and fo rewarding the one, and punifhing the other accordingly.

E. It feemed to me, that the inhabitants of the neareft planets to the fun muft be blinded by too much light ; and that thofe of the fartheft planets from the fun muft be punifhed all their lives, with fo weak a light, as can be called little better than darknefs.—We could not bear feven times as much light as we have from the fun ; nor be able to do our work with only a ninetieth part of the light we have.

N. Your reflection, fifter, is very natural. But, after afking you two or three plain queftions, I believe I fhall be able to give you full fatisfaction on that head.

E. Pray afk them, and I will anfwer them if I can.

N. After you have been a while out in the fnowy ftreet, can you fee 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 ftrong reflection of the fun's light from the fnow, juft as well when you go out into the ftreet, as when you have been walking half an hour in it ?

E. No.

N. Can you give fuch a reafon for this as would fatisfy a philofopher? For you know that the fnow reflects not lefs light for you having been a while walking in it; nor is your room a bit the darker for your having been out of it.

E. I wifh I could, but indeed I cannot.

N. Then I will tell you.——Our eyes are made fo, that their pupils (which let in the light, whereby we fee objects) dilate when the light is weak, that they may take in the more of it; and contract when the light is ftrong, that they may admit the fewer of its rays.——Whilft you are in your room, the pupils of your eyes are dilated; and for that reafon, when you go out, they take in too much of the light reflected from the fnow, which you find is hurtful. But they foon contract fo, as to admit no more of that ftrong light than you can eafily bear.——And then, when you come into your room, with the pupils of your eyes contracted; the room, being not fo light as the ftreet, appears darker to you than it did before you went out: but, in a fhort time, the pupils dilate again; and then they let in a fufficient quantity of light for you to work by.

Now, fuppofing all the other planets to be inhabited by fuch beings as we are, (though for reafons I fhall mention afterwards, we cannnot believe they are), if the pupils of their eyes who live on the planet Mercury are feven times as fmall as ours are, the light will appear no ftronger to them there than it doth to us here. And if the pupils of their eyes who live on 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 feen) the light there will be of the fame ftrength as it is to our eyes here.——Pray, *Eudo-*

fia,

fia, how many full moons, do you think, would there need to be placed in a clear fky, to afford us moon-light equal to common day-light, when the fun doth not fhine 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 moft, would do. For, when the full moon is not clouded, fhe fhines fo clear, that I can read by her light.

N. Sixty, or an hundred : I affure you, that you are greatly miftaken : for it would require ninety thoufand : and *that* number would fill the whole of our vifible fky.

E. You amaze me! but I know you will not deceive me. Pray, how can you find any method of comparing moon-light with day-light, fo as to afcertain the great difference between the quantities thereof?

N. Have you never obferved the moon pretty high up in the morning, after the fun was rifen, when the moon was about three quarters old?

E. Yes, brother : and when I have feen her, as it were, among whitifh clouds, fhe appeared much of the fame colour as they did ; very dim in comparifon with what fhe appears in the night.

N. And yet, fhe was juft as bright then as fhe is in the night ; only the fuperior light of the day made her feem fo much otherwife. Like a candle, which appears very bright in the night-time ; but fet it in the ftreet in day-light, and it will feem very dim, although its real brightnefs is ftill the fame.

E. I think I could almoft tell what you are to infer from all this ; but will not fpeak, left I fhould be miftaken again. And therefore I beg you will proceed.

N. When

N. When the fun is hid by clouds, all the light we have is by reflection from them. The moon reflects the fun's light in the night-time, as the clouds do in the day : and as fhe can reflect no more light in the day than a fmall bit of a whitifh cloud does, that covers as much of the fky as the moon covers ; fhe can reflect no more in the night.——And as the full moon fills only a ninety-thoufandth part of the fky, her light is no more than equal to a ninety-thoufandth part of common day-light. Now, as the light of the fun 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 1000 ; which fhews, that the fun's light at Saturn is 1000 times as great as the light of the full moon is to us.

E. I fee plainly that it muft be fo——Oh !——

N. Why do you figh, *Eudofia ?*

E. Becaufe there is not an univerfity for ladies as well as for gentlemen. Why, *Neander,* fhould our fex be kept in total ignorance of any fcience, which would make us as much better than we are, as it would make us wifer ?

N. You are far from being fingular in this refpect. I have the pleafure of being acquainted with many ladies who think as you do. But if fathers would do juftice to their daughters, brothers to their fifters, and hufbands to their wives, there would be no occafion for an univerfity for the ladies ; becaufe, if thofe could not inftruct thefe themfelves, they might find others who could. And the confequence would be, that the ladies would have a rational way of fpending their time at home, and would have no tafte for the too common and expenfive ways of murdering it, by going abroad to card-tables, balls, and plays : and then, how much better wives, mothers, and miftreffes

they

they would be, is obvious to the common sense of mankind.———The misfortune is, there are but few men who know these 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 surprised to hear you 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 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
<div align="right">Jupiter</div>

Jupiter appear nearly in the fame part of the heavens.

E. Undoubtedly they muft.

N. And therefore, when the Sun and Jupiter appear almoft clofe together, the Earth is almoft the whole diameter of its orbit farther from Jupiter, than when it and Jupiter appear oppofite to each other in the heavens.

E. Certainly.

N. The times when Jupiter's moons muft be eclipfed in his fhadow are eafily calculated ; becaufe, by telefcopic obfervations, the times in which they go round him are accurately known : and the apparent vanifhing of thefe moons in the fhadow may be very well perceived through a telefcope ; or the inftants when they recover their light again, by the fun's fhining upon them, at their going out of the fhadow. And it has been always obferved, fince telefcopes were invented, that thefe eclipfes are feen fixteen minutes fooner when the Earth is neareft to Jupiter, than when it is fartheft from him. So that, if there were two Earths moving round the fun in the fame orbit, and always keeping oppofite to each other ; when one of them is at its leaft diftance from Jupiter, and the other at its greateft, an obferver on the neareft would fee the fame eclipfe fixteen minutes fooner than an obferver on the fartheft would. Which fhews, that light takes fixteen minutes to move through a fpace equal to the width or diameter of the Earth's orbit, which is 190 millions of miles. And, confequently, it muft take eight minutes of time in coming from the fun to the earth : as the fun 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 underftand this ; but a difficulty rifes in my mind.

N. Only

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

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

N. There is no reafon to believe but that it does. And I imagine, I can very eafily convince you that it does fo.

If the particles of light did not fly off from the planets as faft as they came upon them, there would ftill 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 fafter from the planets than it comes upon them, they would appear dimmer and dimmer every night ; which is not at all the cafe.

E. But are *all* the rays which the fun darts on any planet *reflected* from it, and none of them loft or *abforbed* in the matter of which the planet is compofed ? Or, if *fome* of them be abforbed, will not this invalidate your argument ?

N. Not at all, if the *abforbed* rays bear a conftant proportion to the *whole* number of rays with which the planet is fucceffively illuminated ; and this muft undoubtedly be the cafe : for the fame parts of the planet's furface which either reflect, or abforb the rays that fall upon them *this* moment, will be equally difpofed to reflect or abforb the rays that fall upon them in the *next :* and fo the *fame proportion* between the abforbed and reflected rays, or between them and the whole quantity of light thrown on the planet, will be continually preferved.

E. But what if fome parts of the planet's furface be more hardened by drought, or foftened by wet, as on our earth ; or be in any other refpect more difpofed

pofed, either to reflect, or abforb the Sun's rays at fome 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, hard-nefs and foftnefs, fmoothnefs and roughnefs of fome parts of its furface, fo far as they refult from any al-teration of *weather*, &c. if taken upon an average for a whole year, or other given time, and throughout any half of the Earth's furface ; they will, very nearly, if not exactly, balance each other. The fame may be therefore fuppofed to hold good in the other planetary worlds ; and fo the proportion before mentioned will not be fenfibly altered.

E. You have quite removed my difficulty, bro-ther ; and I thank you for having done it. But, as light comes from the Sun to the Earth in eight mi-nutes of time, its fwiftnefs muft be amazingly great. Let me try whether I can compute it : for you taught me not only the four common rules of arithmetic be-fore you went to the univerfity, but even the rule of three. The Sun's diftance from the Earth is 95 milli-ons of miles, in round numbers ; and light moves through that fpace in 8 minutes of time ; divide, there-fore, 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 1,484,375 ; fo that light moves more than a million of times as fwift as a cannon-ball.——Amazing indeed !

N. It is fo :——And now I will tell you fomething which is full as amazing.

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

D *N. Far*

N. Far from it : I only mean the inconceiveable fmallnefs of the particles of light.

E. And how do you know that they are fo inconceiveable fmall ?

N. The force with which a body ftrikes any obftacle, is directly in proportion to the quantity of matter in the body, multiplied by the velocity with which it moves. And confequently, as the volocity 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 fand, we could no more keep our eyes open to bear the impulfe of light, than we could to have fand fhot point blank againft them from a great cannon.

Another way of proving that the particles of light are fo fmall as to exceed all human comprehenfion, is this : Let a lighted candle be fet on the top of a fpire fteeple, in the night-time, and there will be a very large fpherical fpace filled with the light of the candle before a grain of the tallow be confumed ; and as *that* grain of tallow is divided into fo many particles, as fill all the fpace in which the light is diffufed, can you poffibly imagine how fmall the particles are into which it is fo divided ?

E. Indeed I can form no idea thereof.

N. A very good computift has found, that the particles of blood of thofe animals which can only be feen by means of a microfcope, are as much fmaller than a globe whofe diameter is only a tenth part of an inch, as that fmall globe is lefs than the whole earth. And yet, that their particles of blood are like mountains to a grain of fand, when compared with the particles of light.

E. I am glad to hear our breakfaft-bell : —— for, if I fhould hear more of thefe fubjects at prefent, I know not but that I fhould, for fome time, lofe the power of thinking.

N. I had juft done with the fubject of light; but am forry to hear that you muft go from home, for a few days, on a vifit. However, during your abfence, I intend to draw out two or three figures, in order to defcribe the late tranfit of Venus to you by them; and give you fome idea of the method by which the diftances of the planets from the Sun were found, by obfervations made on that tranfit.

E. I am very much obliged to you, Sir, for the trouble you have taken, and are to take further, on my account: and fhall return as foon as poffible.—You know I could not refufe Mifs *Goodall's* invitation.

Pl. III.

Fig. 1.

Fig. 2.
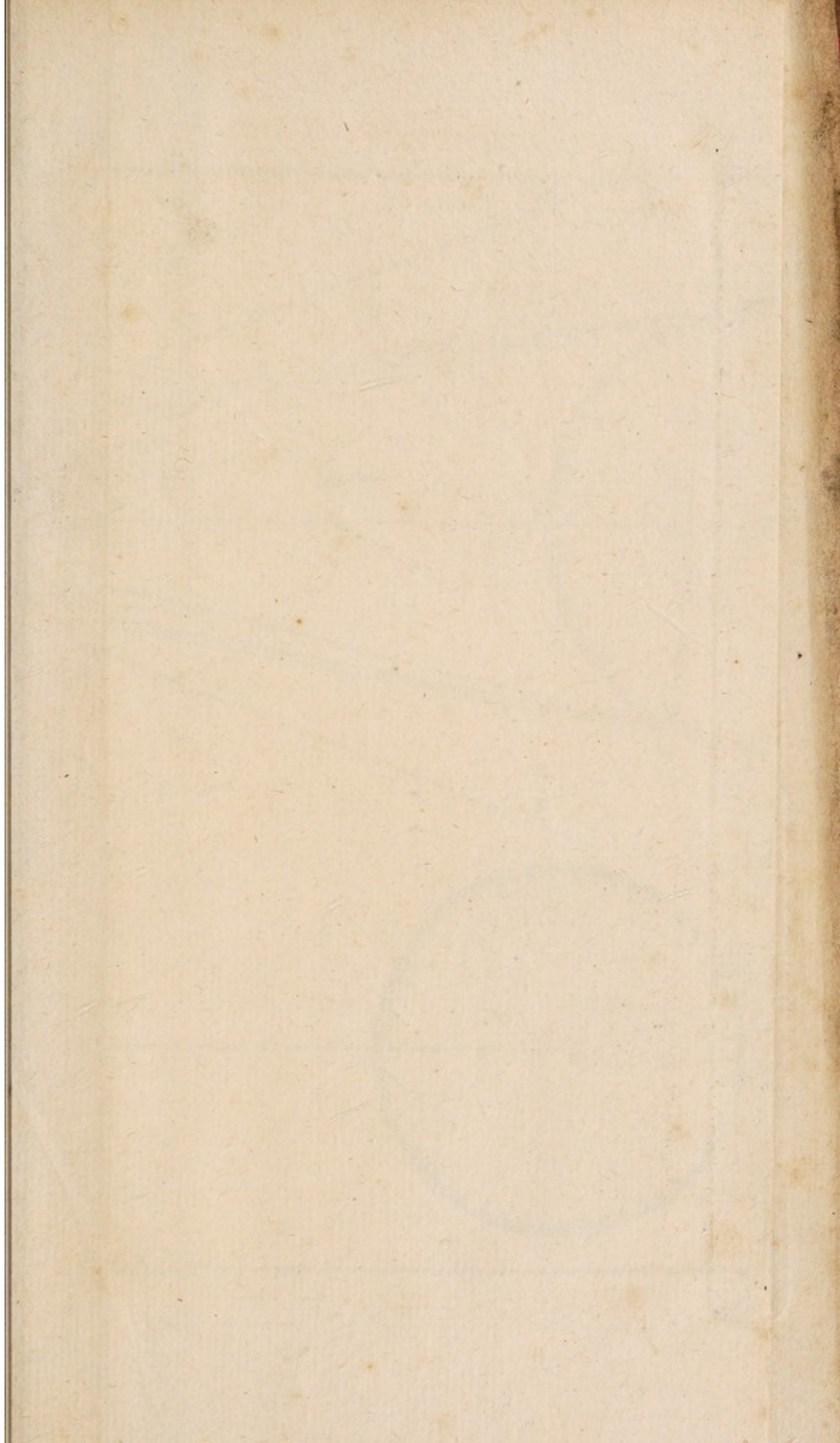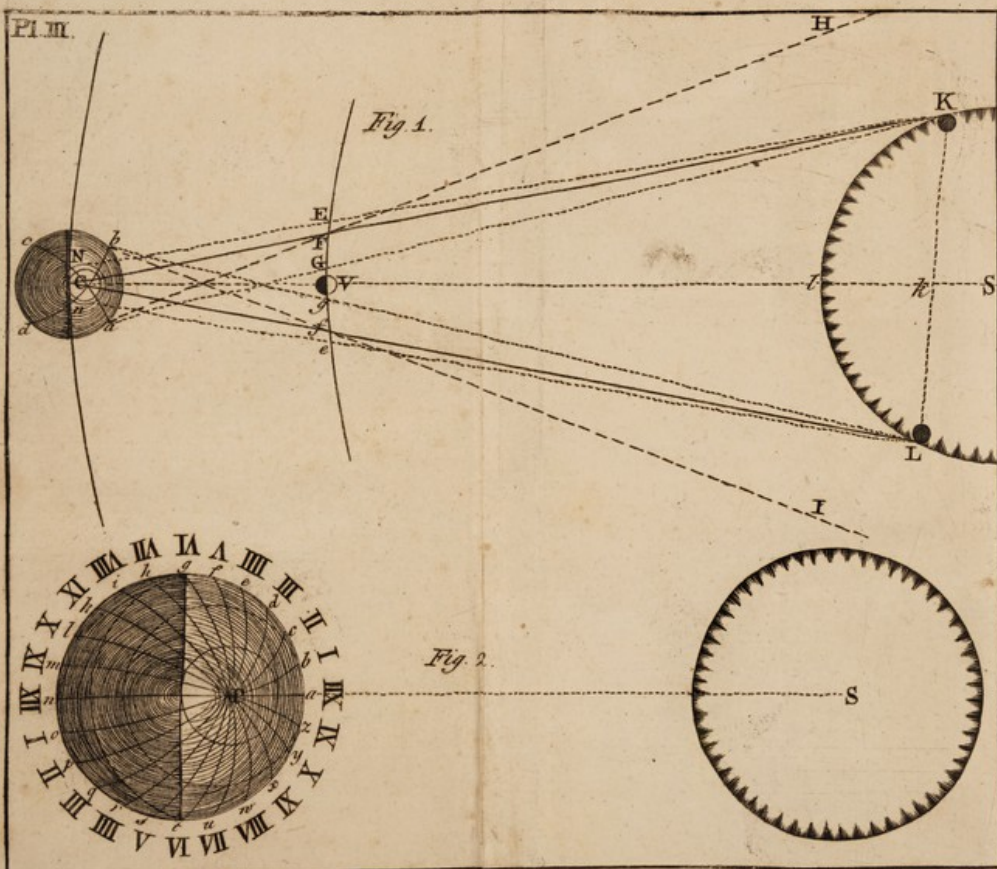
DIALOGUE IV.

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 was 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 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 our astronomical conversations ; by which, I imagine, you spoke

nothing

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 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 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)

fit) her diftance from the Earth is between three and four times lefs than the Sun's diftance from the Earth. And therefore, if Venus be then viewed by two obfervers on the Earth, who are at a great diftance from one another, fhe will appear to each of them, at the fame inftant, to be on different parts of the Sun's furface.— Thus, in *Fig.* 2. of PLATE II. let *S* be the Sun, *V* Venus, and *A B D E* the Earth. Let one obferver be at *A*, another at *B*, and a third at *D* ; all looking at Venus at the fame moment of abfolute time. To the obferver at *A*, Venus (*V*) will appear upon the Sun at *F*, as fhe is feen in the right line *A V F :* to the obferver at *B*, fhe will appear upon the Sun at *G*, being feen by him in the right line *B V G :* and to the obferver at *D*, Venus will appear upon the Sun at *H*, becaufe he fees the planet in the right line *D V H.* Or, if you will fuppofe Venus to be at reft at *V*, during the time that the obferver at *A* is carried, by the Earth's motion on its axis, from *A* to *D*, through the arc *A B D ;* 'tis plain, that, to this obferver, the planet *V* will appear to have moved on the Sun from *F* to *H*, through the fpace *F G H.*

Let us now fuppofe, that the Earth *a b d e* Fig. 3.) is nearer the Sun *s* than as reprefented in *Fig.* 2. in which cafe, Venus *v* will be proportionably nearer the Earth ; and the arc *a b d*, through which the obferver is carried, will bear a greater proportion to the diftance of Venus *v* from the Earth, in *Fig.* 3. than the fame arc *A B D* (in *Fig.* 2.) bears to the diftance of Venus *V* from the Earth. So that, if one obferver fhould be placed at *a*, another at *b*, and a third at *c*, the oberver at *a* would fee Venus on the Sun at *f*, the obferver at *b* would fee her on the Sun at *g*, and the obferver at *d* would fee her on the Sun at *h*, all at the fame inftant of time. Or, if Venus kept at reft at *v*, whilft the obferver 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 fpace
f g h, in *Fig.* 3. is longer than the fpace *F G H* in *Fig.* 2.
and therefore, the nearer the Earth is to the Sun, the
greater will the fpace be through which Venus appears
to move upon the Sun, by the obferver's real motion
along with the Earth, in any given time ; and the far-
ther the Earth is from the Sun, the lefs will the fpace
be through which Venus appears to move upon the
Sun, by the obferver's real motion, in the fame time.

And, confequently, as Venus is really moving on in
her orbit, in the direction of *T V W*, (in *Fig.* 2.) or
t v w (in *Fig.* 3.) whilft the obferver 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 fooner over
the Sun, if the Earth's diftance from the Sun be only
b v s, (as in *Fig.* 3.) than if it be *B V S*, (as in *Fig.* 2.)
So that, the whole duration of her tranfit over the Sun
muft be fhorter, if the Earth's diftance from the Sun be
only *b v s*, than if it be greater, as *B V S*.——Do
you underftand this, *Eudofia?*

E. I think it is fo plain, that any body might under-
ftand it.

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

Now, fuppofe the Earth to be tranfparent like glafs,
and that you were placed at its center *C*, and kept look-
ing at the Sun *S*, during the time in which Venus
moves in her orbit from *F* to *f*, through the fpace
F G V g f: 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*,

just

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 $K k L$, 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.

$F.$ 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 $C F K$; and when she came to f in her orbit, she would seem just beginning to leave the Sun at L, 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 almost from $a b$;

and

and then he will fee her in the line $c f L$, juft beginning to leave the Sun at L; but fhe muft move on from g to f in her orbit, before fhe begins to leave the Sun at L, as feen from the Earth's center C, in the right (or ftraight) line $C f L$; and then, to the obferver at h, fhe will appear quite clear of the Sun to the Weft, in the line $B f I$. So that the whole duration of the tranfit from K to L on the Sun, will be fhorter, as feen by the obferver in motion from a to c, than as feen by the (fuppofed) obferver at reft at the Earth's center C. For, to the former, fhe will move only from G to g in her orbit, during the time fhe appears to move from K to L on the Sun: whereas, to the latter, fhe muft move from F to f in her orbit, in the time fhe appears to pafs 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 tranfit be, from K to L on the Sun, as feen from the Earth's furface and from its center: and the farther the Earth is from the Sun, the lefs will the difference between the durations of the tranfit be, as feen from the Earth's furface and from its center, accordingly.

E. Certainly fo, by what you already told me in your explanation of the fecond and third figures of the fecond *Plate*. For, the nearer the Earth is to the Sun, the nearer alfo, in proportion, it muft be to Venus, and the farther it is from the Sun, the farther alfo it muft be from Venus. So that the fpace through which the obferver is carried by the Earth's motion, from a to b, (PLATE III. *Fig*. 1.) will bear a greater proportion to the diftance of Venus from the Earth in the former cafe than in the latter: and fo, will affect the times of durations of the tranfit, as feen from the Earth's center and from its furface, accordingly.——But I fhould be glad to know, why you fuppofe an obferver to be placed at the Earth's center,

ter, as it is a thing impoffible to be done : and if he was there, he could neither fee the Sun nor Venus.

N. Becaufe the motions of the planets are calculated in the aftronomical tables, as if feen by an obferver at reft. And as the apparent breadth of the Sun is known, and the time of Venus's going round the Sun is alfo known ; the time of her appearing to move through a fpace equal to the Sun's breadth, as feen by an obferver at reft, is eafily calculated, and is the fame as would be obferved by a perfon placed at reft at the center of the Earth. And then, at all kinds of diftance of the Earth from the Sun, it is eafy to calculate how much the duration of the tranfit would be fhortened by the motion of an obferver on the Earth's furface, on the fide of the Earth next to Venus, and who is then moving in a contrary direction to the motion of Venus in her orbit, than the duration of the tranfit would be to an obferver at the Earth's center, or even on its furface if the Earth had no motion on its axis ; in which cafe, the obferver on the furface would be at reft. But as that obferver is really in motion with the Earth, when the duration of the tranfit is obferved by him, and, confequently, known how much fhorter it appeared to him, than it would have done if he had been at reft ; the diftance of the Earth from the Sun may thereby be found : which, as I told you already, is thereupon computed to be 95,173,000 Englifh miles.

E. The diftance of the Earth from the Sun, in miles, being known ; I fhould be glad to know how you find the diftances of all the other planets from the Sun. For we cannot fend people from the Earth to thofe planets, to obferve tranfits.

N. I told you already, in our fecond dialogue, that the relative or comparative diftances of all the planets

from

from the Sun are known long ago, both by the ſtated laws of nature, and by obſervation ; and that they are as follows.

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, 520,096 ; and Saturn's diſtance, 954,006.

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

not yet well afcertained : and fecondly, that all the ob-
fervers did not ufe telefcopes of an equal magnifying
power, which they fhould have agreed to do before-
hand. And undoubtedly, they who ufed the higheft
magnifying telefcopes, could more accurately determine
the inftants of Venus's two internal contacts with the
Sun, than thofe could who ufed fmaller magnifying te-
lefcopes. But 'tis to be hoped, that all proper care will
be taken, in obferving the tranfit on the third of June,
1769. And aftronomers will do well to make the moft
and beft of it they can ; as there will not be another
tranfit in lefs 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 fhould
think, that Venus would pafs between the Earth and
the Sun once every two years at moft.

N. So fhe would, once in every 584 days, if her or-
bit lay in the fame 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-fide of the
plane of the Earth's orbit ; and the other half on the
South-fide of it : fo that her orbit only croffes the
Earth's orbit in two oppofite points. And therefore,
Venus can only pafs directly between the Earth and the
Sun, when, at the times of her conjunctions with the
Sun, fhe is either in or near one or other of thofe points.
At all other times, fhe either paffes above or below the
Sun, and is then invifible, on account of her dark fide
being toward the Earth. But its being fo alfo, at the
time of her late tranfit, made her very confpicuous on
the Sun, like a black patch on a circular piece of white
paper. At her laft tranfit, fhe paffed below the Sun's
center, about a third part of the Sun's breadth ; and at
her next, fhe will pafs as far above it.

E. I

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 *n e 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 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 *N E K* ; but ſhe muſt go on from *E* to *F* before ſhe can be ſeen from *C,* upon the Sun, in the right line *C F K :* and, as ſeen from *C,* in the right line *C f L,* 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 an obſerver who is carried from *N* to *n,* then 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

N. He was fo indeed ; the man who firft propofed this method was the great Doctor HALLEY. And as he was morally certain, that, according to the common courfe of nature, he could not live to fee that tranfit ; he moft earneftly recommended it to future aftronomers, that they might obferve it when he was dead. And, in order to furnifh them with all proper information, he gave in a paper on the fubject to the Royal Society ; which paper was, foon after, publifhed in the Philofophical Tranfactions.

DIALOGUE V.

On the method of finding LATITUDES and LONGITUDES of PLACES.

Neander.

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

Eudofia. I was taken ill, laft night about twelve, of an afthma, which frightened me, as I never was fo before; and kept me awake till five o'clock this morning. Then it left me, and I fell afleep, and have quite over-fleeped my time; for now it is eight o'clock.

N. Why did you not ring your bell, in order that fomething might have been brought to relieve you? efpecially as you know that our mother (among many other good medicines) always keeps an electuary of ho-

E   ney,

ney, powder of liquorice, of elecampane, feeds of anife, and flower of fulphur; which is exceeding good for that diforder, and has cured many of it.

E. I was loath to furprize any body in the night, efpecially as the afthma did not continue long violent. — I raifed my head a good deal; fo 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 fuch fubject this morning, as we have already been about. And therefore, I hope you do not come now with any fuch intention.

E. Indeed I do, if it were but to take off my drowfinefs: and I feel no other ailment at prefent.

N. Well then;—with what fubject fhall I entertain you this morning?

E. I heard you yefterday, for the firft time, mention the *Longitudes of places.* But as I fcarce know what either *Longitude* or *Latitude* means, I fhould be glad to know: efpecially as we have heard fo much lately about finding the Longitude. And as I never heard of any difficulty about finding the Latitude, I imagine, the latter is much more eafily found than the former.

N. It is fo indeed, fifter.

E. What is the reafon of that?—But I believe my queftion is premature: for I fhould have afked firft, what thofe terms mean?

N. Right, *Eudofia*; and now I will inform you. —— *Every circle,* be it great or fmall, is divided (or fuppofed 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' Englifh miles: as is the cafe with the degrees of the equator, and nearly fo with thofe of a great circle taken round the Earth, through the North and South poles.

The

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 fide of the E-quator.—Thus in the little globe, (*Fig.* 1. of PLATE I.) all the places in the northern hemifphire, 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 fartheft points of the Earth from the equator, they have the greateft Latitude ; which is 90 degrees, or a fourth part of 360, the whole circumfer-ence 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 furface is carried round in 24 hours, except its poles, which are at reft. This motion of the Earth will caufe 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 reft ; becaufe they are directly over the poles of the Earth, which are at reft.

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

N. Why not.

E. I fhould think, that the poles of the Heaven would change among the ftars, 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 de-fcribe 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

N. And fo it does.——But if it fhould, by its track, make as dark a circle in the Heaven, as can be made with ink by a pair of compaffes on paper; the diftance of the ftarry Heaven is fo great from us, that a circle therein of 190 millions of miles in diameter, would not appear fo big to us as the fmalleft dott you can poffibly make with a fine pen upon paper. Which fhews, that if the Earth were as big as would fill its whole orbit, it would appear no bigger than a dimenfionlefs point, if feen from the ftars. For, notwithftanding the Earth's conftantly changing its place in its orbit, the poles of the Heaven could never be perceived to change their places, a fingle vifible point, even when obferved with the niceft inftruments. And therefore, we always confider the poles of the Heaven to be fixed points; and to keep conftantly juft over the poles of the Earth.

E. You have fatisfied me entirely on this head; and at the fame time, convinced me, that the diftance of the ftars muft be inconceivably great. Now, pleafe to proceed.

N. Now, let us fuppofe a great circle to be drawn round the Heaven, through 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 comparifon to the diftance of the ftarry Heaven; let us be on what part of the Earth we will, we fee juft 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; fo 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 furface of a great fphere or hollow globe; 'tis plain, that if we were at the Earth's equator, the equinoctial in the Heaven would

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 either the North or South pole of the Earth, the like pole of the Heaven would appear to be one degree elevated above our horizon, becaufe we would fee 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 fo on, till we go to either of the Earth's poles, 90 degrees from the equator; and then, the like pole of the Heaven would be juft over our head, or 90 degrees above our horizon; which is the greateft elevation it can have, as feen from any part of the Earth. And as the number of degrees we are from the Earth's equator is called our Latitude, fo the number of degrees of the elevation of the celeftial pole is equal thereto. At London the North pole of the Heaven is elevated $51\frac{1}{2}$ degrees above the horizon; which fhews, that London has $51\frac{1}{2}$ degrees of North Latitude from the equator.

And as Latitude begins at the 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 vifible circle in the Heaven divided into degrees, to reckon by.

N. But we have an inftrument 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 towards the Earth's center, when allowed to hang freely. And if we look at the pole along one of the ftraight 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

above the horizon of our place.——And, by that means, the elevation of the pole, and confequently the Latitude of the place is known.

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

N. No : but there is a ftar of the fecond magnitude, about two degrees from the North pole, and it is called *the pole ftar.* And as the Earth's motion on its axis caufeth an apparent motion of all the ftars round the poles of the Heaven ; the pole ftar appears to us to defcribe a circle, of four degrees diameter, round the pole it felf, every 24 hours. And therefore, if we fubtract two degrees from the greateft obferved height of the pole ftar, or add two degrees to the leaft obferved height thereof ; the refult gives the elevation of the pole at the place of obfervation.

As the North pole is elevated $51\frac{1}{4}$ degrees above the horizon of London ; all thofe ftars which are within $51\frac{1}{2}$ of that pole never fet below the horizon of London. And therefore, if the greateft and leaft altitudes of any of thefe ftars be taken with a quadrant, half the difference of thefe altitudes being added to the leaft, or fubtracted from the greateft, gives the elevation of the pole above the horizon.

And thus, we can very eafily and accurately find the Latitude of any place, by means of any ftar which never fets below the horizon of that place.

The Latitude of any place may alfo be found by the Sun's altitude at noon, on any day of the year, quite independent of the ftars. — I will firft endeavour to fhew you the reafon of this, and then fhew you the method.

The Equinoctial in the Heaven is directly over the Equator on the Earth. And juft 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 E-quinoctial, 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 declination to be North on that day, substract 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 substracted from 90 degrees, will give the Latitude of the place.

Thus,

Thus, on the 21ft of June, the tables fhew us, that the Sun's declination is $23\frac{1}{2}$ degrees north; and if the Sun's altitude be obferved with a quadrant on the noon of that day, the altitude will be found to be juft 62 degrees.———Now, fubftract $23\frac{1}{2}$ degrees from 62, and the remainder will be $38\frac{1}{2}$ degrees for the height or elevation of the higheft point of the Equinoctial above the horizon of London; which height being fubftracted 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 obferved altitude at noon, and the fum will be the elevation of the higheft point of the equinoctial above the horizon of the place; which elevation being fubftracted from 90 degrees, will leave a remainder e- qual to the Latitude of the place.

Thus, on the 21ft of December, the table fhews 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 juft 15 de- grees; which being added to $23\frac{1}{2}$ degrees South decli- nation, gives $38\frac{1}{2}$ degrees for the height of the equi- noctial, which height being fubftracted from 90 de- grees, leaves $51\frac{1}{2}$ remaining, for the Latitude of Lon- don, as before. ——— Do you underftand all this *Eudofia?*

E. I think I do, on account of the reafons you have given for the procefs.———But I will confider it by and by; and then tell you if I find any difficulty.

N. Do fo: and now we will talk about the Lon- gitude. The curve lines which you fee drawn on the globe, from pole to pole (PLATE I. *Fig.* 1.) are called *Meridians*; and each of them is a meridian to every place through which it paffes; becaufe when it comes even with the Sun, by the turning of the globe on its axis, the Sun is then at the greateft height, as

feen

feen from all places on that meridian; and confequently, it is then mid-day or noon to each of them.——There are only 24 meridian femicircles on the globe, at equal diftances from each other; but we may fuppofe the whole fpaces between them to be filled up with other fuch meridians, becaufe every place, which is ever fo little to the Eaft or Weft 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 Englifh aftronomers and geographers begin (what they call) the Longitude, at the meridian of London, and thence reckon the Longitudes of other places to the Eaft or Weft, as the meridians of thofe places lie Eaft or Weft from the meridian of London. So that, the Longitude of any place, Eaft or Weft 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 Englifh way of reckoning. Thus, a meridian drawn through *Copenhagen*, in *Denmark*, would cut the Equator 13 degrees eaftward 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 weftward of the point where the meridian of London cuts it: and therefore, we fay, the Longitude of *Copenhagen* is 13 degrees Eaft from the meridian of London (which is termed *the firft meridian* by the Englifh) and the Longitude of *Philadelphia* is 74 degrees Weft.

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 of any place; I fuppofe moft nations reckon the Longitude of all other places

from

from the meridian of the principal city of their own kingdom or nation.

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

N. Becaufe we have a fixt point, or pole, in the heaven, which fhews us our Latitude by its elevation above the horizon of our place : but there is no vifible meridian in the Heaven, to keep directly over the meridian of any place on the Earth.——If there were fuch a meridian, the Longitudes of all other places from it might be as eafily 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 underftand you perfectly well.——But, pray, what are the beft methods that have been yet propofed for finding the Longitude ?

N. The beft method, in theory, is by a machine that will meafure time exactly, fo as to go as true at fea, as a good clock does on land.

E. Pleafe to explain this.

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

at

at the meridian of London; and every place whofe meridian is 30 degrees Weft from the meridian of London, will have noon, and every other hour, two hours later than it is fo at the meridian of London; and fo on.

E Although this feems plain, I fhould be glad to have it illuftrated 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 eaftward 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 femicircles as can be fhewn in the figure, at 15 degrees diftance from each other; and fuppofe *a P* to be the meridian of London.

Then, whichever fide of the Earth is at any time turned toward the fun, it will be *day* on that fide, and *night* on the other; as exprefled by the *light* and fhaded parts of the Earth in the figure. And, as it muft be XII o'clock at noon on any meridian which is turned toward the fun, at any moment of abfolute time, becaufe *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 fame inftant, on the oppofite meridian *n P*, becaufe 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 fo, all the intermediate hours, on the intermediate meridians, at the very inftant when it is noon on the meridian *P a*. So that, fuppofing *P a* to be the meridian of London, it is plain, that when it is XII o'clock *there*, it will be 1 o'clock in the afternoon on the meridian *P b*, becaufe *that* meridian is paft by the fun 15 degrees, or one hour, to the eaftward; II o'clock in the afternoon on the meridian *P c*: III o'clock on the meridian *P d*; and fo on. But, it can only be XI in the forenoon, on the meridian *P z*, when it is noon on the me-

ridian

ridian *P a* ; becaufe *P z* is then an hour fhort of being even with the fun : X o'clock in the forenoon on the meridian *P y,* becaufe that meridian wants two hours of being even with the fun ; and fo on.

Now, as every mafter of a fhip knows how to find the time of the day at the place of his fhip, by the height of the fun ; or the time of the night by the height of any given ftar that revolves at a good diftance from either of the celeftial poles ; if he firft finds the Latitude of the place of his fhip : 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 fets out from any port, as fuppofe from London, let him fet his watch to the exact time at *that* port : and then, let him fail where he will, his watch will always fhew him what the time is at that port from which he fet out.

Now, fuppofe him to be at fea, on his way to the Weft Indies ; and that he has failed from London at *a* as far weftward as *x,* and then wants to find the Longitude of the place of his fhip at *x.* He firft finds the Latitude of the place *x,* and then, by the altitude of the fun, finds the time at that place ; which we fhall fuppofe to be IX o'clock in the morning : he then looks at his watch, which fhews 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 Weft of London ; and as every hour of time anfwers to 15 degrees of Longitude, he finds that the meridian of the place of his fhip is 3 times 15, or 45 degrees Weft from the meridian of London. And, as every hour anfwers to 15 degrees of Longitude, fo every four minutes anfwers to one degree. If he had been as far eaftward (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 fhip, when his watch

<div align="right">would</div>

would have fhewn him that it was then only mid-day at London : and fo, in *that* cafe, he would have known that the Longitude of his fhip was 45 degrees Eaft from the meridian of London.

E. This appears to me to be a very rational and eafy method of finding the Longitude, if a watch can be made that will keep exact time at fea.——Pray has there ever been fuch a watch made, fo as that it can be depended upon ? for otherwife I fhould think it very dangerous ; becaufe, for every four minutes that it would either gain or lofe, it would caufe an error of a whole degree in reckoning the Longitude.

N. Mr. *Harrifon* has fucceeded the beft of any who ever yet attempted to make fuch a watch. But *that* watch has been found not to keep time quite fo exactly as was expected, after fome months trial at the Royal Obfervatory at Greenwich. Yet it muft be acknowledged that Mr. *Harrifon* has very great merit, and deferves the reward he has got for his ingenuity : and many are of opinion, that he can ftill make a watch that will meafure 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 fure one) for finding the Longitude, has been practifed for many years : and *that* is, by the eclipfes of Jupiter's fatellites ; but it is attended with two inconveniencies : firft, as it requires the telefcope to be quite fteady, by which thofe eclipfes are obferved ; it cannot be put in practice at fea, on account of the unfteadinefs of the fhip : and fecondly, no obfervations of thefe eclipfes can be made in the day-time, becaufe Jupiter is not then vifible.

E. But I fhould think it muft ftill be very ufeful in finding the Longitudes of places on the land, where the telefcope may be kept quite fteady.——Pray, explain the method by which the Longitude has been thus found.

N. The

N. The Englifh aftronomers have calculated tables which fhew the times of thofe eclipfes, all the year round, on the meridian of London ; and the French have done the like for the meridian of Paris.——Now, fuppofe an Englifhman to be at *Kingfton* in *Jamaica,* and that he obferves either of Jupiter's moons to be eclipfed juft at One o'clock in the morning : he looks at the tables, to fee at what time the fame eclipfe 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 *Kingfton* in Jamaica, is thus found to be 5 hours 8 minutes, or 308 minutes ; which being divided by 4, (becaufe 4 minutes of time anfwer to one degree of Longitude) quotes 77 for the number of degrees by which the meridian of Kingfton is Weft from the meridian of London : and thus he finds, that Kingfton is in 77 degrees of Weft Longitude from London.

E. You have explained thefe matters very fully ; and I thank you for it.

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

E. But I am quite well now brother ; and you have finifhed in very good time, as the bell juft rings for breaftfaft.

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, *Eudosia.*——I hope you rested well last night, and had no return of your late complaint.

Eudosia. 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 propose for us to enter upon, this morning?

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

<div align="right">lengths,</div>

lengths, unlefs it were by a particular motion of the Sun northward and fouthward, acrofs the Equator in a year.—— But, from what you have already told me, it appears plain, by the ftated laws of nature, that the Sun cannot have any fuch motion

N. Indeed he cannot.——And you fhall foon fee the reafon of the different lengths of days and night, and of all the four feafons of the year, without any motion of the Sun northward and fouthward acrofs the Equator.—— Pleafe to light *that* candle, by way of a Sun, and fet it upon the table, whilft I fhut the windows ; fo 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 fmall three inch globe, fo as to reach a little way out from its furface in the North and South poles.————I move the globe round the flame of the candle, keeping it always at the fame height from the table, and its axis perpendicular to the table : and you fee that the candle is always even with the Equator of the globe, and enlightens it juft from pole to pole.

E. Exactly fo.

N. And that one half of the globe is enlightened by the candle, whilft the other half is not : and confe-quently, that it appears as if it were *day* on the fide of the globe next the candle, and *night* on the oppofite fide.

E. Very plain.

N. I now turn the globe round its axis many times during the time I move it round the candle as before ; and you fee that every part of its furface, from the North pole to the South, goes equally through the light and fhade. 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 furface from pole to pole, would be twelve hours in the light, and twelve hours in the dark.

E. Un-

Pl. IV.

Fig. 1.

Fig. 2.
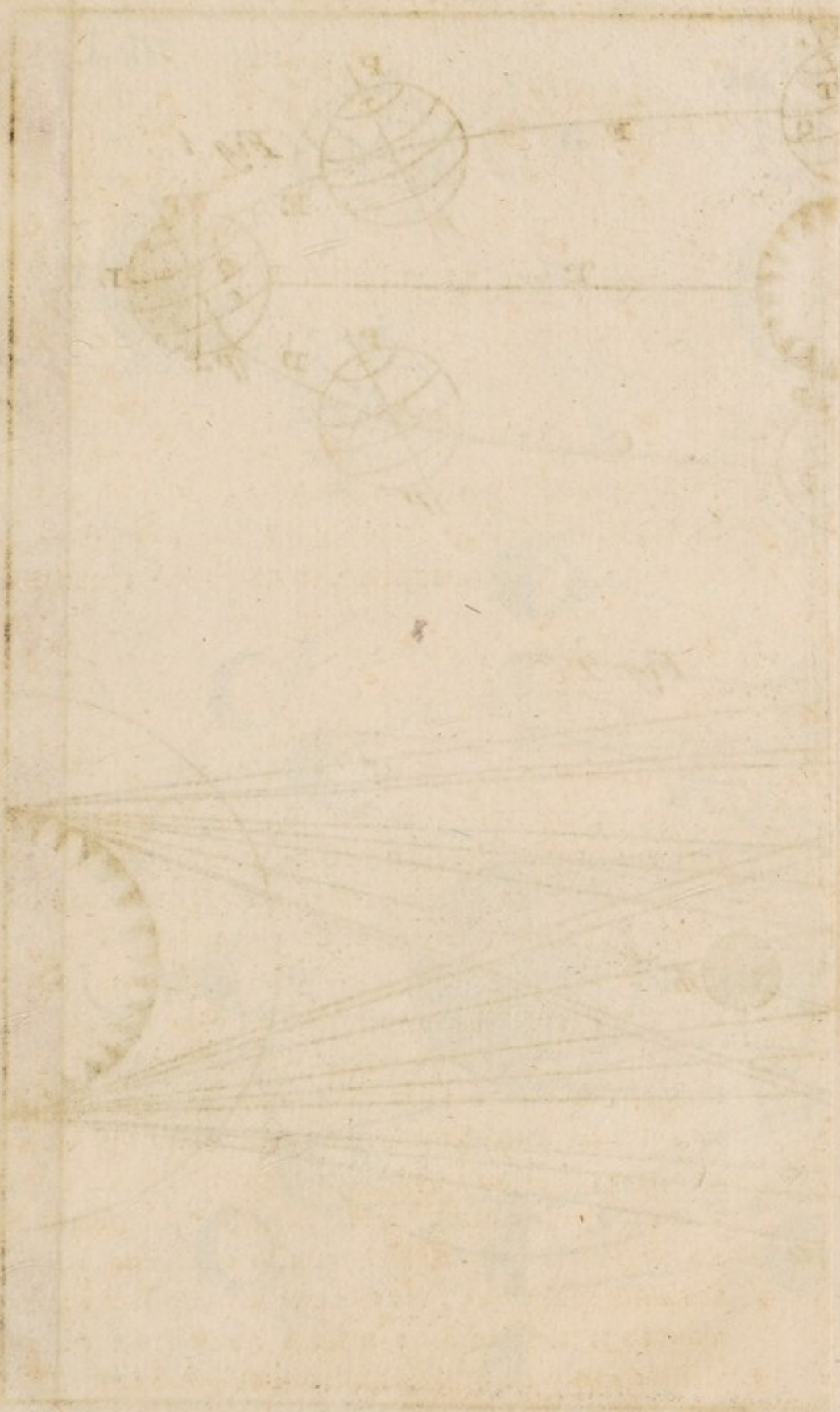
E. Undoubtedly it would.

N. Then, you fee, that fuppofing the candle to have no motion from one fide of the Equator to the other, and the axis of the globe to keep perpendicular to its orbit, in its whole courfe 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 fee that the candle fhines as far over the North pole as the axis of the globe is inclined toward the candle; and that all thofe places of the northern hemifphere which go through the dark, go through lefs of it than they do of the light; fo that their days are longer than their nights: and the candle, being on the North-fide of the Equator, fhines as far fhort of the South pole, as it fhines over the North pole: and confequently, all the places on the fouthern hemifphere of the globe, which go through the light, go through a lefs portion of it than they do of the dark; and fo have their days fhorter 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 fhine round the South pole. And now, all the northern places of the globe which go through the light, go through lefs of it than they do of the dark; fo that the days are fhorter than the nights on the North-fide of the Equator, and the contrary on the South-fide of it. ———You now fee, that turning the poles of the Earth alternately, more or lefs, toward and from the Sun, will have the fame effect, as if the Sun really moved northward and fouthward, to different fides of the Equator.

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

F

N. They

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

Let *A B C D E F G H A* reprefent the Earth's orbit (feen obliquely, which caufeth it to appear of an elliptical fhape.) 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, fuppofe 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 fet off $23\frac{1}{2}$ of thefe degrees from *P* to *u*. Then, at the diftance *P u* from the North pole, draw a circle all around it; which call *the North polar circle*: and fuppofe juft fuch 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 fide 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 courfe, let its axis *P p* ftill incline $23\frac{1}{2}$ degrees toward the right-hand fide of the plate.

Then 'tis plain, that when the Earth is at *I*, the whole North polar circle falls within the enlightned part of the Earth; and all the northern places between the Equator *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, thefe places will have longer days than they have nights: and the Sun will point as far North of the Equator *Q*, as fhewn by the ftrait line *R*, as he fhines round the North pole *P*; for the diftance *Q T*, northward from the Equator, is equal to the diftance *P u* from the North pole; which is $23\frac{1}{2}$ degrees.———This is the Earth's pofition on the

21ſt of June, when our days are at the longeſt, and nights at the ſhorteſt.

At the diſtance $\mathcal{Q} T$ (23½ 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 far-ther 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 $\mathcal{Q}$.

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.

When the Earth is at K, its axis $P p$ 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 $C D$ 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 him when the Earth was at I : and there-

fore,

fore, 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 fhewn 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 fouthern tropic*, becaufe it is the utmoft limit of the Sun's South declination from the Equator. This is the Earth's pofition on the 21ft of December, when all thofe places in the northern hemifphere, which go through the light and the dark, go through the leaft portion of the light, and the greateft of the dark, that they can do on any day of the year. And therefore, the days are then at the fhorteft, and nights at the longeft, 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 $E\,F$ of its orbit, its axis $P\,p$ is gradually more and more turned fidewife to the Sun ; the northern places fall more and more into the light, and their days lengthen and nights fhorten. 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 fidewife 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 furface 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.

Laftly, 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 fo, have their days longer and nights fhorter, till the Earth comes to I on the 20th of June, when the days in thofe places are at the longeft, and nights at the fhorteft ; becaufe they incline the moft to the Sun that they can do on any day

of

of the year; and confequently, 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 fame fide of the heavens, in its whole annual courſe round the Sun; as in the figure it does toward the right hand fide of the plate; it is evident, that its axis muſt incline conſtantly, more or leſs, toward the Sun during our fummer-half of the year; and more or leſs from him during our winter-half. That, when it is fummer in the northern hemiſphere, it muſt be winter in the ſouthern, and the contrary: and that there can be no difference of feaſons 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 feaſons.——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, *Eudoſia*; 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 feeing a book lying open on your table, I looked into it; and found mention made of the *ecliptic*, the *figns* thereof, and the *Sun's place*. Pray, what is the ecliptic, and what are its figns?

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.

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, 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 the Sun appears to enter these Signs, are as follows.

Aries,	*Taurus,*	*Gemini,*	*Cancer,*	*Leo,*	*Virgo,*
March	April	May	June	July	August
20	20	21	21	23	23
Libra,	*Scorpio,*	*Sagittarius,*	*Capricornus,*	*Aquarius,*	*Pisces,*
Sept.	Octob.	Novemb.	Decemb.	Janu.	Febr.
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 23d ; so that he must yet be in Cancer. Take 11 from 23, and there remains 12 ; so that the Sun is now 12 de-

grees

grees fhort of the laft point of *Cancer* ; and confequent-ly, he is in the 18th degree thereof.

N. You are perfectly right, fifter : and I think we have done with this part of our fubject.

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 breakfaft.

E. Which, I hope, will not be in lefs than half an hour : and till then, I fhould be glad to learn fomething about the Moon.

N. Very well : it is your province to afk queftions, and mine to anfwer them,

E. What is the caufe of the Moon's appearing of fuch different fhapes as fhe does to us every month, always increafing from change to full, and decreafing from full to change ?

N, Be pleafed to light the candle again, and fet it on yonder table, at the farther end of the room, whilft I clofe the window-fhutters. And then, do you ftand at a good diftance from the candle, and look toward it.

E. Very well, brother ;——Now,

N. Here is a fmall 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 yourfelf round, and keep looking at it. Let the candle reprefent 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, fo 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 fide of it is toward you when it is between your head and the

candle; the light fide when it is carried half round, or oppofite to the candle with refpect to your head; and, in the middle between thefe two pofitions, you have half the light and half the dark fide toward you.

E. Very true.——And when the globe is between me and the candle, the whole of its enlightened fide difappears: when you move it a little way from that pofition, I fee a little of its enlightened fide, appearing horned, like the Moon when fhe is a few days old. When you carry it a quarter round, I fee half its enlightened fide, which appears juft like the Moon when fhe is a quarter old. As you move it farther onward, I fee more and more of its enlightened fide; and it continues to increafe like the Moon, till it is juft oppofite to the candle, when I fee the whole of its enlightened fide; and then it appears quite round, like the full Moon. After which, I fee lefs and lefs of its enlightened fide, which gradually decreafes like the Moon, until you bring it again between me and the candle; and then, the whole of its enlightened fide difappears, as before.

N. And doth not this fhew very plainly, why the Moon muft appear to us to increafe from the change to the full; and decreafe from the full to the change?

E. Very plainly, indeed: and, I think, it alfo fhews that the Moon does not fhine by any light of her own; but only by reflecting the Sun's light that falls upon her. For, if fhe fhone by her own light, we fhould always fee her round, like the Sun.

N. That is a very good and juft obfervation, fifter; and it is a remark that I might poffibly 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

N. Here is a figure for that purpose (PLATE IV. *Fig.* 2.) in which, let *S* reprefent the Sun, *E* the Earth, *M* the Moon ; and *a b c d e f g h a* the Moon's orbit, in which fhe goes round the Earth from change to change, according to the order of the letters ; that is, eaftward in the heavens ; although the Earth's daily motion round its axis, the fame way, being quicker than the Moon's progreffive motion, makes her appear to go round weftward. When the Moon is at *M*, between the Earth and the Sun, her dark fide is then toward the Earth ; and fhe difappears, becaufe *that* fide reflects no light. When fhe is at *N*, a little of her enlightened fide will be feen from the Earth ; and then fhe will appear horned, as at *n*. When fhe is at *O*, half her enlightened fide will be toward the Earth, and fhe will then appear as at *o*, or in her firft quarter, being then got a quarter of her orbit out from between the Earth and the Sun. When fhe is at *P*, more than half of her enlightened fide is toward the Earth ; and fhe appears (what we call) Gibbous, as at *p*. When fhe is oppofite to the Sun, as at *Q*, the whole of her enlightened fide is toward the Earth ; and fhe appears round and full, as at *q*.

E. Let me interrupt you a little here. Pray how ean the Sun fhine upon the Moon, when the Earth is directly between her and the Sun ? For, I fhould think, that the Earth would ftop the Sun's light from going to the Moon.

N. It does fometimes ; and then the Moon is eclipfed : and fometimes the Moon comes directly between the Earth and the Sun at the time of her change ; and then we fay, the Sun is eclipfed. But we fhall talk of thefe matters afterward.

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 he 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 very 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-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 it 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 2183½ miles ; and it is in proportion to the Earth's diameter as 100 is to 365, or as 20 to 73.

E. What

E. What are thofe fpots which we fee on the Moon ? I think I have heard fome people fay that they are feas.

N. So they were thought to be, before there were good telefcopes to view the 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 fo copioufly as the whiter parts do. For we fee they are full of pits and deep valleys : but if they were feas, they would have even and fmooth furfaces.

E. So they certainly would, brother. But as it may be known by thefe fpots whether the Moon turns round her own axis or not ;———if fhe does turn round, I fhould be glad to know in what time ; becaufe I fhould thereby know the length of her days and nights.

N. She turns round her axis exactly in the time fhe goes round her orbit ; and this we know by her keeping always the fame fide toward the Earth.

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

N. Exactly fo.

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

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 muft always be equally long ; and fhe can have no different feafons ?

N. You are very right, *Eudofia.*

E. But pray, brother, how is it poffible that we can only fee one and the fame fide of the Moon, at all times, if fhe turns round her axis ?——— For I

fhould

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 so round, without turning it at all on its axis, all its 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.
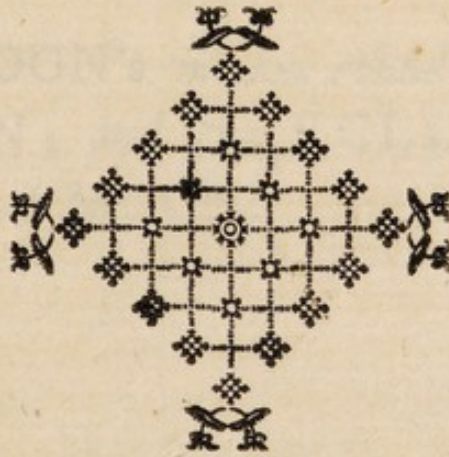
E. I find it impossible to do so:——— for, in each revolution of the globe about the ink-horn, in order to make the globe keep still the same side toward it, I am obliged to turn the axis once round betwixt my finger and thumb: and, as the axis is fixt in the globe, I cannot turn the axis round without 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 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 around to the Sun between change and change.———For, in the time that I carried the globe
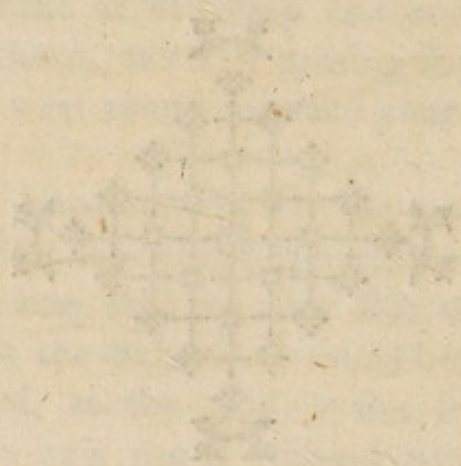
round

round the ink-horn, and kept always the fame fide toward it ; you, who were on the out-fide of the circle in which I carried the globe fo round, faw all its fides.

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

DIALOGUE

DIALOGUE VII.

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

Neander.

SO, Sifter;——if yefterday had not been Sunday, I believe you would not have given yourfelf *that* day's reft from your aftronomical ftudies.

Eudofia. To me, brother, thefe ftudies are recreations, which I efteem better than bare reft.——And, on Sunday we reft 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; and therein our duty is clofely connected with our intereft.——Shall we now refume our

subject

fubject about the Moon ? as I told you, laft Saturday morning, that we had not done with her.

E. If you pleafe, Sir.

N. Then you muft always ftart the game; and when *that* is done, we will purfue it.

E. I think the Moon would always appear full as feen from the Sun, if fhe were big enough to be feen by an obferver placed on the Sun's furface.

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

E. And I imagine, that if an obferver were placed on the fide of the Moon which always keeps toward the Earth, the Earth would appear to him in all the different fhapes 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 difappear, or be *new* to the Moon.

N. What reafon have you for thinking fo, *Eudofia ?*

E. Becaufe, whichever fide of the Earth or Moon is turned toward the Sun at any time, *that* fide is then enlightened by the Sun. And therefore, when the dark fide of the Moon M (*Fig.* 2. of PLATE IV.) is toward the Earth E, the enlightened fide of the Earth is then fully toward the Moon; and muft appear to her like a great full Moon. And when the enlightened fide of the Moon at Q is fully toward the Earth, the dark fide 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 firft quarter) at O, the Earth muft appear half decreafed to the Moon, being then half way between its full and change, as feen from her. And laftly, when the Moon is in her third quarter at T, as feen from the Earth, the Earth muft appear as in its firft quarter to the Moon; it being then the middle

time

time between the new and full Earth, as feen from the Moon.

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

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

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

E. When you explained the Longitude to me, you made me underftand, that if there were a vifible meridian in the Heaven, keeping always over one and the fame meridian on the Earth, (which it would do if it revolved eaftward in 24 hours as the Earth does) the Longitude of any other meridian of the Earth from *that* meridian, might as eafily be found as the elevation of the pole above the horizon is found.———Now, feeing that the Moon keeps always one and the fame fide toward the Earth, 'tis plain, that the Earth will be always over an obferver's head who is on that part of the Moon's furface which feems to us to be her center. And therefore, if Longitude on the Moon were reckoned from the meridian of that obferver, thofe on all her other meridians on the fame fide, might find how many degrees lie between their meridian and that which is under the Earth, by obferving how many degrees the Earth is Eaft or Weft of their meridian. But, as thofe inhabitants who live on what we call the *back* of the Moon, never fee the Earth ; they are deprived of *that* eafy method of finding their Longitude.

G   *N.* Truly,

N. Truly, fifter, I ought to make you a very *fine speech* for that thought: but having no talent that way, all I fhall fay is, that I am very well pleafed by it.

E. I am very glad to hear you fay fo, becaufe you thereby affure 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 muft do fo 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 fphere of the Earth's attraction: and therefore, let the Earth move in its orbit as faft as it will, the Moon muft accompany it. For you know, that if you put a pebble into a fling, and whirl it round your head; the pebble will go round and round your head, whether you ftand ftill in one and the fame place, or whether you 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 ftring to confine the pebble in its orbit, will be the fame in one cafe as in the other.

E. I thank you, brother, for having fet me right in this matter; and at the fame time for convincing me, by the fimile, 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, fhe would fly out of her orbit, and fo abandon the Earth. And if her centrifugal force were lefs than the power by which the Earth attracts her, fhe would come nearer and nearer the Earth in every revolution, and would fall upon it at laft.

Pl. V.

Fig. 1.

Fig. 2.
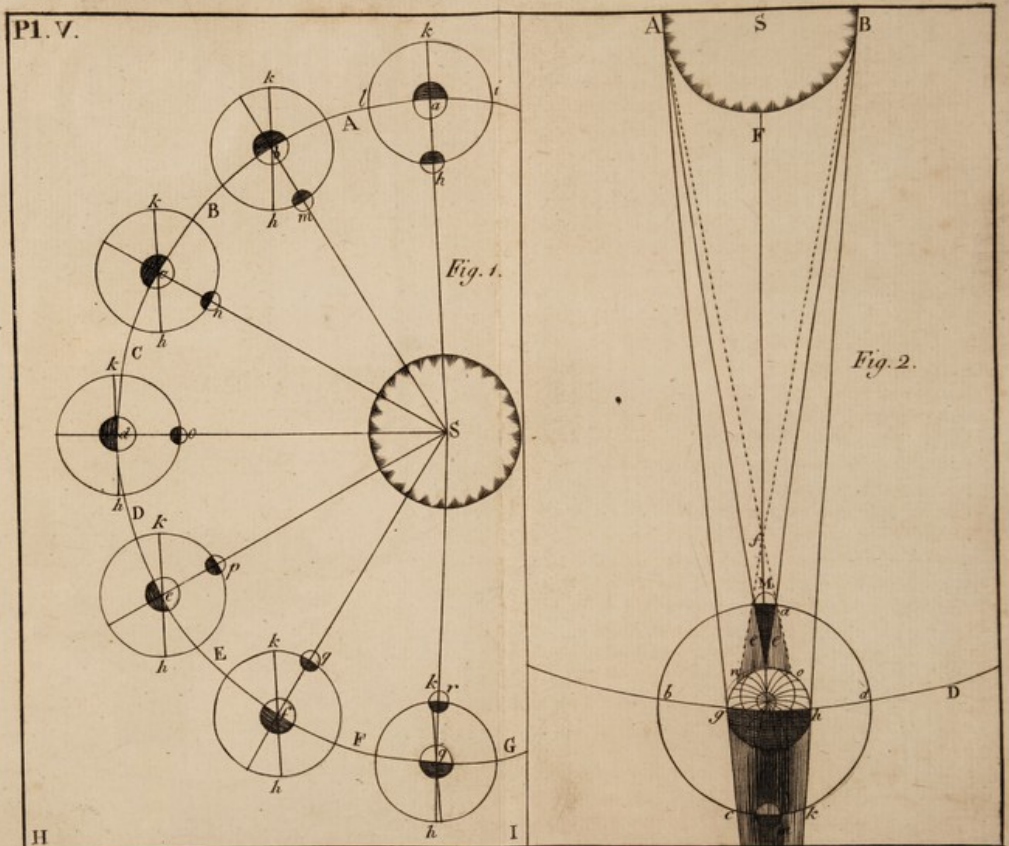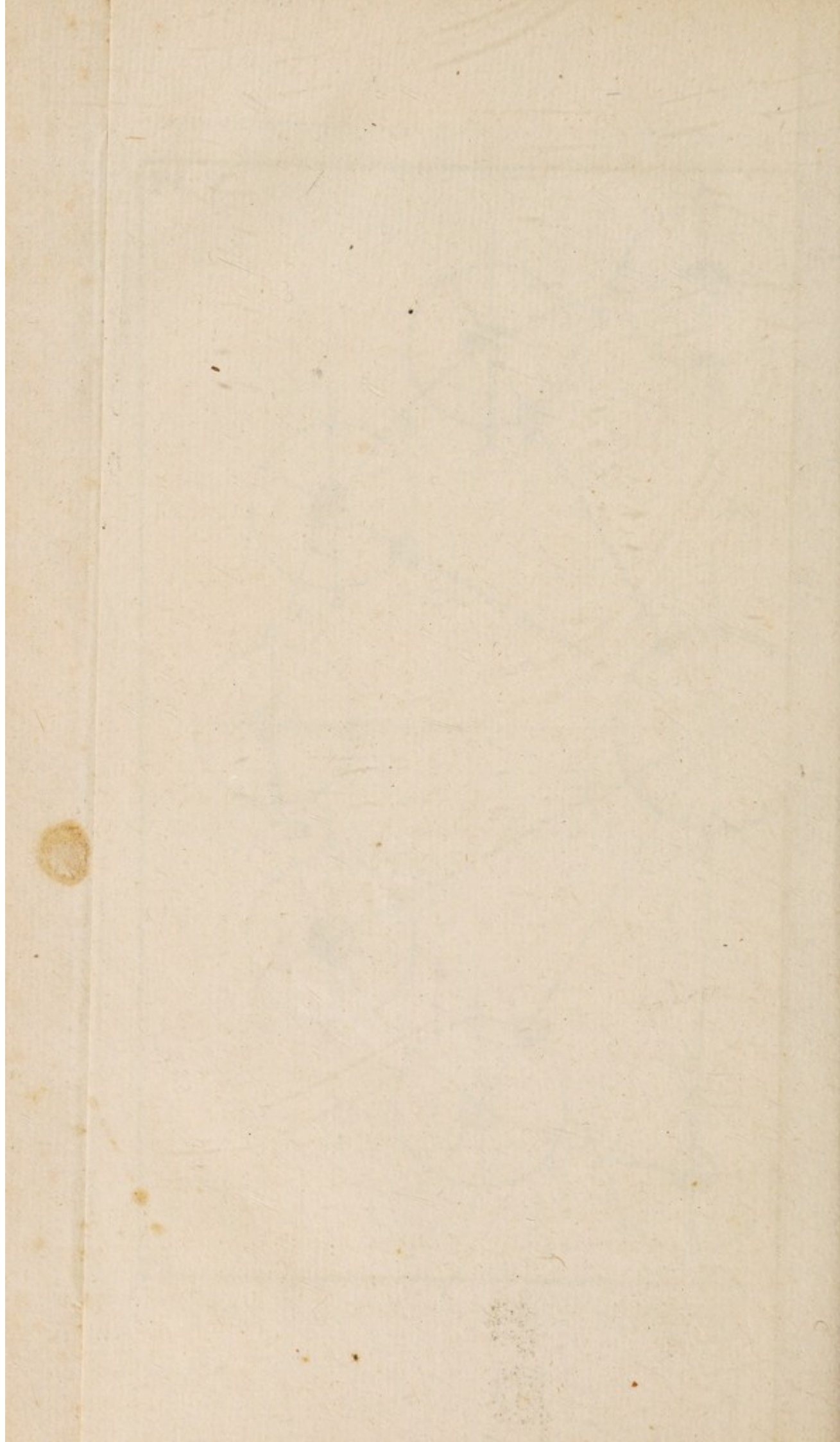
N. I find, dear *Eudofia*, that you very feldom need to be fet right: and when I do, you always improve upon it, by making farther obfervations.

E. By the laft figure you explained, it would feem, that the Moon goes juft 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 muft 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 obferve that the minute-hand muft go as much more than round to the fame point again, before it overtakes the hour-hand, as the hour-hand advances in the interval between its laft 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, laft Saturday afternoon, in order to explain this matter to you by it. But, as you underftand the thing fo well already, we have no occafion for the figure.

E. Nay, brother;——I beg you will fhow 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, juft 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 *i k l* the Moon's orbit, in which fhe 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 *k h* of the Moon's orbit, when the Earth is at *a*; fo as, if that line were continued, it would go on ftraight to the Sun's center *S :* 'tis plain,

G 2   that

that when the Moon is in the end *h* of *that* line, she muft 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 faid diameter *k h*, *k h*, *k h*, *k h*, will ftill continue parallel to the pofition *k h*, 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 poined *once* toward a fixed ftar, whofe diftance from the Sun is fo great, that the whole diameter of the Earth's orbit bears no fenfible proportion to that diftance (which is really the cafe), the point *h* would *always* keep between the Earth and the fame ftar.

E. I underftand you very well : but, do you fay *The ftars are fixed ?*

N. I do fay fo ; and will convince you afterward that *they are.*

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

N. In the time the Moon goes round from *h* to *h* again, in the direction *h i k l h*, fhe goes quite round her orbit ; which fhe would always do between change 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 fucceeds it ; 'tis plain, that when the Earth is at *b*, and the Moon new at *m*, fhe will have gone more than round her orbit from *h* to *h* again, by the fpace *h m*. And as all circles, be they ever fo great or ever fo fmall, contains 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 fpace *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 juft 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 fecond change of the Moon from *h*, the Earth will

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 confifts of as many degrees as the part *a b c* of the Earth's orbit does.——And fo on, through the whole figure.

E. I fee all this very plainly; and that the figure in-cludes fix 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 *laft* of thefe changes, it feems (by the figure) that the Earth has not gone half way round the Sun : for the laft line of conjunction *S r g* is not quite even with the firft line of conjunction *a h S*.

N. Nor fhould it be ; for if it be rightly drawn (and I find I muft take care how I draw figures for you), it muft want $5\frac{1}{3}$ degrees of the Earth's progreffive motion in half a year. For fix courfes of the Moon, from change to change, contain only 177 days, 4 hours, 24 minutes, 18 feconds, which wants 5 days, 7 hours, 35 minutes, 42 feconds, of 182 days, 12 hours, which is the half of a common year. And, in that difference of time, the Earth moves fomewhat 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 feconds : pray in what time does the Moon go round her orbit ?

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

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

N. Twenty-nine degrees, fix minutes, twenty-five feconds. —— And here you are to underftand, that a mi-nute is the 60th part of a degree, and a fecond is the 60th part of a minute.

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

G 3 *N.* True,

N. True, *Eudosia* ; 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 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 exceeding 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 *E.* Let these lines be supposed to turn round the middle line *F M E* ; and the space *e e,* 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

would cover a larger part of its furface ; and if fhe were farther from the Earth, her fhadow would end in a point, fhort of the Earth's furface ; and then, fhe could not hide the whole body of the Sun from any part of the Earth ; and thofe who were juft under the point of the dark fhadow, would fee the edge of the Sun, like a fine luminous ring, all around the dark body of the Moon.

But, although the Moon can hide the whole body of the Sun, only from a fmall part of the Earth, at any time, when the Sun appears to be thus eclipfed by the Moon; yet, in all fuch eclipfes, the Moon hides more or lefs of the Sun from a very large portion of the Earth's furface. For,

Draw the ftraight line *A f o* from the eaftern edge of the Sun, clofe by the weftern edge of the Moon, to the Earth at *o*.———Then draw the ftraight line *B f n* from the weftern edge of the Sun, clofe by the eaftern edge of the Moon, to the Earth at *n*. Let thefe lines *(A f o* and *B f n)* be fuppofed to turn round the middle line *F M E*, and their ends *(n* and *o)* will defcribe a large circle on the Earth's furface, around *E* ; within the whole of which circle, the Sun will appear to be more or lefs eclipfed by the Moon at *M*, as the places within that circle are more or lefs diftant from its center *E*, where the dark fhadow falls. For, when the Moon is at *M*, an obferver on the Earth at *n*, will fee the eaftern edge of the Moon, juft, as it were, touching the weftern edge of the Sun at *B* ; and an obferver at *o* will fee the weftern edge of the Moon, juft, as it were, touching the eaftern 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 fhadow, all around the dark one, from *n* to *o*, on the

G 4   Earth's

Earth's furface, is called the *Penumbra*, or partial fha-
dow of the Moon.

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

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 furface, its figure thereon will be elliptical; and
then, the fpace that it covers will be much larger; e-
fpecially if the Moon be then at her leaft diftance from
the Earth.

E. What! brother: is not the Moon's diftance from
the Earth always the fame?

N. By no means: for the Moon's orbit is of an ellip-
tical (or oval) figure; and every ellipfis has two centers,
which are between the middle and the ends of its longeft
diameter: and the Earth's center is in one of the centers
(or, *as they are called*, focufes) of the Moon's elliptical
orbit.———So that, when I formerly told you, that the
Moon's diftance from the Earth's center is 240,000
miles, I only meant her *mean* (or middle) *diftance* between
her greateft and leaft diftances.

E. Then I underftand, that the Moon's diftance
from the Earth muft be continually changing.———But
fuppofing the Sun to be eclipfed when the Moon is at
her leaft diftance from the Earth; what is the diameter
of the fpot upon the Earth's furface that would be
quite covered by the Moon's dark fhadow; from all
parts of which fpot, the Sun would be totally hid by
the Moon?

N. About 180 miles.

E. As the Moon's diftance from the Earth is little
more than a 396th part of the Sun's diftance from it,
(as I have computed) I fuppofe the Moon's fhadow at the
Earth will move almoft as faft as the Moon moves in

<div align="right">her</div>

her orbit.——Pray, in what time will the dark part of the fhadow move over about 180 miles of the Earth's furface?

N. In four minutes and an half: and would go over *that* fpace fooner, if the Earth's motion round its axis (which is eaftward, and confequently the fame way that the Moon's fhadow goes over the Earth) did not keep the place on which the fhadow falls, longer in the fhadow than it would be, if the Earth had no fuch motion.

E. Then an eclipfe 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 furface move the quickeft of all. And when it falls upon any part of Britain, whofe motion is flower, becaufe it is nearer the motionlefs pole, it would be fooner over.

E. How then could the Sun be darkned fo long as three hours, at the time of our SAVIOUR's crucifixion, as it is mentioned to be in the Gofpels?

N. There is no way of accounting for *that* darknefs, upon aftronomical principles: for it was entirely out of the common courfe of nature.

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

N. Becaufe our Saviour was crucified on a full Moon day; and then, the Moon being oppofite to the Sun, could not poffibly hide the Sun from any part of the Earth.

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

N. Becaufe it was at the time of the Paffover: and the Paffover was always kept at the time of full Moon.

E. You

E. You have made this very clear.——And now, if you pleafe, I fhould be glad to have the caufe of the Moon's eclipfes explained.

N. In the fame figure, draw the ftraight line *A g c* from the eaftern edge of the Sun, clofe by the eaftern edge of the Earth at *g*; and the ftraight line *B h k* from the weftern edge of the Sun, clofe by the weftern edge of the Earth at *k*.——Let thefe two lines be fuppofed to turn round the middle line *F M m*, and they will include the fpace between the part which is filled by the Earth's fhadow *g c k h*.————'Tis plain, that when the Moon is at *m* in her orbit, fhe is totally covered by the Earth's fhadow, and eclipfed by it; as it muft then fall upon her, becaufe the Earth is between her and the Sun.

E. But how is it, that the Moon is at all vifible, when the Earth muft entirely ftop the Sun's light from falling upon her, and fhe has no light of her own? For, the fame fide of the Moon that is toward the Earth at her change, is alfo toward the Earth at her full.——— And, as we cannot fee her at the change, I fhould think we could not fee her when fhe is totally eclipfed; be-caufe *that* fide of her which is dark in the former cafe, when the Sun cannot fhine upon it, fhould be as dark in the latter, when the Earth intercepts the Sun's rays from it.————But the Moon was very vifible in her laft total eclipfe; for I faw her, and fhe appeared of a co-lour fomewhat like that of tarnifhed copper.

N. You are very fhrewd in your remarks, fifter:—— and I will tell you why the Moon is not invifible when fhe is totally eclipfed.

The air, or atmofphere, which furrounds the Earth, to the height of about 47 miles, is the caufe of this. For, all the rays of the Sun's light which pafs through the atmofphere, all around the Earth, in the boundary (*g h*) of light and darknefs, are, by the atmofphere, bent inward, toward the middle of the Earth's fhadow:

and

and thofe rays, fo mixed with the fhadow, fall upon the Moon, and do enlighten her in fome fmall degree. She reflects the rays back to the Earth which fall upon her, and fo fhe is vifible *only* on that account. For, if the Earth had no atmofphere, its fhadow would be quite dark ; and the Moon would be as invifible, when fhe is totally immerfed therein, as fhe is at the time of her change.

E. I thank you, brother, for all thefe informations ; but I ftill want more.

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

E. I fee plainly by the figure, that the Sun can never be eclipfed (in a natural way) but at the time of new Moon ; becaufe the Moon's fhadow cannot fall upon the Earth at any other time : and that the Moon can never be eclipfed but when fhe is full ; becaufe that is the only time when the Earth's fhadow 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 eclipfes ; 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 fame plane) with the Earth's orbit *C b d D*, as it is drawn on the flat paper, the Sun would be eclipfed 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-fide of the plane of the Earth's orbit, and the other half on the South-fide of it : and confequently, the Moon's orbit only croffes the Earth's orbit in two oppofite points ———When either of thefe points are between the Earth and the Sun, or nearly fo, at the time of new or full Moon, the Sun or Moon will be eclipfed accordingly. But, at all other new Moons, the Moon either paffeth above or below the Sun, as feen from the Earth : and, at all other full Moons, the

Moon

Moon either paffeth above or below the Earth's fhadow. One of thefe points is called *the Afcending Node* of the Moon's orbit ; becaufe, when the Moon has paft by it, fhe afcends northward, or to us, above the plane of the Earth's orbit ; and the oppofite point is called *the Defcending Node* of the Moon's orbit ; becaufe, as foon as fhe has paft by it, fhe defcends fouthward ; which, to us in the northern parts of the Earth, is below the plane of the Earth's orbit.

E. Suppofing that either of thefe nodes were between the Earth and the Sun juft now ; how much time would elapfe before the other could be fo ?

N. It would be juft half a year, if a line drawn from the one to the other kept always parallel to its prefent pofition (like the above-mentioned diameter of the Moon's orbit, *k h*, in *Fig.* 1.) : but the nodes move backward, or toward the Weft, contrary to the Moon's motion eaftward in her orbit, at the rate of $19\frac{1}{3}$ 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 muft be *fome* diftances from thefe nodes, within which the Sun and Moon muft be eclipfed ; I fhould be glad to know what thefe diftances are ?

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

E. Now, let me fee.———The Moon's whole orbit contains 360 degrees ; of which there are only 17 on each fide of each node, within which the Sun may be eclipfed. Twice 17 is 34, about one node, and there are as many about the other : in all, 68 degrees out of 360, for eclipfes of the Sun. And, as there are 12 degrees on each fide of each node, within which the Moon can be eclipfed ; there muft be no more than 48 degrees in all out of the whole 360, for the eclipfes of

the

the Moon. Am I right, brother? If I am, 'tis no wonder that we fhould have fo many new and full Moons, and fo few eclipfes.

N. You are quite right, *Eudofia*; and I am very glad to find that you make fuch a quick progrefs.

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

N. Yes.

E. I wifh you would teach me to do fo too, if you think I have a fufficient capacity for that branch of fcience.

N. You have much more; and I will inftruct you with pleafure; for you have not only learnt the four common rules of arithmetic, but even as far as the Rule of Three.——And, in thefe calculations, no farther arithmetic is neceffary than *addition* and *fubtraction*. But you muft learn firft to calculate the times of new and full Moons.

E. That I will do, with very great pleafure.

N. Then we will fet about it to-morrow morning, if you pleafe: but the whole will take up a week at leaft: during which time, we muft fufpend our ufual confabulations.

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

N. You remember the book which you faw, a few days ago, in this room; in which you told me you had taken notice of fomething concerning the Ecliptic and its figns.——Did you look at the title-page of that book?

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

N. It is *Fergufon's* Aftronomy. I fent for it to Mr. *Cadell's* fhop, in the Strand, oppofite Catharine-ftreet, on purpofe to make you a prefent of it. There it is;

and

and I am fure 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 breaſtfaſt, which is later than uſual to day) tell me what it is.

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

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

DIALOGUE
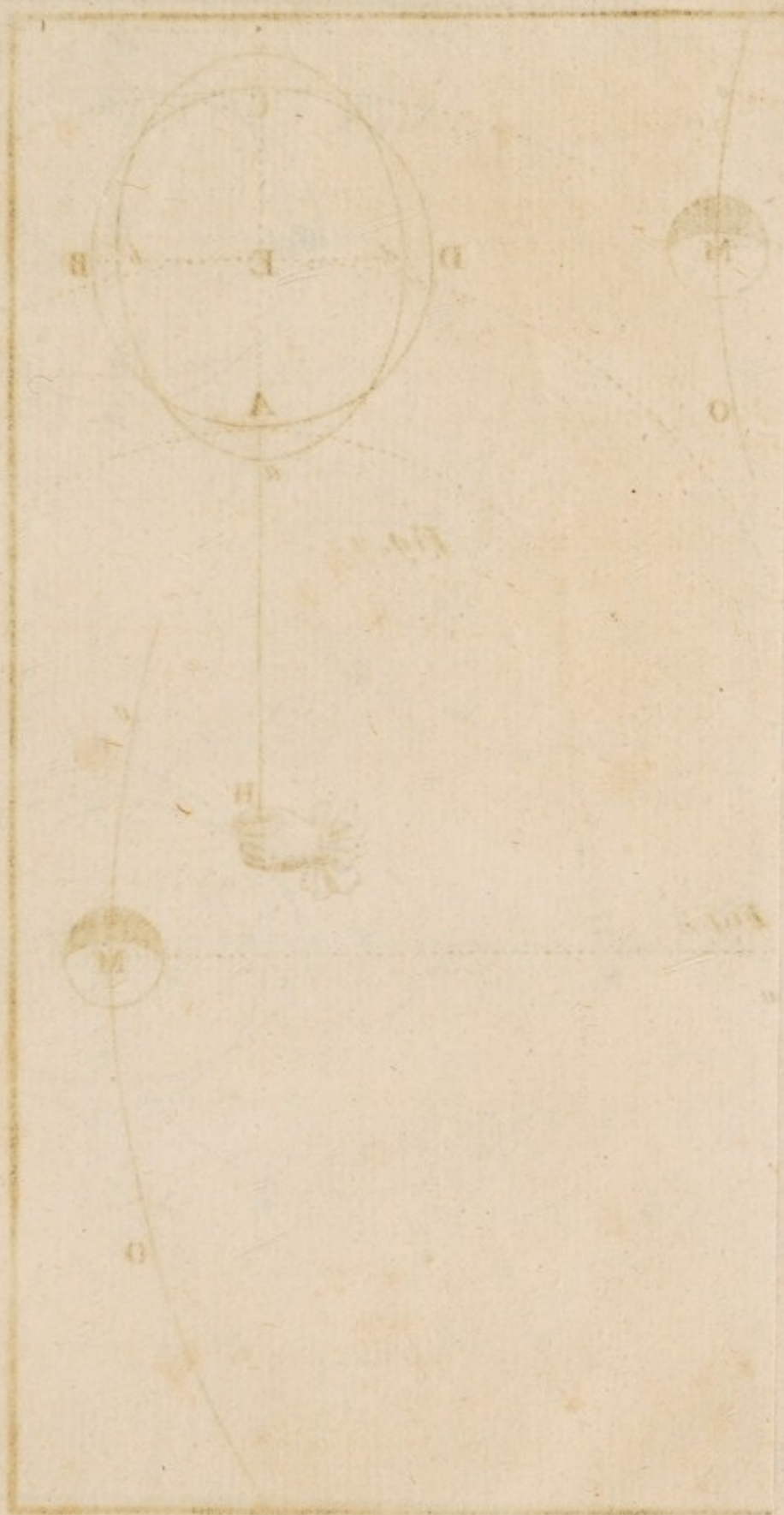
Pl. VI.
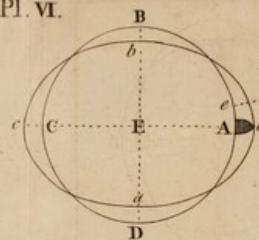
Fig. 1.

Fig. 2.
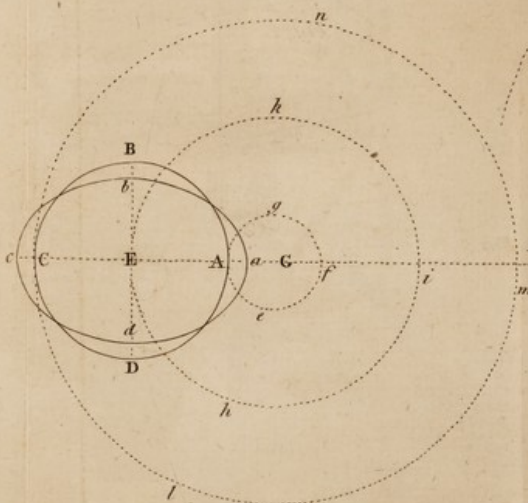
Fig. 3.

DIALOGUE VIII.

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

Neander.

YOU are very punctual, fifter.——I have drawn out fome figures for you fince breakfaft ; and, juft as you entered the room, I was putting the laft letter of reference to them. Here they are.

Eudofia. I thank you, brother ; and do fuppofe that, by thefe figures, you intend to explain the caufe of the ebbing and flowing of the Sea.

N. I do.——In *Fig.* 1. of PLATE VI. let *ABCDA* be the Earth, all covered with water except the top of an ifland *A a.* Let the Earth be in conftant motion,

turning

turning eaftward round its center *E*, every 24 hours, according to the order of the letters *A B C D* ; and let *M* be the Moon, moving eaftward in her orbit *O o*, 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, fo the Moon re-attracts the Earth.

E. Yes, Sir.

N. Do you remember my telling you, fome days ago, that the attraction diminifhes, as the fquare of the diftance from the attracting body increafes ?

E. I remember it very well.

N. Then you know, that the Moon muft attract the fide *A* of the Earth which is neareft to her (at any time) with a greater degree of force than fhe attracts the Earth's center *E* ; and that fhe attracts the center *E* with a greater degree of force than fhe attracts the fide *C* of the Earth, which is then fartheft from her.

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 fafter 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 fo ; becaufe every particle of matter attracts with an equal degree of force ; and therefore, the body which has the greater quantity of matter muft attract the other with fo much the greater degree of force.

N. Well done, *Eudofia*. Let us now fuppofe the Earth and Moon falling toward each other. The earthy parts of our globe being connected, and cohering toge-ther, would not yield to any difference of the Moon's attractive force ; but would all move equally faft toward

the

the Moon : as if a cord were tied to each end of a great folio book on the table, and you fhould pull one cord with the force of four pounds, and I pull the other cord the fame way with the force of eight pounds, fo as to move the book ; all the parts of it will move equally faft, notwithftanding 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 fmall : and therefore, they will be differently affected, according to the different degrees of the Moon's attractive force, at different diftances 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 fafter toward the Moon than the Earth's center does ; and confequently, with refpect to the Earth's center, they rife higher toward the Moon, as from A to a : and as the center E moves fafter toward the Moon than the waters on its furface at C do ; the waters at C will be, as it were, left behind : and confequently, with refpect to the center E, they will be raifed, as from C to c.

E. So far, I underftand you perfectly well.

N. But as there is ftill the fame quantity of water on the whole Earth, the waters cannot rife at one place without falling at another.———And therefore, the waters muft fall as low at b and d as they rife, at the fame time, at a and c : fo that an obferver placed over E, at a diftance from the Earth, would fee the furface of the waters not of the round fhape $ABCD$, as they would be if the Moon did not difturb them by her attraction, but of the elliptical fhape a b c d.

Then, as the Earth turns eaftward round its axis, 'tis plain, that when the ifland 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*, fix hours from under the Moon : when it is at C, it will be in the *high water* again,

H twelve

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 orbit *O o*, but kept always in the ſame right line *A M*, the iſland *A a* would have two ebbings 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 *Eudoſia :*———for, in the time of the iſland's revolving from *A* to *A* again (in the direction *ABCDA*) 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 muſt move on from *A* to *e*, 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 *e ?*

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 compleat days and nights in going round from change to change. But as the time is only 29 days, 12 hours, 44 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, 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, 6 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 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

H 2

round

round the Sun in a year, if the Earth had no Moon to attend it.

E. You may thank yourfelf, *Neander,* for all thofe inferences and applications ; as they only refult from your explanations, and leading me fo gradually on, from one fubject 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* diftance, compared with the Moon's diftance from the Earth's center, muft be in proportion to the quantity of matter in the 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 diftance from the Earth's center is 240,000 miles.——Now, I divide 240,000 by 40, and the quotient is 6000 ; which I think, muft be the diftance of the common center of gravity between the Earth and Moon, from the Earth's center : and, that the faid common center of gravity muft always be in a right line between the centers of the Earth and Moon ; becaufe both thefe 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 illuftrate this affair 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 juftly believed that I was mifleading you.

Here

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

E. True ; ——— and juft like the fhape of the furface *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 fhape *ABCD.*

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

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

E. Yes ; for they would run from the higheft parts *a* and *c* to the loweft parts *b* and *d*, till their furface was equally diftant from the Earth's center *E*, all a-round.

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

E. Why ; the hoop will endeavour to fly off, as a pebble in a fling 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 confider.———I think they will not. For as the part *C* will go round your head in the fame time as the part *A*, but fafter, becaufe it is further diftant 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 diftance from your hand is greater.

N. Exactly fo, becaufe it will move fo much fafter, as the circle it defcribes is larger. Now obferve, I whirl it round my head. What fhape is it *now* of ?

E. It

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

N. Yes, for the tightnefs of the ftring draws out the fide next my hand, from *A* to *a*; and the centrifugal force of the other fide throws it out as far, from *C* to *c.* And now, if an inflexible circular ring (like the rigid Earth) *A B C D* fhould lie upon the elliptical hoop *a b c d,* and turn 29 times and a 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 fucceffively even with the higheft parts *a* and *c* of the elliptical hoop, and with the loweft parts *b* and *d* of it; as the Ifland *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 fomewhat analogous to *Fig.* 2.

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

Let *A B C D* be the Earth, *M* the Moon, *O o* the Moon's orbit, and *G* the common center of gravity between the Earth and the Moon, round which both thefe 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 diftance from the common center of gravity *G*; becaufe the fpaces through which thefe parts move, will be refpectively as their diftance from *G*; that is, as the femidiameters of thofe circles which they all defcribe in the fame 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* defcribes the fmall circle *A e f G A* in the time the point *E* defcribes the larger circle

E h i

$E h i k$, and in the time the point C defcribes the ftill 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 confequently retains the center E in the orbit $E h i k E$. But her attraction at A is greater than E, and lefs at C than at E. So that where the Moon's attraction is greateft, as at A, the centrifugal force is leaft: and therefore, the excefs of attraction caufeth the waters to rife, as from A to a, on the fide of the Earth which is at any time neareft the Moon M. But, at C (the fide which is then fartheft from the Moon) the attraction is leaft, and the centrifugal force greateft: and therefore, the waters will rife as high from C to c, by the excefs of the centrifugal force there, as they rife on the oppofite fide from A to a by the excefs of the Moon's attraction. Are you fatisfied now, *Eudofia?*

E. I was fadly afraid, that the rifing of the tides on the fide 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 juft as plain, that they muft rife as high on the fide of the Earth which is oppofite to the Moon, as they do on the fide which is under the Moon. Did you ever fee this confirmed by an experiment?

N. Yes; I have feen Mr. *Fergufon* do it, to the fatisfaction of every obferver, by a plain experiment in one of his machines, called the *Whirling Table*; and he is the firft that ever did fo. He has given a full account of it in his Lectures on *Mechanics, Hydroftatics, Pneumatics, Optics,* with *the Ufe of the Globes,* and *the Art of Dialing.* In that book, there are plates of all his machines for the above purpofes. I fhall fend for it from Mr. *Cadell's* fhop to-morrow, and make you a prefent of it, on account of the quick progrefs you have

made

made in aftronomy: and then you can by yourfelf, learn a courfe of experimental philofophy.

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

N. The Earth is fo fmall, in comparifon of its diftance 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 fide of it which is next the Sun, and the centrifugal force on the oppofite fide. But ftill there is fome difference, as the Earth moves on its orbit. And therefore, if the Earth had no Moon to attend it, there would be *fmall tides* occafioned by the Sun. Confequently, 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 fo, raife the tides higher at thefe times than at any other: and this is called the *Spring Tides.* But, when the Moon is in her quarters, her action on the tides is *crofs-wife* to the Sun's; for then the Sun is in a line with the *low-water*, and his action keeps the tide from falling fo low there, and confequently from rifing fo high under and oppofite to the Moon, as they would do by the action of the Moon, if the Sun did not difturb them at all; and this is called *the neap Tides.*

E. I underftand you very well; and do fee plainly, that a ftraight line drawn from the Moon's center through the Earth's center, would be in the higheft part of the tides on both fides of the Earth.

N. You are a little miftaken in that point, *Eudofia*; which may be owing to its being fo reprefented in the figures. But, I am fure you would not have been fo,

if

if you had remembred what I told you in our firſt Dia-
logue ; namely, that all bodies which are put into a
ſtate of motion will perſevere in that motion, till ſome-
thing ſtops their courſe. If you put water into a baſon,
and give it a little ſhake, and then ſettle the baſon ſud-
denly ; the water will riſe a little further, on the ſide
to which you gave it the motion, after the baſon is ſet-
tled 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 meri-
dian : and this continuance of attraction, tho' 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 re-
gularly 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

and corners of the land run out all manner of ways into the oceans and feas: the regular courfe of the tides is much interrupted thereby; and alfo by their running through fhoals and channels. So that, at different places, the tides are higheft at very different diftances of the Moon from the meridian. But, at whatever diftance the Moon is from the meridian, on any given day, *at any place*, when the tide is at its height *there*; it will be fo again on the next day, much about the time when the Moon is at the like diftance from the meridian again.

E. You have quite fatisfied me about the tides: and now I will go to my room, and ftudy *Fergufon's* method of calculating the times of new and full Moons.
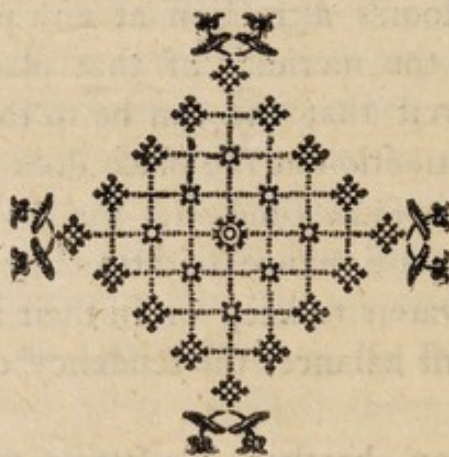
DIALOGUE IX.

On the fixed STARS, and SOLAR and SYDEREAL TIME.

Neander.

WHAT is the matter, sister? —— Surely you could not have gone to your room and returned, since you left me.

Eudosia. 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 least I should forget it again, I now beg leave to re-mind you of it, if you have leisure at present.

N. For *that,* I refer you to *Ferguson*'s astronomy: and, before you have read the first three chapters, you

will

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 Sun's, 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 *Sydereal 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 Sydereal time is the time 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 of 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

apy

any given Star is on the meridian; the latter clock would gain 3 minutes 55 feconds and 54 fixtieth parts of a fecond upon the former, in each revolution of the fame Star to the meridian.

E. What is the reafon of *this* ?

N. Much the fame as *that* of the Moon's going round her orbit in lefs time than fhe goes round from change to change, or from between the Earth and the Sun to the fame pofition again : as I explained to you, by *Fig.* 1. of PLATE V. laft Monday morning, in our Seventh Dialogue : and we may make the fame figure do for the prefent fubject. You remember I told you that the whole diameter of the Earth's orbit is but as a point, in comparifon to the diftance of the Stars ; which is the fame as to fay, that a globe of 190 millions of miles in diameter, which would fill the Earth's orbit, would appear no bigger than a dimenfionlefs point, if it were feen from any of the Stars : and the prefent fubject will prove this to be true.

E. I am far from doubting the truth of your word; but I fhould be very glad to fee the demonftration.

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 beft 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 fenfible proportion to the diftance of the Stars. For then, if the hour and minute-hands of a clock fhould revolve exactly 366 times from XII to XII again (there being fuppofed 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 fet to the uppermoft XII, when any given Star is on the meridian on the 21ft of December ; then, on the 20th of March afterward, when the hands were

at the fame XII as before, the fame Star would be a
little on the Eaft fide of the meridian, if the Earth's
orbit were of any fenfible bignefs in proportion to the
diftance of the Star; and a little on the Weft fide
of the meridian, when the hands were at XII on the
23d of September: but we never find any fuch dif-
ference.

E. To me, your demonftration is felf-evident.

N. Then, you are convinced, that when the meri-
dian of any place has revolved from any Star to the fame
Star again, the Earth hath turned *abfolutely* once round its
axis; becaufe the fame meridian has revolved fo, as to be
again parallel to any fixed plane, to which it was pa-
rallel before, when the fame Star was upon it.

E. I am.

N. Very well, fifter:———now, in *Fig.* 1. of PLATE
V. let *S* be the Sun, *ABCDEFG* 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 fhall fuppofe to be at *h.*

Let the ftraight line *a h S* be produced onward, to
five or fix miles beyond the Sun, as feen from *h*; and
let a Star be placed at the farthermoft end of that line.
———Then, the diftance of the Star from the Sun *S*
will be fo great, that the Earth's orbit *A B C*, &c. will
bear no fenfible proportion thereto, if it were viewed
from the Star; and therefore, to an obferver 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 pofition 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 fame parallel
pofition again: which it will always do in the time of the
Earth's turning *abfolutely* round its axis.

E. Undoubtedly

E. Undoubtedly it will.

N. Now, fuppofe the Earth to advance in its orbit from *a* to *b*, in the time that it turns once round its axis; and then, the *fame* meridian *b h* will be parallel to the pofition it had at *a h*, when the Sun and Star were *both* even with it; or, as we fay, 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 muft 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 fame proportion to the Earth's whole circumference, that the arc, or part *a b*, of the circumference of the Earth's orbit bears to *its* whole circumference.

When the Earth is at *c* in its orbit, and the fame meridian *c h* comes even with the Star the fecond time, the meridian muft revolve from *h* to *n* before it can be even with the Sun again, or the Sun be upon it the fecond 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 fix hours of being even with the Sun in the right line *d o S*, and the place *h* muft revolve 6 hours, or through the arc *h o* of 90 degrees, before the Sun can be on its meridian *d h*.

And confequently, when the Earth has gone half round its orbit, the fame meridian will be even with the Star twelve 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 laftly, when the Earth has gone quite round its orbit, its rotation on its axis will have brought the fame meridian once more round from the Star to the Star again, than from the Sun to the Sun again.————So that,

let the year contain how many days it will, as mea-
sured 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 num-
ber of solar days in the year, because the Earth's mo-
tion on its axis is the same way as its 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, *Eudosia.* —— 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

DIALOGUE X.

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

Neander.

WELL, 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 was 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.

Eudosia. 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?

I   *E.* After

E. After looking a little at *Fergufon*'s tables for calculating the true times of new and full Moons, and finding fome expreffions in the titles of the tables which I did not underftand, 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 *thefe terms* explained to my fatisfaction ; but alfo the *principles* on which the tables are conftructed : and, on account of what you have already told me about the attractions of the Sun, Moon, and Earth, I think I underftand the principles tolerably well.

N. I can very eafily take your word for that, *Eudofia*.

E. Having read the *precepts*, and compared them with the tables and *examples* of *calculation*, I then tried to calculate the true times of fome new and full Moons which are exemplified in the precepts ; and finding my calculations to agree very nearly with *Fergufon*'s examples, I tried to calculate the true time of new Moon in July 1748, old ftile, as you defired me ; of which Mr. *Fergufon* has given no example.——And finding that the Sun muft have been eclipfed at the time of *that* new Moon, I even *attempted* to take out the *elements* for projecting that eclipfe.

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

E. I am almoft 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 femi-diameter of the Earth's difc at that time, as feen from the Moon -	0	53	32
3. The angle of the Moon's vifible path with the ecliptic — —	5	35	0
4. The Moon's latitude, North defcending	0	28	6
5. The Moon's horary motion from the Sun	0	27	17
6. The Sun's diftance from the neareft folftice — — —	32	42	40
7. The Sun's declination, North —	19	35	21
8. The Sun's diftance at noon from the vertex of London — — —	31	54	39
9. The Sun's femidiameter — —	0	15	50
10. The Moon's femidiameter — —	0	14	53
11. The femidiameter of the penumbra -	0	30	43

N. Well done, *Eudofia.*——I calculated the fame elements before I gave you the book ; and now we will compare the calculations together.———All right ;——for, do you fee,——we have not differed three feconds in any part.———And I did not tell you till now, that I had made any fuch calculation.

E. This gives me great pleafure, indeed.———But, upon reading the method of projecting eclipfes, I often find mention made of a *Sector* ; which I take to be a mathematical inftrument ; and, as you know that I am entirely unacquainted with any of thefe inftruments, I am afraid I can proceed no further, unlefs you will fhew me a Sector, and teach me how to ufe it.

N. It is true, that by means of a Sector, thefe kinds of projections may be much fooner made than without it.———But, as I know you are yet totally unacquainted

with

with mathematical inftruments, I will now fhew you how to project an eclipfe of the Sun, only by means of a pair of compaffes and a common ruler : And then, you will be at no lofs about projecting any eclipfe of the Moon , which is much eafier to be done than to project an eclipfe of the Sun.——I will firft tell you fome things, by which you will underftand the reafon why all the different parts of the conftruction of a folar eclipfe muft be as we lay them down ; and then proceed to con-ftruct the Sun's eclipfe which fell on the 14th of July, 1748, as it appeared at London. You know, it is but a few days fince you covered one of the panes of glafs in the window of your room with gum water ; and, when it was dry, you placed yourfelf about a foot from the glafs ; and, keeping your head fteady, you delineated a land-fkip on the glafs, with your black lead pencil, of all the diftant objects which you faw through the glafs, drawing them on thofe parts of the glafs which were juft between them and your eye ; as if the pencil had touched the objects themfelves.

E. I have often done fo : then drawn them with ink (which the gum water caufes to ftick) and then laid a paper 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 thofe things would be vifible to an ob-ferver at the Sun ; and fuppofe yourfelf to be there, holding a pane of glafs between you and the Earth, and
<div align="right">delineating</div>

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 would fee 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 eclipfeth the Sun from any part of the Earth, you would fee her between you and the Earth, as paffing over it from left to right hand, the fame way as it turns on its axis : and you would fee a great part of the Moon's penumbra or partial fhadow, all around her, (as it were) like a dark brownifh ring, travelling with her over the Earth.

As the Sun fhines round the North pole of the Earth, from the 20th of March to the 23d of September, you would fee *that* pole all the while in the enlightened part of the Earth's difc (or flat round furface, as it would appear to you; like as the Sun and Moon do to us) : and, from the 23d of September to the 20th of March, the fame pole would be hid from your eye-fight, behind the vifible and illuminated difc of the Earth ; becaufe it is in the dark all that time.

If a ftraight walking-ftick be placed at a diftance 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 fo. 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 lefs fidewife 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

the fouthern half to incline the contrary way from the axis of the ecliptic : for then, thefe two axes will feem to crofs each other in the middle point of the Earth's axis.

Now, as the Earth's axis really inclines 23½ degrees from a perpendicular to the plane of the Earth's orbit, and always keeps inclining to one and the fame fide of the Heavens, in the Earth's whole courfe round the Sun ; it will appear in different pofitions of inclination to the axis of the ecliptic, as feen from the Sun, at different times of the year ; the North pole being fometimes toward your right hand from the axis of the ecliptic, and at other times toward your left hand from the axis of the ecliptic ; conftantly varying the apparent angle of its inclination, according to the time of the year.

From the 21ft of December to the 21ft of June, the North pole of the Earth's axis lies toward the right hand from the axis of the ecliptic, as feen from the Sun : and moft of all fo on the 20th of March. From the 21ft of June to the 21ft of December, the North pole of the Earth's axis lies more or lefs to the left hand, as feen from the Sun ; and moft of all fo on the 23d of September.

E. I wifh you would be fo good as to write down thefe matters for me, when you are at leifure ; becaufe I am afraid I fhall forget them.

N. You may depend upon it that I will ; efpecially as they are the very principles on which we are now about to conftruct an eclipfe of the Sun : which is, in the firft place, by delineating a figure of the Earth, with its axis, Equator, &c. according to their pofitions as fuppofed to be feen from the Sun (or from the Moon juft between the Earth and the Sun) at the time of the eclipfe. Now, we will go to work, according to your calculated elements.
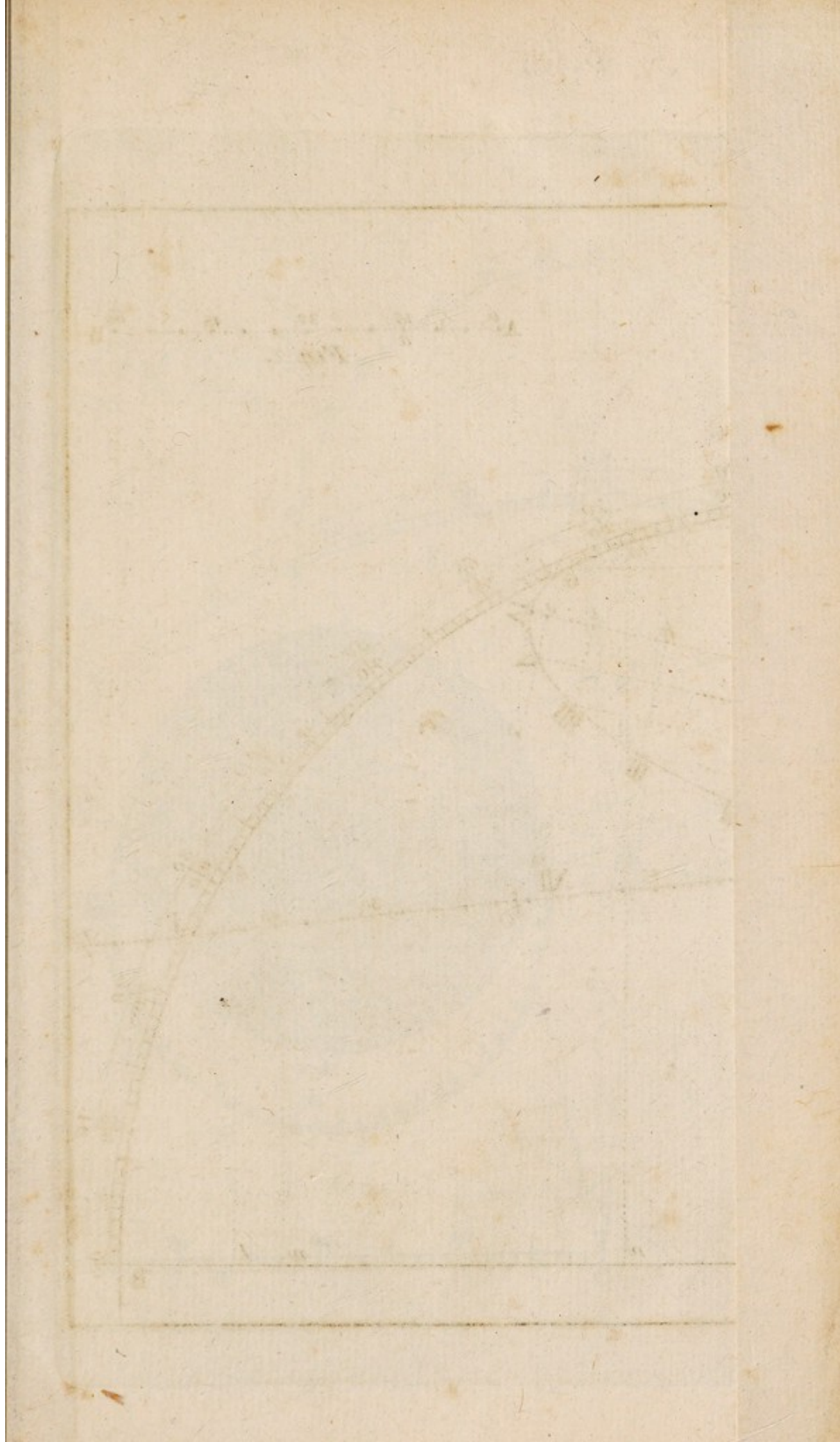
Pl. VII.

A Projection of the Sun's Eclipse observed
at London, July 14. 1748. Old Stile.

Fig. 1.

Fig. 2.
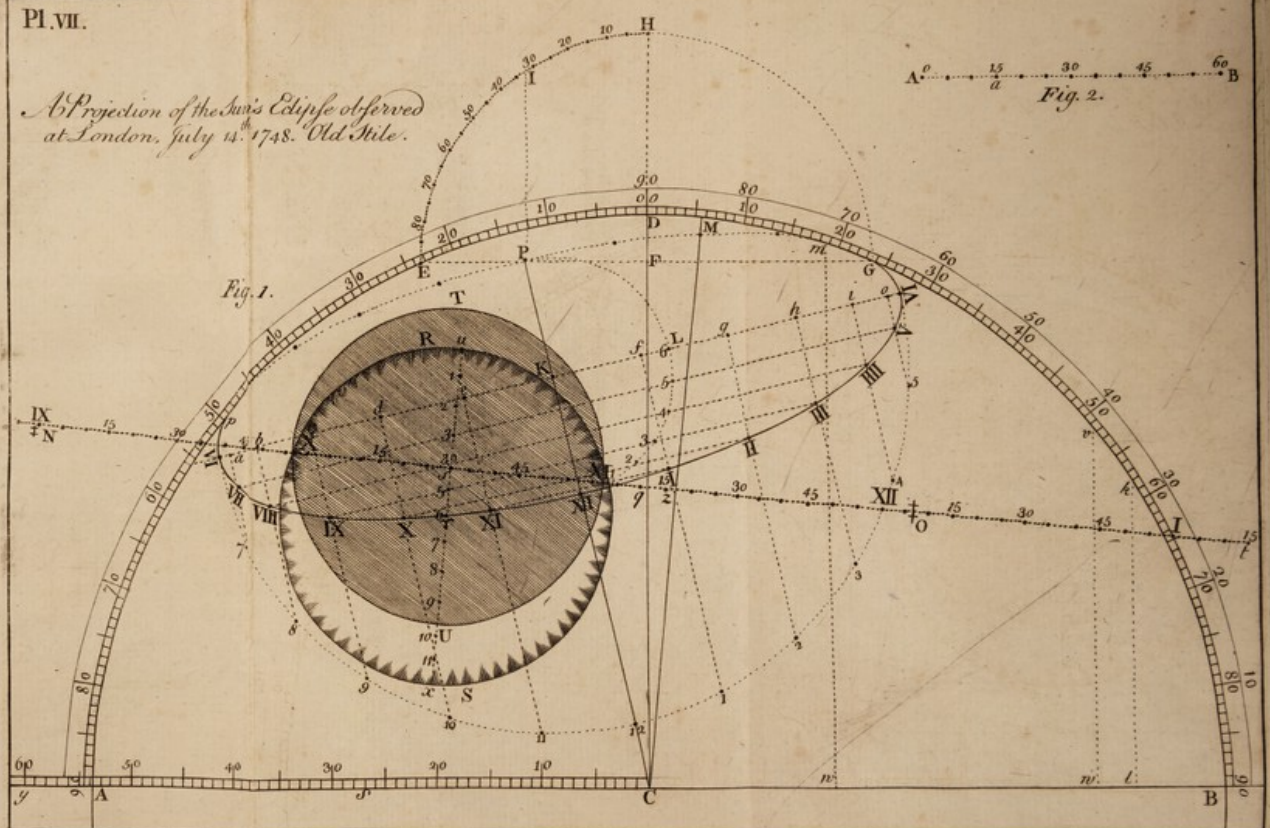
Make a scale, as *y A C* (PLATE VII. *Fig.* 1.) almost half the length of the paper intended for your projection, and divide it into 60 equal parts at least, reckoning each part to be one minute, or a sixtieth part of a degree.——Then, take the semidiameter of the Earth's disc. 53 minutes 32 seconds (or 53½) 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 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 C B* shall be a portion of the Ecliptic equal to the diameter of the Earth as seen from the 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 23½ 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 *CDH* ; 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 July. —— If the Earth's 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 IP, parallel to HD, from $32\frac{2}{3}$ degrees of the quadrant HE, till it meets the line EFG at P: then, from P to C, draw the right line PC; so PC 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, 19 degrees 35 minutes neglecting the 21 seconds) from the Latitude of London, 51 degrees 30 minutes, and the remainder will be 31 degrees 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 ADB) at 31 degrees 55 minutes counted upward from B, draw the right line kl, parallel to CD: and taking the extent kl in your compasses, set it from C to XII on the Earth's axis CP. 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 14th of July 1748.

Add the Sun's declination, $19° 35'$, to the Latitude of London $51° 30'$, 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 $71° 5'$, counted upward in the right hand side of the semicircle ADB from B to m, draw the right line mn parallel to CD. Then, taking the extent mn in your compasses, set it from C towards or beyond P on the Earth's axis CP, as it happens to reach short of P or beyond it : but in the present case, it reaches so little above P, that we may reckon CP to be its whole extent :

and

and fo, the point *P* fhall reprefent the place or fituation of London at midnight, beyond the illuminated part of the Earth's difc, as feen from the Sun; and confequently 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° 30′ from 90″ 00′; and there will remain 38½ for its Co-latitude.——Then, from 38°½, counted upward from *B* to *v* in the femicircle *A D B*, draw the right line *v w*; and, having taken its length in your compaffes, fet 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 difc, as feen from the Sun, from the time of Sun-rife till the time of fun-fet at London; proceed as follows.

The compaffes being opened from *K* to VI, fet one foot in *K*, and with the other foot defcribe 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 defcribe the femicircle *P L* 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 3 IV, and VII 5 V, all parallel to the right line VI *K* VI; and, through the points where thefe lines meet the

<div align="right">former</div>

former parallel lines 7*a*, 8*b*, 9*c*, 10*d*, &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. This curve shall represent the parallel of Latitude of London, or the path which London (by the Earth's motion on its axis) appears to discribe 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 7*a*, 8*b*, 9*c*, &c. till they meet the foresaid parallel lines drawn through the division-points of the quadrant *P L*.——The points *p* and *G*, where the elliptical curve touch 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 from *r* to *C*, on the left hand side from the axis of the Ecliptic.

Take

Take the Moon's Latitude, 28′ 6′, from *C* to *s*, with your compaffes, in the fcale *A C*, and fet 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 Moon's orbit *C z M:* and *N q O t* fhall be the path of the center of the Moon's fhadow over the Earth; and will reprefent as much of the Moon's orbit, feen from the Sun, as fhe moves through, during the time that her fhadow or penumbra is going over the Earth.

From *C*, on the fcale *A C*, take the Moon's horary motion from the Sun, 27′ 17″, in your compaffes; and make the line *A B (Fig.* 2.) equal in length to *that* extent: and divide the faid line into 60 equal parts, for fo many minutes of time.———Then, as the time of new Moon, on the 14th of July 1748, was at 15 minutes 3 feconds after **XI** o'clock, take 15 minutes (neglecting the three feconds) from *A* to *a* on the line *A B* in your compaffes, and fet them off, in *Fig.* 1. from the *middle point* between *q* and *z*, in the right line *N q z O*, to XI in that line; becaufe the tabular time of new Moon is mid-way between the point *q*, where the axis *C D* of the Ecliptic and the axis *C M* of the Moon's orbit cuts the line or path of the penumbra's center on the Earth.

Take the whole length of the line *A B (Fig.* 2.) in your compaffes; and, with that extent, make marks along the line *N O (Fig.* 1.) both ways from XI; and fet the hour-letters to thefe marks, as in the figure. — Then, divide each fpace, from mark to mark, into fixty equal parts or horary minutes, which fhall fhew the points of the Earth's difc where the center of the penumbra falls, at every hour and minute, during its tranfit over the Earth.

Apply one fide of the fquare to the line of the penumbra's path *NO*, and move the fquare forward or backward till the other fide cuts the fame hour and mi-

nute,

nute, as at *s* and *r*, both in the path of the penumbra's center and the path of London : and the *minute*, which the fquare cuts at the fame inftant in both thefe paths, is the *inftant* of the vifible conjunction of the Sun and Moon at London; and confequently, of the greateft obfcuration of the Sun by the Moon ; which, according to the projection, is at 30 minutes paft X o'clock in the morning.

Take the Sun's femidiameter, 15′ 50″, in your compaffes from the fcale ; and fetting one foot at *r* as a center, in the path of London ; with the other foot defcribe the circle *R S* for the Sun, as feen from London at the time of the greateft obfcuration. Then, take the Moon's femidiameter, 14′ 53″, in your compaffes from the fcale ; and fetting one foot in the Moon's path at *s*, with the other foot defcribe the circle *T U* for the Moon, as feen from London, when fhe obfcures moft of all of the Sun, during the eclipfe ; which may be meafured by a diameter line *u s r x*, drawn acrofs 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 prefent projection, there are $9\frac{2}{3}$ digits eclipfed.

Take the femidiameter of the penumbra, 30′, 43″, from the fcale in your compaffes ; and, fetting one foot in the path of the 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 compaffes fall into the fame inftant at both the paths ; which inftant will denote the time when the eclipfe began at London. Then, do the like among the afternoon hours ; and where the point of the compaffes fall into the fame inftants in both the paths, they will fhew at what time the eclipfe ended at London.———Thefe trials fhew that the beginning of the eclipfe was juft at IX o'clock in the morning, and

its ending at 7 minutes after XII o'clock at noon; as the compaffes reach juft 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 laft, finifhed the projection, and found what was wanted to be known from it.

E. The whole procefs is very pleafant, but, I think, it is fomewhat tedious.

N. That is, becaufe we have been obliged to divide the femicircle *A D B* and the quadrant *E H* with a pair of compaffes.————If the Sector had been ufed, the labour would have been much fhortened, becaufe we could have taken off all the meafures directly from it; and fo, have avoided all the trouble of dividing, not only of the femicircle and quadrant, but alfo even of the fcale.

E. I wifh you would teach me how to ufe the Sector.

N. I will fend to my mathematical inftrument-maker, Mr. *Bennet,* in Crown Court, near St. Ann's Church, Soho, for a compleat cafe of mathematical inftruments, and will make you a prefent of it, and inftruct you how to ufe them before I leave this place, In the mean time, I will afk you a few queftions relative to the fubjects we have been upon: and, if you can anfwer them cleverly, I fhall not fcruple to tell you, that you have made a very extraordinary progrefs.

E. I thank you, Sir, for your intended prefent and future inftructions: and will anfwer your queftions as well as I can *.

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* The fubject of what is here put down, by way of queftion and anfwer, was given by the author fome time ago to a gentleman who has fince publifhed it, not without the author's leave, at the end of a printed book.

N. What would be the confequence, if the Earth were fixed in any point of its orbit, fo as to have no progreffive motion therein ; and to turn round its axis with its prefent velocity, having its axis perpendicular to the plane of the Ecliptic ?

E. The folar , or natural day would be of the fame length with the fydereal day ; which is equal to 23 hours 56 minutes 4 feconds of the time now mea-fured by a well regulated clock. The Sun would con-ftantly 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 them. And confe-quently, there would be no different feafons.

N. What would be the confequence, if the Moon's diftance from the Earth was fuch, as that fhe fhould appear to be of the fame magnitude with the Sun ; that her orbit were circular, and lay in the plane of the Ecliptic ; and that fhe moved round the Earth in her orbit with her prefent velocity ?

E. The Moon would always revolve in the plane of the Equator ; and (fuppofing the Earth had no pro-greffive motion in its orbit) the Moon would go round from change to change in the time fhe now goes round her orbit, which is, in 27 days 7 hours 43 minutes 5 feconds. The diameters of the Sun and Moon would always appear to be equal. The Moon would eclipfe the Sun totally, for an inftant of time, at all thofe places over which the center of her fhadow paffed, which would be directly along the Equator. The eclipfes would be only partial on different fides of the Equator, and never vifible at more than 2350 miles from it. The Moon would be totally eclipfed in the Earth's fhadow at every time fhe was full ; and the durations of all her eclipfes would be equal.

N. What would be the confequence, if the Moon's orbit acquired an elliptical form, fuch as it is now of: that it continued in the plane of the Ecliptic, and the Earth had no progreffive motion, but only turned round its axis as before?

E. The lengths of days and nights would be the fame as above, and the times between the new or full Moons would remain the fame. The Sun would be eclipfed (as above) at every change, and the Moon at every full; and the center of the Moon's fhadow, when the Moon is new, would always pafs along the Equator. If the changes fell in that part of the Moon's orbit which is furtheft from the Earth, the Sun would never be totally eclipfed; but would appear like a fine luminous ring all around the dark body of the Moon, at thefe places on the Equator where the Moon were directly over head at the inftant of the change. If the changes fell in that part of the Moon's orbit which is neareft the Earth, all the eclipfes 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 thofe parts which are at the greateft and leaft diftance from the Earth, the eclipfes of the Sun would be juft total for an inftant of time at the Equator, and no where elfe. All the Moon's eclipfes would be total with continuance, as above.

N. Suppofe now, that the Earth fhould revolve about the Sun, with its prefent velocity, in the plane of the Ecliptic, its axis keeping always perpendicular thereto: that the Moon fhould revolve as above, with her prefent velocity; and that her orbit fhould remain always in the plane of the Ecliptic?

E. In that cafe, the days and nights would always continue (as above) of equal length; only the 24 folar hours would be 3 minutes 56 feconds longer than the

24 fydereal hours, as they now are ; but there would be no different feafons. The Moon would go round her orbit in 27 days 7 hours 43 minutes 5 feconds ; and round from the Sun to the Sun again, or from change to change, in 29 days 12 hours 44 minutes 3 feconds ; as fhe now does. The Sun would be eclipfed (as above) at every change, and the Moon at every full ; and all the Sun's eclipfes would be central only at the Equator ; but they would fometimes be total there for four minutes, fometimes total only for an inftant, and at other times annular ; according to the diftance of the Moon from the Earth in different parts of her elliptical orbit at thefe times.

N. With the above circumftances, relating to the Earth's progeffive motion in its orbit, and the Moon's motion in her orbit ; what would be the confequence if the Earth's axis fhould become inclined to the Ecliptic, as it now is ; and the earth turn round its axis with its prefent velocity ?

E. We fhould then have all the variety of feafons we now enjoy. The times between the new and full Moons would be the fame as in the laft anfwer above, and the eclipfes of the Sun and Moon the fame. Only, the Sun's central eclipfes would not fall always at the Equator, but fometimes on one fide of it, and fometimes on the other ; that is, between the Equator and *that* pole of the Earth which was inclining toward the Sun at the time of the eclipfe.———In our Spring, the center of the Moon's fhadow would go obliquely over the Earth, from the fouthern tropic to the northern.——— In fummer, the fhadow would begin to take the Earth at the Equator, and thence bend its courfe 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 fhadow would go obliquely over the Earth, from the northern tropic to the

<div align="right">fouthern :</div>

fouthern :——— and, in winter, it would take the Earth at the Equator, from which it would bend its courfe to the fouthern tropic, and go on obliquely from that tropic to the Equator, where it would leave the Earth. And, in each of thefe four cafes, the Sun's eclipfe would be central to all the parts of the Earth over which the center of the Moon's fhadow paffed ; fometimes total only for an inftant, fometimes total for four minutes, and at other times only annular.———The eclipfes of the Moon would be as above.

N. Suppofing now, that the Moon's orbit fhould become inclined to the Ecliptic, as it is at prefent, but that her nodes fhould have no motion therein ; and every other circumftance fhould remain as in the laft queftion ?

E. Then, the Sun would never be eclipfed at more than 17 degrees from either of the nodes, at the time of any new Moon whatever ; nor would the Moon be eclipfed at more than 12 degrees from either of the nodes at any time whatever of being full. So that we fhould have but few eclipfes (as is now the cafe) in comparifon of the number of our new and full Moons. And the eclipfes would be confined to the fame feafons of the year ; for there would be half a year between thofe which happened about one node and about the other, becaufe there would be juft half a year between the conjunctions of the Sun with one node and with the other.

N. Every thing remaining as above, excepting the ftability of the nodes, and of thofe two points of the Moon's orbit which are moft and leaft diftant from the Earth : What would be the confequence if thefe 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, *Eudoſia !*——You have anſwered all my queſtions to my mind : 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 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.

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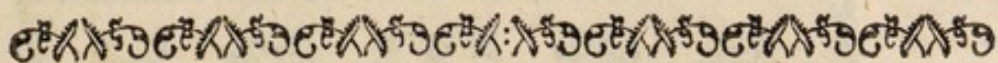
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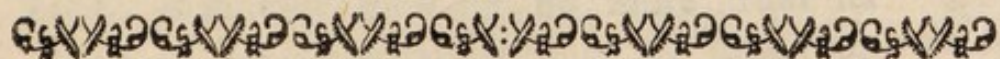
GLOBES,

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ARMILLARY SPHERE.

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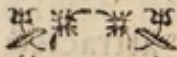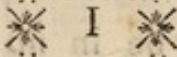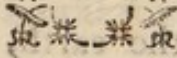
DESCRIPTION AND USE

OF THE

GLOBES, &c.

The description and use of the globes, and armillary sphere.

F a map of the world be accurately delineated on a spherical ball, the surface thereof will reprefent the furface of the earth : for the highest hills are fo inconfiderable with refpect to the bulk of the earth, that they take off no more from its roundnefs, than grains of fand do from the roundnefs 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 per-pendicular height.

K 3   That

Proof of the earth's being globular. That the earth is fpherical, or round like a globe, appears, 1. from its cafting a round fhadow upon the moon, whatever fide be turned towards her when fhe is eclipfed. 2. From its having been failed round by feveral perfons. 3. From our feeing the farther, the higher we ftand. 4. From our feeing the mafts of a fhip, whilft the hull is hid by the convexity of the water.

And that it may be peopled on all fides without any one's being in danger of falling away from it. The attractive power of the earth draws all terreftrial bodies towards its center ; as is evident from the defcent of bodies in lines perpendicular to the earth's furface, at the places whereon they fall ; even when they are thrown off from the earth on oppofite fides, and confequently, in oppofite directions. So that the earth may be compared to a great magnet rolled in filings of fteel, which attracts and keeps them equally faft to its furface on all fides. Hence, as all terreftrial bodies are attracted toward the earth's center, they can be in no danger of falling from any fide of the earth, more than from any other.

Up and down, what. The heaven or fky furrounds the whole earth ; and when we fpeak of *up* or *down*, we mean only with regard to ourfelves ; for no point, either in the heaven, or on the furface of the earth, is *above* or *below*, but only with refpect to ourfelves. And let us be upon what part of

the

the earth we will, we ftand with our feet toward its center, and our heads toward the fky : and fo we fay, it is *up* toward the fky, and *down* toward the center of the earth.

To an obferver placed any where in the indefinite fpace, where there is nothing to limit his view, all remote objects appear equally diftant from him ; and feem to be placed in a vaft concave fphere, of which his eye is the center. Every aftronomer can demonftrate, that the moon is much nearer to us than the fun is ; that fome of the planets are fometimes nearer to us, and fometimes farther from us, than the fun ; that others of them never come fo near us as the fun always is ; that the remoteft planet in our fyftem, is beyond comparifon nearer to us than any of the fixed ftars are ; and that it is highly probable fome ftars are, in a manner, infinitely more diftant from us than others. And yet all thefe celeftial objects appear equally diftant from us. Therefore, if we imagine a large hollow fphere of glafs to have as many bright ftuds fixed to its infide, as there are ftars vifible in the heaven, and thefe ftuds to be of different magnitudes, and placed at the fame angular diftances from each other as the ftars are ; the fphere will be a true reprefentation of the ftarry heaven, to an eye fuppofed to be in its center, and viewing it all around. And if a fmall globe, with a map of the earth upon it, be placed on an axis in the center of this ftarry

All objects in the heaven appear equally diftant.

The face of the heaven and earth reprefented in a machine.

sphere, and the sphere be made to turn round
on this axis, it will represent the apparent mo-
tion of the heavens round the earth.

If a great circle be so drawn upon this sphere,
as to divide it into two equal parts, or hemis-
pheres, and the plane of the circle be perpendi-
cular to the axis of the sphere, this circle will
represent the *equinoctial*, which divides the hea-
ven into two equal parts, called the *northern* and
the *southern hemispheres* ; and every point of that
circle will be equally distant from the *poles*, or
ends of the axis in the sphere. That pole
which is in the middle of the northern hemis-
phere, 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 equinoc-
tial at an angle of 23½ degrees in two opposite
points, it will represent the *ecliptic*, or circle of
the 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 his place
every day a 365th part of the ecliptic ; and

going

The *equi-noctial.*

The *poles.*

The *ecliptic.*

The *sun.*

going round weftward, the fame way as the ftars do; but with a motion fo much flower than the motion of the ftars, that they will make 366 revolutions about the axis of the fphere, in the time that the fun makes only 365. During one half of thefe revolutions, the fun will be on the north fide of the equinoctial; during the other half, on the fouth; and at the end of each half, in the equinoctial.

If we fuppofe the terreftrial globe in this machine to be about one inch in diameter, and the diameter of the ftarry fphere to be about five or fix feet, a fmall infect on the globe would fee only a very little portion of its furface; but it would fee one half of the ftarry fphere; the convexity of the globe hiding the other half from its view. If the fphere be turned weftward round the globe, and the infect could judge of the appearances which arife from that motion, it would fee fome ftars rifing to its view on the eaftern fide of the fphere, whilft others were fetting on the weftern: but as all the ftars are fixed to the fphere, the fame ftars would always rife in the fame points of view on the eaft fide, and fet in the fame points of view on the weft-fide. With the fun it would be otherwife, becaufe the fun is not fixed to any point of the fphere, but moves flowly along an oblique circle in it. And if the infect fhould look towards the fouth, and call that point of the globe, where the equinoctial in the fphere

The *earth*.

The apparent motion of the heavens.

feems

feems to cut it on the left fide, the *eaft point* ; and where it cuts the globe on the right fide, the *weft point* ; the little animal would fee the fun rife north of the eaft, and fet north of the weft, for 182½ revolutions ; after which, for as many more, the fun would rife fouth of the eaft, and fet fouth of the weft. And in the whole 365 revolutions, the fun would rife only twice in the eaft point, and fet twice in the weft. All thefe appearances would be the fame, if the ftarry fphere ftood ftill (the fun only moving in the ecliptic) and the earthly globe were turned round the axis of the fphere eaftward. For, as the infect would be carried round with the globe, he would be quite infenfible of its motion ; and the fun and ftars would appear to move weftward.

We are but very fmall beings when compared with our earthly globe, and *the globe itfelf* is but a dimenfionlefs point compared with the magnitude of the ftarry heavens. Whether the earth be at reft, and the heaven turns round it, or the heaven be at reft, and the earth turns round, the appearance to us will be exactly the fame. And becaufe the heaven is fo immenfely large, in comparifon of the earth, we fee one half of the heaven as well from the earth's furface, as we could do from its center, if the limits of our view are not intercepted by hills.

We

We may imagine as many circles defcribed *Circles of the* upon the earth as we pleafe; and we may ima- *fphere.* gine the plane of any circle defcribed upon the earth to be continued, until it marks a circle in the concave fphere of the heavens.

The *horizon* is either *fenfible* or *rational.* The *The hori-* *fenfible* horizon is that circle, which a man *zon.* ftanding upon a large plane, obferves to ter- minate his view all around, where the heaven and earth feem to meet. The plane of our fen- fible horizon continued to the heaven, divides it into two hemifpheres; one vifible to us, the other hid by the convexity of the earth.

The plane of the *rational horizon,* is fuppofed parallel to the plane of the fenfible; to pafs through the center of the earth, and to be con- tinued to the heavens. And although the plane of the fenfible horizon touches the earth in the place of the obferver, yet *this* plane, and *that* of the rational horizon, will feem to coincide in the heaven, becaufe the whole earth is but a point compared to the fphere of the heaven.

The earth being a fpherical body, the hori- zon, or limit of our view, muft change as we change our place.

The *poles of the earth,* are thofe two points on *Poles.* its furface in which its axis terminates. The

one

one is called the *north pole*, and the other the *south pole*.

The *poles of the heaven*, are thofe two points in which the earth's axis produced terminates in the heaven : fo that the *north pole* of the heaven is directly over the north pole of the earth ; and the *fouth pole* of the heaven is directly over the fouth pole of the earth.

Equator.   The *equator* is a great circle upon the earth, every part of which is equally diftant from either of the poles. It divides the earth into two equal parts, called the *northern* and *fouthern hemif-pheres*. If we fuppofe the plane of this circle to be extended to the heaven, it will mark the *equi-noctial* therein, and will divide the heaven into two equal parts, called the *northern* and *fouthern* hemifpheres of the heaven.

Meridian.   The *meridian* of any place is a great circle paffing through that place and the poles of the earth. We may imagine as many fuch meri-dians as we pleafe, becaufe any place that is ever fo little to the eaft or weft of any other place, has a different meridian from that place ; for no one circle can pafs through any two fuch places and the poles of the earth.

The *meridian* of any place is divided by the poles, into two femicircles : that which paffes through the place is called the *geographical*, or

upper

upper meridian ; and that which paſſes through the oppoſite place, is called the *lower meridian.*

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.*

Noon and *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 we imagine 24 ſemicircles, one of which is the geographical meridian of 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 is 360. And as the earth's motion is eaſtward, the ſun's apparent motion will be weſtward, at the rate of 15 degrees each hour, Therefore,

Hour-circles.

They

They whofe geographical meridian is 15 degrees eaftward from us, have noon, and every other hour, an hour fooner than we have. They whofe meridian is fifteen degrees weftward from us, have noon, and every other hour, an hour later than we have: and fo on in proportion, reckoning one hour for every fifteen degrees.

As the earth turns round its axis once in 24 hours, and fhews itfelf all round to the fun in that time; fo it goes round the fun once a year, in a great circle called the *ecliptic,* which croffes the equinoctial in two oppofite points, making an angle of $23\frac{1}{2}$ degrees with the equinoctial on each fide. So that one half of the ecliptic is in the northern hemifphere, and the other in the foutliern. It contains 360 equal parts, called degrees (as all other circles do, whether great or fmall) and as the earth goes once round it every year, the fun will appear to do the fame, chang- ing his place almoft a degree, at a mean rate, every 24 hours. So that whatever place, or de- gree of the ecliptic, the earth is in at any time, the fun will then appear in the oppofite. And as one half of the ecliptic is on the north fide of the equinoctial, and the other half on the fouth; the fun, as feen from the earth, will be half a year on the fouth fide of the equinoctial, and half a year on the north: and twice a year in the equinoctial itfelf.

The

The ecliptic is divided by aftronomers into 12 equal parts, called *figns*, each fign into 30 *degrees*, and each degree into 60 *minutes :* but in ufing the globes, we feldom want the fun's place nearer than half a degree of the truth.

The names and characters of the 12 figns are as follow ; beginning at that point of the ecliptic where it croffes the equinoctial to the north-ward, and reckoning eaftward round to the fame point again. And the days of the months on which the fun now enters the figns, are fet down below them.

Aries,	*Taurus,*	*Gemini,*	*Cancer,*
♈	♉	♊	♋
March	April	May	June
20	20	21	21

Leo,	*Virgo,*	*Libra,*	*Scorpio*
♌	♍	♎	♏
July	Auguft	September	October
23	23	23	23

Sagittarius,	*Capricorn,*	*Aquarius,*	*Pifces,*
♐	♑	♒	♓
November	December	January	February
22	21	20	18

By remembering on what day the fun enters any particular fign, we may eafily find his place any day afterward, whilft he is in that fign, by

reckoning

reckoning a degree for each day ; which will occasion no error of consequence in using the globes.

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 23½ 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 23½ 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.

Tropics. The *tropics* are lesser circles in the heaven, parallel to the equinoctial ; one on each side of it, touching the ecliptic in the points of its greatest declination ; so that each tropic is 23½

degrees

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 $23\frac{1}{2}$ *Polar-circles.* degrees from the poles, all around. That which goes round the north pole, is called the *arctic circle*, from ἄρκτ۞, which signifies a *bear*; there being a constellation or groupe 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 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 fun every year, which is the caufe of the different lengths of days and nights, and of the viciffitude of feafons ; take the following method, which will be both eafy and pleafant.

An idea of the feafons.   Let a fmall terreftrial globe, of about three inches diameter, be fufpended by a long thread of twifted filk, fixt to its north pole : then, having placed a lighted candle on a table, to reprefent the fun, in the center of a hoop of a large cafk, which may reprefent 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 the 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 ; fo that one half of the equator will be above the hoop, and the other half below it : and the candle will enlighten one half of the globe, as the fun enlightens one half of the earth, whilft the other half is in the dark.

Things being thus prepared, twift the thread towards the left hand, that it may turn the globe the fame way by untwifting ; that is, from weft, by fouth, to eaft. As the globe turns round its axis or thread, the different places of its furface 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

continues to turn round, and to fhew itfelf all around to the candle, carry it flowly round the hoop by the thread, from weft, by fouth, to eaft ; which is the way that the earth moves round the fun, once a year, in the ecliptic : and you will fee, that whilft the globe continues in the lower part of the hoop, the candle (being then north of the equator) will conftantly fhine round the north pole ; and all the northern places which go through any part of the dark, will go through a lefs portion of it than they do of the light ; and the more fo, the farther they are from the equator : confequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the higheft and loweft points, the candle will be directly over the equator, and will enlighten the globe juft from pole to pole ; and then, every place on the globe will go through equal portions of light and darknefs, as it turns round its axis ; and confequently, the day and night will be of equal length at all pla- ces upon it. As the globe advances thencefor- ward, towards the higheft part of the hoop, the candle will be on the fouth fide of the equator, fhining farther and farther round the fouth pole, as the globe rifes higher and higher in the hoop ; leaving the north pole as much in darknefs, as the fouth pole is then in the light, and making long days and fhort nights on the fouth fide of the equator, and the contrary on the north

fide,

fide, whilft the globe continues in the northern or higher fide of the hoop : and when it comes to the higheft point, the days will be at the longeft, and the nights at the fhorteft, in the fouthern hemifphere ; and the reverfe in the northern. As the globe advances and defcends in the hoop, the light will gradually recede from the fouth pole, and approach towards the north pole, which will caufe the northern days to lengthen, and the fouthern days to fhorten in the fame proportion. When the globe comes to the middle point, between the higheft and loweft points of the hoop, the candle will be over the equator, enlightening the globe juft from pole to pole, when every place of the earth (except the poles) will go through equal portions of light and darknefs ; and confequently, the day and night will be then equal, all over the globe.

And thus at a very fmall expence, one may have a delightful and demonftrative view of the caufe of days and nights, with their gradual increafe and decreafe in length, through the whole year together, with the viffitudes of fpring, fummer, autumn, and winter, in each annual courfe of the earth round the fun.

If the hoop be divided into 12 equal parts, and the figns be marked in order upon it, beginning with *Cancer* at the higheft point of the hoop, and reckoning eaftward (or contrary to the apparent motion of the fun) you will fee

how

how the fun appears to change his place every
day in the ecliptic, as the globe advances eaſt-
ward 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 ſou-
thern half of the ecliptic, the ſun appears in
the northern half, and *vice verſa :* that the far-
ther 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.

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 diſtin-
guiſh them, the iſlands properly ſituated, the
rivers and principal towns inſerted, as they have
been aſcertained upon the earth by meaſurement
and obſervation.

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,

degrees, which are generally ſubdivided into halves, and into quarters if the globe is large. Each tropic is 23½ degrees from the equator, and each polar circle 23½ 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 other times *hour-circles.*

The globe is hung in a braſs ring, called the *braſen 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, 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

<div align="right">the</div>

the equator, where they end at 90 : their ufe is to
fhew how to elevate either the north or fouth
pole above the horizon, according to the latitude
of any given place, as it is north or fouth of the
equator.

The brafen meridian is let into two notches
made in a broad flat ring, called the *wooden ho-
rizon*, the upper furface of which divides the
globe into two equal parts, called the *upper* and
lower hemifpheres. One notch is in the north
point of the horizon, and the other in the
fouth. On this horizon are feveral concentric
circles, which contain the months and days of
the year, the figns and degrees anfwering to the
fun's place for each month and day, and the 32
points of the compafs.—The graduated fide of
the brafs meridian lies towards the eaft fide of the
horizon, and fhould be generally kept toward the
perfon who works problems by the globes.

There is a fmall *horary circle*, fo fixed to the
north part of the brafen 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 brafen meridian ;
which is the contrivance of the ingenious Mr.
Jofeph Harris, mafter of the affay-office in the
Tower of London ; and makes it very conve-

nient

nient for putting the poles of the globe through
the horizon, and for elevating the pole to small
latitudes and declinations of the fun; which
cannot be done where there is only one horary
circle fixed to the outer edge of the brafen me-
ridian.

There is a thin flip of brafs, called the *qua-*
drant of altitude, which is divided into 90 equal
parts or degrees, anfwering exactly to fo many
degrees of the equator. It is occafionally fixed
to the uppermoft point of the brafen meridian
by a nut and fcrew. The divifions end at the
nut, and the quadrant is turned round upon it.

As the globe has been feen by moft people,
and upon the figure of which, in a plate, nei-
ther the circles nor countries can be properly
expreffed, we judge it would fignify very little
to refer to a figure of it ; and fhall therefore
only give fome directions how to choofe a globe,
and then defcribe its ufe.

Directions
for choofing
of globes.
1. See that the papers be well and neatly
pafted 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 feveral arches, nor the papers
either coming fhort, or lapping over one ano-
ther.

2. See

2. See that the colours be tranfparent, and not laid too thick upon the globe to hide the names of places.

3. See that the globe hang evenly between the brafen meridian and the wooden horizon; not inclining either to one fide or to the other.

4. See that the globe be as clofe to the horizon and meridian as it conveniently may; otherwife, you will be too much puzzled to find againft 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 fouth pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the eaft and weft points, in all elevations of the pole from 0 to 90 degrees.

7. See that the degree of the brafen meridian marked with 0, be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the brafen meridian above the horizon; which you may know, if you bring any of the decimal divifions on the meridian to the north point of the horizon, and find their complement to 90 in the fouth point.

9. See

9. See that when the quadrant of altitude is placed as far from the equator, on the brasen meridian, as the pole is elevated above the horizon, the beginning 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 slight.

Directions
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

that you may look on the weft fide thereof;
which turning will be apt to jog the ball fo, as
to fhift away that degree of the globe which
was before fet to the horizon or meridian : to
avoid which inconvenience, you may thruft in
the feather-end of a quill between the ball of the
globe and the brafen meridian ; which, without
hurting the ball, will keep it from turning in the
meridian, whilft you turn the weft fide 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 fide
of the brafen meridian, on which the degrees
are numbered from the equator; and obferve

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* The latitude of a place is its diftance from the equator,
and is north or fouth, as the place is north or fouth of the
equator. Thofe who live at the equator have no latitude, be-
caufe it is there that the latitude begins.

† The longitude of a place is the number of degrees (rec-
koned upon the equator) that the meridian of the faid place is
diftant from the meridian of any other place from which we
reckon, either eaftward or weftward, for 180 degrees, or half
round the globe. The Englifh 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 *firft meridian*. The
places upon this meridian have no longitude, becaufe it is there
that the longitude begins.

what

what degree of the meridian the place then lies under ; which is its latitude, north or fouth, as the place is north or fouth of the equator.

The globe remaining in this pofition, the degree of the equator, which is under the brafen meridian, is the longitude of the place (from the meridian of *London* on the *Englifh* globes) which is eaft or weft, as the place lies on the eaft or weft fide of the firft meridian of the globe.—All the *Atlantic Ocean*, and *America*, is on the weft fide of the meridian of *London* ; and the greateft part of *Europe*, and of *Africa*, together with all *Afia*, is on the eaft fide of the meridian of *London*, which is reckon the *firft meridian* of the globe by the *Englifh* geographers and aftronomers·

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 eaftward or weftward from the firft meridian, as it is mentioned to be eaft or weft ;) and bring the point of longitude in the equator to the brafen meridian, on that fide which is above the fouth point of the horizon : then count from the equator, on the brafen meridian, to the degree of the given latitude, towards the

north

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 braſen 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, is the difference of latitude required. And the number of degrees contained between theſe places, reckoned on the equator, 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 de-

grees

grees for every hour, and one degree for every four minutes.

N. B. When we fpeak of bringing any place to the brafen meridian, it is the graduated fide of the meridian that is meant.

PROBLEM IV.

Any place being given, to find all thofe places that have the fame longitude or latitude with it.

Bring the given place to the brafen meridian, then all thofe places which lie under that fide of the meridian, from pole to pole, have the fame longitude with the given place. Turn the globe round its axis, and all thofe places which pafs under the fame degree of the meridian that the given place does, have the fame latitude with that place.

Since all latitudes are reckoned from the equator, and all longitudes are reckoned from the firft meridian, it is evident, that the point of the equator which is cut by the firft meridian, has neither latitude nor longitude.—The greateft latitude is 90 degrees, becaufe no place is more than 90 degrees from the equator. And the greater longitude is 180 degrees, becaufe no place is more than 180 degrees from the firft meridian.

<div align="right">PROBLEM</div>

PROBLEM V.

To find the * antœci, † periœci, *and* ‡ antipodes, *of any given place.*

Bring the given place to the brasen meridian, and having found its latitude, keep the globe in that situation, and count the same number of degrees of latitude from the equator towards the

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* The *antœci* 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 *periœci* 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.

contrary

contrary pole, and where the reckoning ends, you have the *antœci* of the given place upon the globe. Thofe who live at the equator have no *antœci*.

The globe remaining in the fame pofition, fet 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 fame latitude with the given place, is the *periœci* required. Thofe who live at the poles have no *periœci*.

As the globe now ftands (with the index at the lower XII) the *antipodes* of the given place will be under the fame point of the brafen meridian where its *antœci* ftood before. Every place upon the globe has its *antipodes*.

PROBLEM VI.

To find the diftance 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 ; then multiply thefe degrees by 60, and the product will give the diftance in geographical miles: but to find the diftance in Englifh miles, multiply the degrees by 69½, and

the

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, inter-
cepted 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.

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 brasen meridian,
and screw the quadrant of altitude to the me-

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* Any circle that divides the globe into two equal parts, is *Great circle,*
called a *great circle*, as the equator or meridian. Any circle
that divides the globe into two unequal parts (which every pa-
rallel of latitude does) is called a *lesser circle*. Now, as every *Lesser circle,*
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 equa-
tor, 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 fol-
lowing table shews the length of a degree of longitude, in geo-
graphical miles, and hundredth parts of a mile, for every de-
gree of latitude, from the equator to the poles : a degree on the
equator being 60 geographical miles.

M   ridian,

ridian, 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.

A Table

A table shewing the number of miles in a degree of longitude, and in any given degree of latitude.

Deg.	Miles. Parts.	Deg.	Miles. Parts.	Deg.	Miles. Parts.	Deg.	Miles. Parts.	Deg.	Miles. Parts.
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	43.88	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 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 brasen meridian, and set the index to the given hour ; this done, turn the globe until the index points to the

M 2   upper

upper XII, and then, all the places that lie under the brasen meridian have noon at that time.

N. B. The upper XII always stands for noon; and when the bringing of any place to the brasen 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 brasen 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 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

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* 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.

which

which the fun is (or his place) on that day at noon. Find the fame degree of that fign in the ecliptic line upon the globe, and having brought it to the brafen meridian, obferve what degree of the meridian ftands over it ; for that is the fun's declination, reckoned from the equator.

PROBLEM XI.

The day of the month being given, to find all thofe places of the earth over which the fun will pafs vertically on that day.

Find the fun's place in the ecliptic for the given day, and having brought it to the brafen meridian, obferve what point of the meridian is over it ; then, turning the globe round its axis, all thofe places which pafs 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 fun's declination, the fun muft be directly over head to each of them at its refpective noon.

PRO-

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 brafen meridian, and mark the degree of latitude that is exactly over it on the meridian; then turn the globe round its axis, and obferve the two degrees of the ecliptic which pafs exactly under that degree of latitude : laftly, find on the wooden horizon, the two days of the year in which the fun is in thofe degrees of the ecliptic, and they are the days required : for on them, and none elfe, the fun's declination is equal to the latitude of the given place : and confequently, he will then be vertical to it at noon.

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* 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 $23\frac{1}{2}$ on each fide of the equator : the *temperate zones* lie between the tropics and polar circles, or from $23\frac{1}{2}$ degrees of latitude, to $66\frac{1}{2}$, on each fide of the equator ; and are each 43 degrees in breadth : the *frigid zones* are the fpaces included within the polar circles, which being each $23\frac{1}{2}$ degrees from their refpective poles, the breadth of each of thefe zones is 47 degrees. As the fun never goes without the tropics, he muft every moment be vertical to fome place or other in the torrid zone.

PROBLEM XIII.

To find all thofe places of the north frigid zone, where the fun begins to fhine conftantly without fetting, on any given day, from the 21ft of March, to the 23d of September.

On thefe two days, the fun 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 fo make equal day and night to all places of the earth. But as the fun declines from the equator, towards either pole, he will fhine juft as many degrees round that pole, as are equal to his declination from the equator ; fo that no place within that diftance of the pole will then go through any part of the dark, and confequently the fun will not fet to it. Now, as the fun's declination is northward, from the 21ft of March to the 23d of September, he muft conftantly fhine round the north pole all that time ; and on the day that he is in the northern tropic, he fhines upon the whole north frigid zone ; fo that no place within the north polar circle goes through any part of the dark on that day. Therefore,

Having

Having brought the fun's place for the given day to the brafen meridian, and found his declination (by Prob. IX.) count as many degrees on the meridian, from the north pole, as are equal to the fun's declination from the equator, and mark that degree from the pole where the reckoning ends : then, turning the globe round its axis, obferve what places in the north frigid zone pafs directly under that mark ; for they are the places required.

The like may be done for the fouth frigid zone, from the 23d of September to the 21ſt of March, during which time the fun ſhines conſtantly on the fouth pole.

PROBLEM XIV.

To find the place over which the fun is vertical, at any hour of a given day.

Having found the fun's declination for the given day (by Prob. IX.) mark it with a chalk on the brafen meridian : then bring the place where you are (fuppofe London) to the brafen meridian, and fet 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 fun's declination marked upon the
                                        meridian,

meridian, has the fun that moment in the zenith, or directly over head.

PROBLEM XV.

The day and hour at any place being given, to find all thofe places where the fun is then rifing, or fetting, or on the meridian: confequently, all thofe places which are enlightened at that time, and thofe which are in the dark.

This problem cannot be folved by any globe fitted up in the common way, with the hour-circle fixed upon the brafs meridian; unlefs the fun be on or near fome of the tropics on the given day. But by a globe fitted up according to Mr. *Jofeph Harris*'s invention (already mentioned) where the hour-circle lies on the furface of the globe, below the meridian, it may be folved for any day of the year, according to his method; which is as follows.

Having found the place to which the fun is vertical at the given hour, if the place be in the northern hemifphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place be in the fouthern hemifphere, elevate the fouth pole accordingly; and bring the faid place to the brafen meridian. Then, all thofe places which are in the weftern femicircle of the horizon, have

the

the fun rifing to them at that time ; and thofe in the eaftern femicircle have it fetting: to thofe under the upper femicircle of the brafs meridian, it is noon ; and to thofe under the lower femi-circle, it is mid-night. All thofe places which are above the horizon, are enlightened by the fun, and have the fun juft as many degrees above them, as they themfelves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the brafen meridian over the place to which the fun is vertical ; and then, laying it over any other place, obferve what number of degrees on the quadrant are intercept-ed between the faid place and the horizon. In all thofe places that are 18 degrees below the weftern femicircle of the horizon, the morning twilight is juft beginning ; in all thofe places that are 18 degrees below the eaftern femicircle of the horizon, the evening twilight is ending; and all thofe places that are lower than 18 degrees, have dark night.

If any place be brought to the upper femicir-cle of the brafen meridian, and the hour-index be fet to the upper XII or noon, and then the globe be turned round eaftward on its axis; when the place comes to the weftern femicircle of the horizon, the index will fhew the time of fun-rifing at that place; and when the fame place comes to the eaftern femicircle of the hori-zon, the index will fhew the time of fun-fet.

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 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 braſen 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

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. I.) 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 brasen 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

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* The *zenith*, in this sense, is the highest point of the brasen 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.

the

the brafen meridian, and faften the quadrant of
altitude fo, 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 fun's place in the ecliptic for
the given day (found by Prob. X.) to the gradu-
ated fide of the brafen meridian, and fet the
hour-index to XII at noon, which is the upper-
moft XII on the hour-circle ; and the globe
will be rectified.

The latitude of any place, is equal to the
elevation of the neareft 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 fhall fee 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 fhall fee the correfponding pole
of the heaven rifing gradually above our hori-
zon, juft as many degrees as we have gone from
the equator : and if we were at either of the
earth's poles, the correfponding pole of the
heaven would be directly over our head. Con-
fequently, the elevation or height of the pole in
degrees above the horizon, is equal to the num-

ber

ber of degrees that the place is from the eqûa-
tor.

PROBLEM XVIII.

*The latitude of any place, not exceeding * 66¼
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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* All places whose latitude is more than 66½ degrees, are in
the frigid zones : and to those places the sun does not set in sum-
mer, for a certain number of diurnal revolutions, which occa-
sions this limitation of latitude.

PRO-

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 a chalk which is in the western side of the hori-zon, 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 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

<div align="right">western</div>

western side of the horizon, and the point oppo-
site to it, which was marked with the chalk,
will be rising in the east : then, bring the qua-
drant 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 brasen me-
ridian cuts it : then find, on the wooden hori-
zon, 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, be-
tween *Cancer* and *Libra*, coincides with the north
point of the horizon, where the brasen meridian
cuts it ; and find, on the wooden horizon, on

what

what day the fun is in that point of the ecliptic;
which is the day that the fun leaves off conſtantly
ſhining on the faid place, and rifes and fets to it
as to other places on the globe. The number of
natural days, or compleat revolutions of the fun
about the earth, between the two days above
found, is the time that the fun keeps conſtantly
above the horizon without fetting : for all that
portion of the ecliptic, which lies between the
two points which interfect the horizon in the
very north, never fets below it : and there is
juſt as much of the oppofite part of the ecliptic
that never rifes ; therefore, the fun will keep as
long conſtantly below the horizon in winter, as
above it in fummer.

Whoever confiders the globe, will find, that
all places of the earth do equally enjoy the be-
nefit of the fun, in refpect 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 oppofite feafon.

PROBLEM XXI.

To find in what latitude the sun shines constantly without setting, for any length of time less than * 182½ *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 brasen meridian, on 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.

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* 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.

PROBLEM XXII.

The latitude of a place, not exceeding 66½ 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 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 ;

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* The sun's altitude, at any time, is his height above the horizon at that time.

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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 the compaſs, if they agree, the compaſs has no variation in that place : but if they differ, the compaſs 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 ſun's place in the ecliptic, and the degree of the quadrant cut by the ſun's place is his altitude at that time above the horizon ; and the degree of the horizon cut by the

quadrant

quadrant is the fun's azimuth, reckoned from the fouth.

PROBLEM XXV.

The latitude, the fun'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 loft.

Rectify the globe for the latitude and * zenith, and fet 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 fun's place; and the day of the month anfwering thereto, will be found over the like place of the fun on the wooden horizon. Keep the quadrant of altitude in that pofition, and having brought the fun's place to the brafen meridian, and the hour-index to XII at noon, turn back the globe, until the fun's place cuts the quadrant of altitude again, and the index will fhew the hour.

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* By rectifying the globe for the zenith, is meant fcrewing the quadrant of altitude to the given latitude on the brafs meridian.

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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 between the beginning of *Aries* and beginning of *Cancer* is to be used : from the 21st of June to the 23d of September, between the beginning of *Cancer* and beginning of *Libra :* from the 23d of September to the 21st of December, between the beginning of *Libra* and the beginning of *Capricorn ;* and from the 21st of December to the 20th 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 pole to that latitude; then, bring the beginning of *Cancer* ♋ to the brasen 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 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 brasen meridian, and elevate

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the north pole to about 66$\frac{1}{2}$ degrees ; but if the
latitude be fouth, bring the beginning of *Capri-*
corn to the meridian, and elevate the fouth pole
to about 66$\frac{1}{2}$ degrees, becaufe the longeft day in
north latitude, is when the fun is in the firft
point of *Cancer* ; and in fouth latitude, when he
is in the firft point of *Capricorn.* Then fet the
hour-index to XII at noon, and turn the globe
weftward, until the index points at half the
number of hours given; which done, keep the
globe from turning on its axis, and flide the
meridian down in the notches, until the afore-
faid point of the ecliptic (viz. *Cancer* or *Capri-*
corn) comes to the horizon ; then, the elevation
of the pole will be equal to the latitude re-
quired.

P R O B L E M XXVIII.

The latitude of any place, not exceeding 66$\frac{1}{2}$ *de-*
grees, being given ; to find in what * *climate*
the place is.

Find the length of the longeft day at the
given place by Prob. XXVI. and whatever be the

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* A *Climate,* from the equator to either of the polar circles,
is a tract of the earth's furface, included between two fuch
parallels of latitude, that the length of the longeft day in the
one exceeds that in the other by half an hour ; but from the
polar circles to the poles, where the fun keeps along above the
horizon without fetting, each climate differs a whole month
from the one next to it. There are twenty-four climates be-
tween the equator and each of the polar circles ; and fix from
each polar circle to its refpective pole.

number of hours whereby it exceedeth twelve, double that number, and the fum 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 fun fhines.

Set the wooden horizon truly level, and the brafen meridian due north and fouth by a mariner's compaſs : then, having rectified the globe, ſtick a fmall fewing-needle into the fun's place in the ecliptic, perpendicular to that part of the furface of the globe : this done, turn the globe on its axis, until the needle comes to the brafen meridian, and fet the hour-index to XII at noon ; then, turn the globe on its axis, until the needle points exactly towards the fun (which it will do when it cafts no fhadow on the globe) and the index will fhew the hour of the day.

PROBLEM XXX.

A pleafant way of fhewing all thofe places of the earth which are enlightened by the fun, and alfo the time of the day when the fun fhines.

Take the terreftrial ball out of the wooden horizon, and alfo out of the brafen meridian ;

<div align="right">then</div>

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 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. *Thofe places which lie on the equator, have no latitude, it being there that the latitude begins; and thofe places which lie on the firft meridian have no longitude, it being there that the longitude begins. Confequently, that particular place of the earth where the firft meridian interfects the equator, has neither longitude nor latitude.*

3. *In all places of the earth, except the poles, all the points of the compafs may be diftinguifhed in the horizon: but from the north pole, every place is fouth; and from the fouth pole, every place is north. Therefore, as the fun is conftantly above the horizon of each pole for half a year in its turn, he cannot be faid to depart from the meridian of either pole for half a year together. Confequently, at the north pole it may be faid to be noon every moment for half a year; and let the winds blow from what part they will, they muft always blow from the fouth; and at the fouth pole, from the north.*

4. *Becaufe one half of the ecliptic is above the horizon of the pole, and the fun, moon and planets, move in (or nearly in) the ecliptic; they will all*

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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 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 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 same 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 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*

<div align="right">

altitude

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altitude be set to 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 qua-
drant, and thence ascending, it will cross the qua-
drant 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 poles, the days and nights are equally long,
viz. 12 hours each, when the sun is in the equi-
noctial ; 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 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 polar
circles, but when the sun enters the signs ♈ Aries
and ♎ Libra. For in every other part of the e-
cliptic, the circle of the sun's daily motion is divided
into two unequal parts by the horizon.

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* From the middle of Gemini to the middle of Cancer, the
quadrant may be set 20 degrees.

10. *The*

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 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*

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 of getting 18 degrees below it (till which time the twilight always continues.) And 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.*

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* Between the tropics.
† Between the polar circles and poles.
‡ Between the tropics and polar circles.

15. To

15. *To all places in the northern hemisphere, from the equator to the polar circle, the longest day 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 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 compleat 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 will get so much the sooner*

above

above the ſetting ſun, than if they had kept 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 a compleat 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 the earth, they will differ four days; if thrice, then ſix, &c.
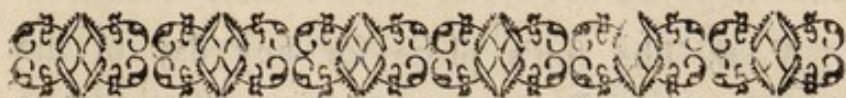
O   THE

THE USE OF THE

CELESTIAL GLOBE,

AND

ARMILLARY SPHERE.

AVING done for the prefent with The *celestial* the terreftrial globe, we fhall proceed *globe.* to the ufe of the celeftial ; firft pre-mifing, that as the equator, ecliptic, tropics, polar circles, horizon, and brafen meridian, are exactly alike on both globes, all the former pro-blems concerning the fun are folved the fame way by both globes. The method alfo of recti-fying the celeftial globe is the fame as rectifying To rectify the terreftrial, viz. Elevate the pole according it. to the latitude of your place, then fcrew the quadrant of altitude to the zenith, on the brafs meridian ; bring the fun's place in the ecliptic to the graduated edge of the brafs meridian, on the fide which is above the fouth point of the

O 2 wooden

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 longitude 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 all 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 it which cuts the ecliptic at the beginning of *Aries* ♈ ; and thence eastward, quite round, to the same semicircle again. Consequently those stars which lie

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* *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) called the *equinoctial colure :* and the *great circle* that passes through the *beginning of* ♋ and ♑, and also through the poles of the ecliptic, and poles of the world, is called the *solstitial colure.*

Colures.

between

between the equino&ial and the northern half of the ecliptic, have north declination and ſouth latitude ; thoſe which lie between the equino&ial 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 12 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, 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 *Conſtellati-* to their ſituations and poſitions in the heaven, *ons.* the antients divided the whole viſible firmament of ſtars into particular ſyſtems, which they

called

called *conftellations* ; and digefted them into the forms of fuch animals as are delineated upon the celeftial globe. And thofe ftars which lie between the figures of thofe imaginary animals, and could not be brought within the compafs of any of them, were called *unformed ftars*.

Becaufe the moon and all the planets were obferved to move in circles or orbits which crofs the ecliptic (or line of the fun's path) at fmall angles, and to be on the north fide of the ecliptic for one half of their courfe round the heaven of ftars, and on the fouth fide of it for the other half, but never to go quite 8 degrees from it on either fide, the antients diftinguifhed that fpace by two leffer circles, parallel to the ecliptic (one on each fide) at 8 degrees diftance from it. And the fpace included between thefe circles, they called the *zodiac*, becaufe moft of the 12 conftellations placed therein refemble fome

Its figns, or living creature.——Thefe conftellations are, 1.
divifions.   *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 fcorpion ; 9. *Sagittarius* ♐, the archer ; 10. *Capricornus* ♑, the goat ; 11. *Aquarius* ♒, the water bearer ; and 12. *Pifces* ♓, the fifhes.

Remark.   It is to be obferved, that in the infancy of aftronomy, thefe twelve conftellations ftood at or near the places of the ecliptic, where the

above

above characteriftics are marked upon the globe : but now, each conftellation has got a whole fign forwarder, on account of the receffion of the equino&ial points from their former places. So that the conftellation of *Aries,* is now into the former place of *Taurus*; that of *Taurus,* into the former place of *Gemini*; and fo on.

The ftars appear of different magnitudes to the eye ; probably becaufe they are at different diftances from us. Thofe which appear brighteft and largeft, are called *ftars of the firft magnitude*; the next to them in fize and luftre, are called *ftars of the fecond magnitude*; and fo on to the *fixth*, which are the fmalleft that can be difcerned by the bare eye.

Some of the moft remarkable ftars have names given them, as *Caftor* and *Pollux* in the heads of the *Twins*, *Sirius* in the mouth of the *Great Dog*, *Procyon* in the fide of the *Little Dog*, *Rigel* in the left foot *Orion*, *Ar&urus* near the right thigh of *Bootes*, &c.

Thefe things being premifed, which I think are all that the young *Tyro* need be acquainted with, before he begins to work any problem by this globe, we fhall now proceed to the moft ufeful of thofe problems ; omitting feveral which are of little or no confequence.

O 4 PRO-

PROBLEM I.

*To find the * right afcenfion and † declination of
the fun, or any fixed ftar.*

Bring the fun's place in the ecliptic to the
brafen meridian, then that degree in the equi-
noctial which is cut by the meridian, is the fun's
right afcenfion; and that degree of the meridian
which is over the fun's place, is his *declination*.
Bring any fixed ftar to the meridian, and its
right afcenfion will be cut by the meridian in the
equinoctial ; and the degree of the meridian
that ftands over it, is its *declination*.

So that *right afcenfion* and *declination*, on the
celeftial globe, are found in the fame manner as
longitude and *latitude* on the terreftrial.

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* The degree of the equinoctial, reckoned from the beginning
of *Aries* that comes to the meridian with the fun or ftar, is its
right afcenfion.

† The diftance of the fun or ftar in degrees from the equi-
noctial towards either of the poles, north or fouth, is its de-
clination, which is north or fouth 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 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,

refpect, as taught by the 17th problem, for the terreftrial ; and turn it about, until the index points to the given hour : then, the upper hemifphere of the globe will reprefent the vifible half of the heaven for that time : all the ftars upon the globe being then in fuch fituations, as exactly correfpond to thofe in the heaven. And if the globe be placed duly north and fouth, by means of a fmall fea-compafs, every ftar on the globe will point toward the like ftar in the heaven : by which means, the conftellations and remarkable ftars may be eafily known. All thofe ftars which are in the eaftern fide of the horizon, are then rifing in the eaftern fide of the heaven ; all in the weftern, are fetting in the weftern fide ; and all thofe under the upper part of the brafen meridian, between the fouth point of the horizon and the north pole, are at their greateft altitude, if the latitude of the place be north : but if the latitude be fouth, thofe ftars which lie under the upper part of the meridian, between the north point of the horizon and the fouth pole, are at their greateft 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 brasen 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 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 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

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* 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.*

horizon:

horizon : then turn the globe on its axis, until the ftar 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 ftar, being given ; to find the hour of the night.

Rectify the globe as in the former problem, guefs at the hour of the night, and turn the globe until the index points at the fuppofed hour; then lay the graduated edge of the quadrant of altitude over the known ftar, and if the degree of the ftar's height in the quadrant upon the globe, anfwers exactly to the degree of the ftar's obferved altitude in the heaven, you have guefled exactly : but if the ftar on the globe is higher or lower than it was obferved to be in the heaven, turn the globe backwards or forwards, keeping the edge of the quadrant upon the ftar, until its center comes to the obferved altitude in the quadrant; and then, the index will fhew the true time of the night.

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* The number of degrees that the ftar is above the horizon, as obferved by means of a common quadrant, is called its *alti-tude.*

P R O-

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 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 them-ſelves will cut their true altitude in the qua-drant.

drant. At which moment, if a common azimuth compass be so 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 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.

Seek 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

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* The place of the moon or planet, as seen from the earth, is called its geocentric place.

the

the faid mark comes to the eaftern fide of the horizon, to the brafen meridian, and to the weft-ern fide of the horizon, the index will fhew at what time the planet rifes, comes to the meri-dian, and fets, in the fame manner as it would do for a fixed ftar.

PROBLEM X.

To explain the phenomena of the harveft-moon.

In order to do this, we muft premife the follow-ing things. 1. That as the fun 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 almoft 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, fhe advances $13\frac{1}{3}$ degrees in it, every day at a mean rate. 3. That as the fun 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 fun, or oppofite to him, in that part of the ecliptic where fhe was fo the laft time before ; but muft travel as much for-warder, as the fun has advanced in the faid time ; which being $29\frac{1}{2}$ days, makes almoft a whole fign. Therefore, 4. The moon can be but once a year oppofite to the fun, in any par-ticular part of the ecliptic. 5. That the moon is never full but when fhe is oppofite to the fun,

becaufe

becaufe at no other time can we fee all that half of her, which the fun enlightens. 6. That when any point of the ecliptic rifes, the oppofite point fets. Therefore, when the moon is op- pofite to the fun, fhe muft rife at * fun-fet. 7. That the different figns of the ecliptic rife at very different angles or degrees of obliquity with the horizon, efpecially in confiderable latitudes; and that the fmaller this angle is, the greater is the portion of the ecliptic that rifes in any fmall part of time; and *vice verfa.* 8. That, in nor- thern latitudes, no part of the ecliptic rifes at fo fmall an angle with the horizon, as *Pifces* and *Aries* do; therefore, a greater portion of the ecliptic rifes in one hour, about thefe figns, than about any of the reft. 9. That the moon can never be full in *Pifces* and *Aries* but in our au- tumnal months, for at no other time of the year is the fun in the oppofite figns *Virgo* and *Libra.*

Thefe things premifed, take $13\frac{1}{2}$ degrees of the ecliptic in your compaffes, and, beginning at *Pifces*, carry that extent all round the eclip- tic, marking the places with a chalk, where the points of the compaffes fucceffively fall. So you will have the moon's daily motion marked out

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* This is not always ftrictly true, becaufe the moon does not keep in the ecliptic, but croffes it twice every month. However the difference need not be regarded in a general explanation.

P   for

for one compleat 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 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 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

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 XI.

To explain the equation of time, or difference of time between well-regulated clocks and true fundials.

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

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 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 around 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 brasen 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,

Therefore, whilſt the ſun is in the firſt and third quadrants of the ecliptic, 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 equably 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.
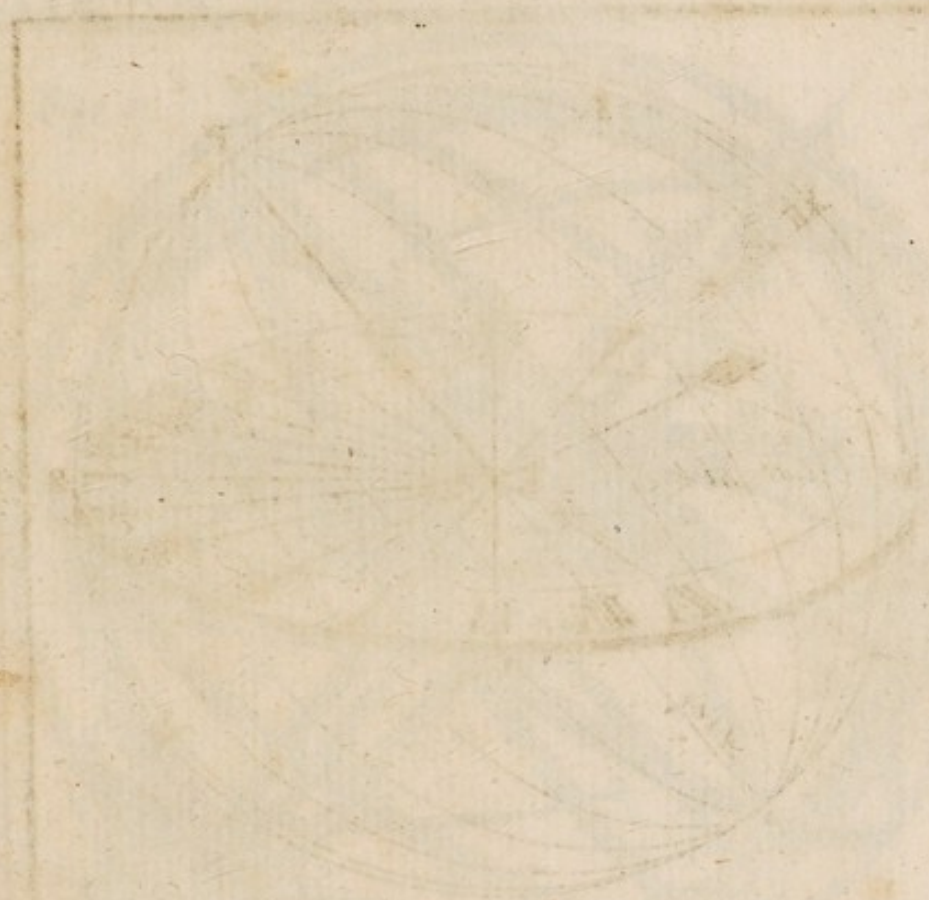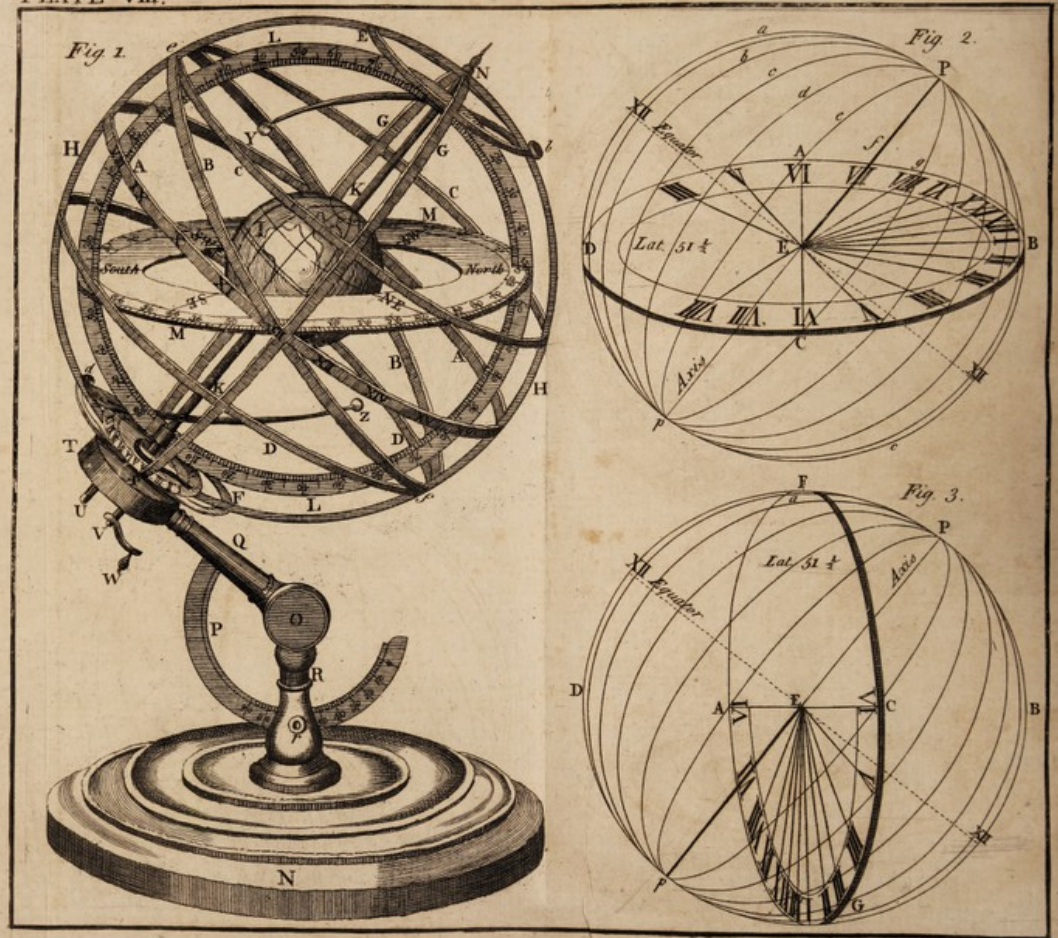
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PLATE VIII.

Fig. 1.

Fig. 2.

Fig. 3.

The Description and Use of the Armillary Sphere.

WHOEVER has feen a common *armillary fphere*, and underftands how to ufe it, muft be fenfible that the machine here referred to, is of a very different, and much more advantageous conftruction. And whoever has feen the curious glafs fphere invented by Dr. LONG, or the figure of it in his Aftronomy, muft know that the furniture of the terreftrial globe in this machine, the form of the pedeftal, and the manner of turning either the earthly globe, or the circles which furround it, are all copied from the Doctor's glafs fphere; and that the only difference is, a parcel of rings inftead of a glafs celeftial globe; and all the additions are a moon within the fphere, and a femicircle upon the pedeftal.

The

The exterior parts of this machine are a compages of brafs rings, which reprefent the principal circles of the heaven, viz. 1. The equinoctial *A A*, which is divided into 360 degrees (beginning at its interfection with the ecliptic in *Aries*) for fhewing the fun's right afcenfion in degrees; and alfo into 24 hours, for fhewing his right afcenfion in time. 2. The ecliptic *B B*, which is divided into 12 figns, and each fign into 30 degrees, and alfo into the months and days of the year; in fuch a manner, that the degree or point of the ecliptic, in which the fun is, on any given day, ftands over that day in the circle of months. 3. The tropic of *Cancer C C*, touching the ecliptic at the beginning of *Cancer* in *e*, and the tropic of *Capricorn D D*, touching the ecliptic at the beginning of *Capricorn* in *f*; each 23½ degrees from the equinoctial circle. 4. The arctic circle *E*, and the antarctic circle *F*, each 23½ degrees from its refpective pole at *N* and *S*. 5. The equinoctial colure *G G*, paffing through the north and fouth poles of the heaven at *N* and *S*, and through the equinoctial points *Aries* and *Libra*, in the ecliptic. 6. The folftitial colure *H H*, paffing through the poles of the heaven, and through the folftitial points *Cancer* and *Capricorn*, in the ecliptic. Each quarter of the former of thefe colures is divided into 90 degrees, from the

<div align="right">equinoctial</div>

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 Υ, which is carried round the ecliptic *B B*, 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 $5\frac{x}{3}$ degrees, in two opposite points called the *moon's nodes*; and also for shifting these points back-ward in the ecliptic, as the *moon's nodes* shift in the heaven.

Within these circular rings is a small terres-trial globe *I*, fixt on an axis *K K*, which ex-tends 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 fixt 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 fame way as the brafs meridian of a common globe, and its ufe is much the fame. To this globe is fitted the moveable horizon *M M*, fo as to turn upon two ftrong wires proceeding from its eaft and weft points to the globe, and entering the globe at oppofite points of its equator, which is a moveable brafs ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, fo as to place any given meridian upon it, directly under the celeftial meridian *L L*. The horizon is divided into 360 degrees all around its outermoft edge, within which are the points of the compafs, for fhewing the amplitude of the fun and moon, both in degrees and points. The celeftial meridian *L L* paffes through two notches in the north and fouth 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 fouth pole of the fphere 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 fabrick is fupported on a pedeftal *N*, and may be elevated or depreffed upon the joint *O*, to any number of degrees from o to 90, by means of the arc *P*, which is fixed into the ftrong brafs arm *Q*, and flides in the upright

piece

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 axes 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 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 keep 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-circle, 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

And fo, by this conftruction, the machine is equally fitted to fhew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the fphere for ufe, firft flacken the fcrew *r* in the upright ftem *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 fide of the ftem *R*; and then the axis of the fphere will be properly elevated, fo as to ftand parallel to the axis of the world, if the machine be fet north and fouth by a fmall compafs : this done, count the latitude from the north pole, upon the celeftial meridian *L L*, down towards the north notch of the horizon, and fet the horizon to that latitude ; then, turn the nut *b* until the fun *Y* comes to the given day of the year in the ecliptic, and the fun will be at its proper place for that day : find the place of the moon's afcending node, and alfo the place of the moon, by an Ephemeris, and fet them right accordingly : laftly, turn the winch *W*, until either the fun comes to the meridian *L L*, or until the meridian comes to the fun (according as you want the fphere or earth to move) and fet the hour-index to the XII, marked noon, and the whole machine will be rectified.—Then turn the winch, and obferve when the fun or moon

rife

rife and fet in the horizon, and the hour-index will fhew the times thereof for the given day.

As thofe who underftand the ufe of the globes will be at no lofs to work many other problems by this fphere, it is needlefs to enlarge any far-ther upon it.

T H E   E N D.