Astronomy explained upon Sir Isaac Newton's principles, and made easy to those who have not studied mathematics. To which are added, a plain method of finding the distances of all the planets from ...

Ferguson, James

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Lectures VIII. and IX. The description and use of the globes, and armillary sphere.

of the interior. For, when a ray *a b* falls upon the lower part of the drop *b c d e*, it is refracted into the direction *b c* by entering the drop; and passing on to the back of the drop at *c*, it is thence reflected in the line *c d*, in which direction it is impossible for it to enter the eye at *f*: but by being again reflected from the point *d* of the drop, it goes on in the drop to *e*, where it passes out of the drop into the air, and is there refracted downward to the eye, in the direction *e f*. Fig. 3.

LECT. VIII and IX.

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

The terrestrial globe.

IF a map of the world be accurately delineated on a spherical ball, the surface thereof will represent the surface of the earth: for the highest hills are so inconsiderable with respect to the bulk of the earth, that they take off no more from its roundness, than grains of sand do from the roundness of a common globe; for the diameter of the earth is 8000 miles, in round numbers, and no known hill upon it is three miles in perpendicular height.

Proof of the earth's being globular.

That the earth is spherical, or round like a globe, appears, 1. from its casting a round shadow upon the moon, whatever side be turned towards her when she is eclipsed. 2. From its having been sailed round by several persons. 3. From our seeing the farther, the higher we stand. 4. From our seeing the masts of a ship, whilst the hull is hid by the convexity of the water.

And that it may be peopled on all sides without any one's being in danger of falling away from it.

The attractive power of the earth draws all terrestrial bodies towards its center; as is evident from the descent of bodies in lines perpendicular to the earth's surface, at the places whereon they fall; even when they are thrown off from the earth on opposite sides, and consequently, in opposite directions. So that the earth may be compared to a great magnet rolled in filings of steel, which attracts and keeps them equally fast to its surface on all sides. Hence, as all terrestrial bodies are attracted toward the earth's center, they can be in no danger of falling from any side of the earth, more than from any other.

Up and down, what.

The heaven or sky surrounds the whole earth: and when we speak of *up* or *down*, we mean only with regard to ourselves; for no point, either in the heaven, or on the surface of the earth, is *above* or *below*, but only with respect to ourselves. And let us be upon what part of the earth we will, we stand with our feet toward its center, and our heads toward the ſky: and ſo we ſay, it is *up* toward the ſky, and *down* toward the center of the earth.

All objects in the heaven appear equally diſtant.

To an obſerver placed any where in the indefinite ſpace, where there is nothing to limit his view, all remote objects appear equally diſtant from him; and ſeem to be placed in a vaſt concave ſphere, of which his eye is the center. Every aſtronomer can demonſtrate, that the moon is much nearer to us than the ſun is; that ſome of the planets are ſometimes nearer to us, and ſometimes farther from us, than the ſun; that others of them never come ſo near us as the ſun always is; that the remoteſt planet in our ſyſtem, is beyond compariſon nearer to us than any of the fixed ſtars are; and that it is highly probable ſome ſtars are, in a manner, infinitely more diſtant from us than others. And yet all theſe celeſtial objects appear equally diſtant from us. Therefore, if we imagine a large hollow ſphere of glaſs to have as many bright ſtuds fixed to its inſide, as there are ſtars viſible in the heaven, and theſe ſtuds to be of different magnitudes, and placed at the ſame angular diſtances from each other as the ſtars are; the ſphere will be a true repreſentation of the ſtarry heaven, to an eye ſuppoſed to be in its center, and viewing it all around. And if a ſmall globe, with a map of the earth upon it, be placed on an axis in the center of this ſtarry ſphere, and the ſphere be made to turn round on this axis, it will repreſent the apparent motion of the heavens round the earth.

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

If a great circle be ſo drawn upon this ſphere, as to divide it into two equal parts, or hemiſpheres, and the plane of the circle be perpendicular to the axis of the ſphere, this circle will repreſent the *equinoctial*, which divides the heaven into two equal parts, called the *northern* and the *ſouthern hemiſpheres*; and every point of that circle will be equally diſtant from the *poles*, or ends of the axis in the ſphere. That pole which is in the middle of the northern hemiſphere, will be called the *north pole of the ſphere*, and that which is in the middle of the ſouthern hemiſphere, the *ſouth pole*.

The *equinoctial*.

The *poles*.

If another great circle be drawn upon the ſphere, in ſuch a manner as to cut the equinoctial at an angle of $23\frac{1}{2}$ degrees in two oppoſite points, it will repreſent the *ecliptic*, or circle of the ſun's apparent annual motion: one half of which is on the north ſide of the equinoctial, and the other half on the ſouth.

The *ecliptic*.

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;

The *ſun*.

ecliptic; and going round weſtward, the ſame way as the ſtars do; but with a motion ſo much ſlower than the motion of the ſtars, that they will make 366 revolutions about the axis of the ſphere, in the time that the ſun makes only 365. During one half of theſe revolutions, the ſun will be on the north ſide of the equinoctial; during the other half, on the ſouth; and at the end of each half, in the equinoctial.

The *earth*.

If we ſuppoſe the terreſtrial globe in this machine to be about one inch in diameter, and the diameter of the ſtarry ſphere to be about five or ſix feet, a ſmall inſect on the globe would ſee only a very little portion of its ſurface; but it would ſee one half of the ſtarry ſphere; the convexity of the globe hiding the other half from its view. If the ſphere be turned weſtward round the globe, and the inſect could judge of the appearances which ariſe from that motion, it would ſee ſome ſtars riſing to its view in the eaſtern ſide of the ſphere, whilſt others were ſetting on the weſtern: but as all the ſtars are fixed to the ſphere, the ſame ſtars would always riſe in the ſame points of view on the eaſt ſide, and ſet in the ſame points of view on the weſt ſide. With the ſun it would be otherwiſe, becauſe the ſun is not fixed to any point of the ſphere, but moves ſlowly along an oblique circle in it. And if the inſect ſhould look towards the ſouth, and call that point of the globe, where the equinoctial in the ſphere ſeems to cut it on the left ſide, the *eaſt point*; and where it cuts the globe on the right ſide, the *weſt point*; the little animal would ſee the ſun riſe north of the eaſt, and ſet north of the weſt, for 182½ revolutions; after which, for as many more, the ſun would riſe ſouth of the eaſt, and ſet ſouth of the weſt. And in the whole 365 revolutions, the ſun would riſe only twice in the eaſt point, and ſet twice in the weſt. All theſe appearances would be the ſame, if the ſtarry ſphere ſtood ſtill (the ſun only moving in the ecliptic) and the earthly globe were turned round the axis of the ſphere eaſtward. For, as the inſect would be carried round with the globe, he would be quite inſenſible of its motion; and the ſun and ſtars would appear to move weſtward.

The apparent motion of the heavens.

We are but very ſmall beings when compared with our earthly globe, and *the globe itſelf* is but a dimenſionleſs point compared with the magnitude of the ſtarry heavens. Whether the earth be at reſt, and the heaven turns round it, or the heaven be at reſt, and the earth turns round, the appearance to us will be exactly the ſame. And becauſe the heaven is ſo immenſely large, in compariſon of the earth, we ſee one half of the heaven as well from the earth's ſurface, as we could do from its center, if the limits of our view are not intercepted by hills.

Circles of the sphere. We may imagine as many circles deſcribed upon the earth as we pleaſe; and we may imagine the plane of any circle deſcribed upon the earth to be continued, until it marks a circle in the concave ſphere of the heavens.

The *horizon.* The *horizon* is either *ſenſible* or *rational.* The *ſenſible* horizon is that circle, which a man ſtanding upon a large plane, obſerves to terminate his view all around, where the heaven and earth ſeem to meet. The plane of our ſenſible horizon continued to the heaven, divides it into two hemiſpheres; one viſible to us, the other hid by the convexity of the earth.

The plane of the *rational horizon*, is ſuppoſed parallel to the plane of the ſenſible; to paſs through the center of the earth, and to be continued to the heavens. And although the plane of the ſenſible horizon touches the earth in the place of the obſerver, yet *this* plane, and *that* of the rational horizon, will ſeem to coincide in the heaven, becauſe the whole earth is but a point compared to the ſphere of the heaven.

The earth being a ſpherical body, the horizon, or limit of our view, muſt change as we change our place.

Poles. The *poles of the earth*, are thoſe two points on its ſurface in which its axis terminates. The one is called the *north pole*, and the other the *ſouth pole.*

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

Equator. The *equator* is a great circle upon the earth, every part of which is equally diſtant from either of the poles. It divides the earth into two equal parts, called the *northern* and *ſouthern hemiſpheres.* If we ſuppoſe the plane of this circle to be extended to the heaven, it will mark the *equinoctial* therein, and will divide the heaven into two equal parts, called the *northern* and *ſouthern* hemiſpheres of the heaven.

Meridian. The *meridian* of any place is a great circle paſſing through that place and the poles of the earth. We may imagine as many ſuch meridians as we pleaſe, becauſe any place that is ever ſo little to the eaſt or weſt of any other place, has a different meridian from that place; for no one circle can paſs through any two ſuch places and the poles of the earth.

The *meridian* of any place is divided by the poles, into two ſemicircles: that which paſſes through the place is called the *geographical*, or or *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 *mid-night*. *Noon and mid-night.*

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 earth'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 whoſe geographical meridian is 15 degrees eaſtward from us, have noon, and every other hour, an hour ſooner than we have. They whoſe meridian is fifteen degrees weſtward from us, have noon, and every other hour, an hour later than we have: and ſo on in proportion, reckoning one hour for every fifteeen degrees. *Longitude.*

As the earth turns round its axis once in 24 hours, and ſhews itſelf all round to the ſun in that time; ſo it goes round the ſun once a year, in a great circle called the *ecliptic*, which croſſes the equinoctial in two oppoſite points, making an angle of $23\frac{1}{2}$ degrees with the equinoctial on each ſide. So that one half of the ecliptic is in the northern hemiſphere, and the other in the ſouthern. It contains 360 equal parts, called degrees (as all other circles do, whether great or ſmall) and as the earth goes once round it every year, the ſun will appear to do the ſame, changing his place almoſt a degree, at a mean rate, every 24 hours. So that whatever place, or degree of the ecliptic, the earth is in at any time, the ſun will then appear in the oppoſite. And as one half of the ecliptic is on the north ſide of the equinoctial, and the other half on the ſouth; the ſun, as ſeen from the earth, will be half a year on the ſouth ſide of the equinoctial, and half a year on the north: and twice a year in the equinoctial itſelf. *Ecliptic.*

The ecliptic is divided by aſtronomers into 12 equal parts, called *ſigns*, each ſign into 30 *degrees*, and each degree into 60 *minutes*: *Signs and degrees.*

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but in uſing the globes, we ſeldom want the ſun's place nearer than half a degree of the truth.

The names and characters of the 12 ſigns are as follow; beginning at that point of the ecliptic where it croſſes the equinoctial to the northward, and reckoning eaſtward round to the ſame point again. And the days of the months on which the ſun now enters the ſigns, are ſet down below them.

Aries,	*Taurus,*	*Gemini,*	*Cancer,*	*Leo,*	*Virgo,*
♈	♉	♊	♋	♌	♍
March	April	May	June	July	Auguſt
20	20	21	21	23	23
Libra,	*Scorpio*	*Sagittarius,*	*Capricorn,*	*Aquarius,*	*Piſces,*
♎	♏	♐	♑	♒	♓
September	October	November	December	January	Feb.
23	23	22	21	20	18

By remembering on what day the ſun enters any particular ſign, we may eaſily find his place any day afterward, whilſt he is in that ſign, by reckoning a degree for each day; which will occaſion no error of conſequence in uſing the globes.

When 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 from the

the equinoctial, one on the north fide of it, and the other on the fouth. The northern tropic touches the ecliptic at the beginning of *Cancer*, the fouthern at the beginning of *Capricorn*; for which reafon the former is called the *tropic of Cancer*, and the latter the *tropic of Capricorn*.

Polar circles.

The *polar circles* in the heaven, are each 23½ degrees from the poles, all around. That which goes round the north pole, is called the *arctic circle*, from ἄρκτος, which fignifies a *bear*; there being a conftellation or groupe of ftars near the north pole, which goes by that name. The fouth polar circle, is called the *antarctic circle*, from its being oppofite to the arctic.

The ecliptic, tropics, and polar circles, are drawn upon the terreftrial globe, as well as upon the celeftial. But the ecliptic, being a great fixed circle in the heavens, cannot properly be faid to belong to the terreftrial globe; and is laid down upon it only for the conveniency of folving fome problems. So that, if this circle on the terreftrial globe was properly divided into the months and days of the year, it would not only fuit the globe better, but would alfo make the problems thereon much eafier.

In order to form a true idea of the earth's motion round its axis every 24 hours, which is the caufe 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 23½ 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 23½ 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 to turn round, and to fhew

itfelf

itſelf all around to the candle, carry it ſlowly round the hoop by the thread, from weſt, by ſouth, to eaſt; which is the way that the earth moves round the ſun, once a year, in the ecliptic: and you will ſee, that whilſt the globe continues in the lower part of the hoop, the candle (being then north of the equator) will conſtantly ſhine round the north pole; and all the northern places which go through any part of the dark, will go through a leſs portion of it than they do of the light; and the more ſo, the farther they are from the equator: conſequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the higheſt and loweſt points, the candle will be directly over the equator, and will enlighten the globe juſt from pole to pole; and then, every place on the globe will go through equal portions of light and darkneſs, as it turns round its axis; and conſequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, towards the higheſt part of the hoop, the candle will be on the ſouth ſide of the equator, ſhining farther and farther round the ſouth pole, as the globe riſes higher and higher in the hoop; leaving the north pole as much in darkneſs, as the ſouth pole is then in the light, and making long days and ſhort nights on the ſouth ſide of the equator, and the contrary on the north ſide, whilſt the globe continues in the northern or higher ſide of the hoop: and when it comes to the higheſt point, the days will be at the longeſt, and the nights at the ſhorteſt, in the ſouthern hemiſphere; and the reverſe in the northern. As the globe advances and deſcends in the hoop, the light will gradually recede from the ſouth pole, and approach towards the north pole, which will cauſe the northern days to lengthen, and the ſouthern days to ſhorten in the ſame proportion. When the globe comes to the middle point, between the higheſt and loweſt points of the hoop, the candle will be over the equator, enlightening the globe juſt from pole to pole, when every place of the earth (except the poles) will go through equal portions of light and darkneſs; and conſequently, the day and night will be then equal, all over the globe.

And thus at a very ſmall expence, one may have a delightful and demonſtrative view of the cauſe of days and nights, with their gradual increaſe and decreaſe in length, through the whole year together, with the viciſſitudes of ſpring, ſummer, autumn, and winter, in each annual courſe of the earth round the ſun.

If the hoop be divided into 12 equal parts, and the ſigns be marked in order upon it, beginning with *Cancer* at the higheſt point of the hoop,

hoop, and reckoning eaftward (or contrary to the apparent motion of the fun) you will fee how the fun appears to change his place every day in the ecliptic, as the globe advances eaftward along the hoop, and turns round its own axis: and that when the earth is in a low fign, as at *Capricorn*, the fun muft appear in a high fign, as at *Cancer*, oppofite to the earth's real place: and that whilft the earth is in the fouthern half of the ecliptic, the fun appears in the northern half, and *vice verfâ:* that the farther any place is from the equator, between it and the polar circle, the greater is the difference between the longeft and fhorteft day at that place; and that the poles have but one day and one night in the whole year.

Thefe things premifed, we fhall proceed to the defcription and ufe of the terreftrial 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 diftinguifh them, the iflands properly fituated, the rivers and principal towns inferted, as they have been afcertained upon the earth by meafurement and obfervation. The *terreftrial globe* defcribed.

The equator, ecliptic, tropics, polar circles, and meridians, are laid down upon the globe in the manner already defcribed. The ecliptic is divided into 12 figns, and each fign into 30 degrees, which are generally fubdivided into halves, and into quarters if the globe is large. Each tropic is $23\frac{1}{2}$ degrees from the equator, and each polar circle $23\frac{1}{2}$ degrees from its refpective pole. Circles are drawn parallel to the equator, at every ten degrees diftance from it on each fide to the poles: thefe circles are called *parallels of latitude*. On large globes there are circles drawn perpendicularly through every tenth degree of the equator, interfecting 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; thefe circles are generally called *meridians*, fometimes *circles of longitude*, and at other times *hour-circles*.

The globe is hung in a brafs ring, called the *brafen meridian*; and turns upon a wire in each pole funk half its thicknefs into one fide of the meridian ring; by which means, *that* fide of the ring divides the globe into two equal parts, called the *eaftern* and *weftern hemifpheres*; as the equator divides it into two equal parts, called the *northern* and *fouthern hemifpheres*. This ring is divided into 360 equal parts or degrees, on the fide wherein the axis of the globe turns. One half of thefe degrees are numbered, and reckoned, from the equator to the

 poles,

poles, where they end at 90: their uſe is to ſhew the latitudes of places. The degrees on the other half of the meridian ring, are numbered from the poles to the equator, where they end at 90: their uſe is to ſhew how to elevate either the north or ſouth pole above the horizon, according to the latitude of any given place, as it is north or ſouth of the equator.

The braſen meridian is let into two notches made in a broad flat ring, called the *wooden horizon*, the upper ſurface of which divides the globe into two equal parts, called the *upper* and *lower hemiſpheres*. One notch is in the north point of the horizon, and the other in the ſouth. On this horizon are ſeveral concentric circles, which contain the months and days of the year, the ſigns and degrees anſwering to the ſun's place for each month and day, and the 32 points of the compaſs.—The graduated ſide of the braſs meridian lies towards the eaſt ſide of the horizon, and ſhould be generally kept toward the perſon who works problems by the globes.

There is a ſmall *horary circle*, ſo fixed to the north part of the braſen 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 braſen meridian; which is the contrivance of the ingenious Mr. *Joſeph Harris*, maſter of the aſſay-office in the Tower of London; and makes it very convenient for putting the poles of the globe through the horizon, and for elevating the pole to ſmall latitudes and declinations of the ſun; which cannot be done where there is only one horary circle fixed to the outer edge of the braſen meridian.

There is a thin ſlip of braſs, called the *quadrant of altitude*, which is divided into 90 equal parts or degrees, anſwering exactly to ſo many degrees of the equator. It is occaſionally fixed to the uppermoſt point of the braſen meridian by a nut and ſcrew. The diviſions end at the nut, and the quadrant is turned round upon it.

As the globe has been ſeen by moſt people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expreſſed, we judge it would ſignify very little to refer to a figure of it; and ſhall therefore only give ſome directions how to chooſe a globe, and then deſcribe its uſe.

Directions for chooſing of globes.

1. See that the papers be well and neatly paſted on the globes, which you may know, if the lines and circles thereon meet exactly, and continue all the way even and whole; the circles not breaking into

into feveral arches, nor the papers either coming fhort, or lapping over one another.

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 that when the quadrant of altitude is placed as far from the equator, on the brafen meridian, as the pole is elevated above the horizon, the beginning of the degrees of the quadrant reaches juft to the plane furface of the horizon.

10. See that whilft the index of the hour-circle (by the motion of the globe) paffes from one hour to another, 15 degrees of the equator pafs under the graduated edge of the brafen meridian.

11. See that the wooden horizon be made fubftantial and ftrong : it being generally obferved, that in moft globes, the horizon is the firft part that fails, on account of its having been made too flight.

In ufing the globes, keep the eaft fide of the horizon towards you (unlefs your problem requires the turning of it) which fide you may know by the word Eaft upon the horizon ; for then you have the graduated fide of the meridian towards you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated fide of the meridian. Directions for ufing them.

In working fome problems, it will be neceffary to turn the whole globe and horizon about, 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 thruſt in the feather-end of a quill between the ball of the globe and the braſen meridian; which, without hurting the ball, will keep it from turning in the meridian, whilſt you turn the weſt ſide of the horizon towards you.

PROBLEM I.

*To find the * latitude and † longitude of any given place upon the globe.*

Turn the globe on its axis, until the given place comes exactly under that graduated ſide of the braſen meridian, on which the degrees are numbered from the equator; and obſerve what degree of the meridian the place then lies under; which is its latitude, north or ſouth, as the place is north or ſouth of the equator.

The globe remaining in this poſition, the degree of the equator, which is under the braſen meridian, is the longitude of the place (from the meridian of *London* on the *Engliſh* globes) which is eaſt or weſt, as the place lies on the eaſt or weſt ſide of the firſt meridian of the globe.—All the *Atlantic Ocean*, and *America*, is on the weſt ſide of the meridian of *London*; and the greateſt part of *Europe*, and of *Africa*, together with all *Aſia*, is on the eaſt ſide of the meridian of *London*, which is reckoned the *firſt meridian* of the globe by the *Engliſh* geographers and aſtronomers.

PROBLEM II.

The longitude and latitude of a place being given, to find that place on the globe.

Look for the given longitude in the equator (counting it eaſtward or weſtward from the firſt meridian, as it is mentioned to be eaſt or weſt;) and bring the point of longitude in the equator to the braſen meridian,

* The latitude of a place is its diſtance from the equator, and is north or ſouth, as the place is north or ſouth of the equator. Thoſe who live at the equator have no latitude, becauſe it is there that the latitude begins.

† The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the ſaid place is diſtant from the meridian of any other place from which we reckon, either eaſtward or weſtward, for 180 degrees, or half round the globe. The Engliſh reckon the longitude from the meridian of London, and the French now reckon it from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called the *firſt meridian.* The places upon this meridian have no longitude, becauſe it is there that the longitude begins.

meridian, on that side which is above the south point of the horizon: then count from the equator, on the brasen meridian, to the degree of the given latitude, towards the north or south pole, according as the latitude is north or south; and under that degree of latitude on the meridian, you will have the place required.

PROBLEM III.

To find the difference of longitude, or difference of latitude, between any two given places.

Bring each of these places to the 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 degrees for every hour, and one degree for every four minutes.

N. B. When we speak of bringing any place to the brasen meridian, it is the graduated side of the meridian that is meant.

PROBLEM IV.

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

Bring the given place to the brasen meridian, then all those places which lie under that side of the meridian, from pole to pole, have the same longitude with the given place. Turn the globe round its axis, and all those places which pass under the same degree of the meridian that the given place does, have the same latitude with that place.

Since

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

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

The globe remaining in the ſame poſition, ſet the hour-index to the upper XII on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the ſame latitude with the given place, is the *periœci* required. Thoſe who live at the poles have no *periœci*.

As the globe now ſtands (with the index at the lower XII) the *antipodes* of the given place will be under the ſame point of the braſen

* 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.

meridian

meridian where its *antæci* ſtood before. Every place upon the globe has its *antipodes*.

PROBLEM VI.

To find the diſtance between any two places on the globe.

Lay the graduated edge of the quadrant of altitude over both the places, and count the number of degrees intercepted between them on the quadrant; then multiply theſe degrees by 60, and the product will give the diſtance in geographical miles: but to find the diſtance in Engliſh miles, multiply the degrees by $69\frac{1}{2}$, and the product will be the number of miles required. Or, take the diſtance betwixt any two places with a pair of compaſſes, and apply that extent to the equator; the number of degrees, intercepted between the points of the compaſſes, is the diſtance in degrees of a great circle *; which may be reduced either to geographical miles, or to Engliſh miles, as above.

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 meridian, directly over that place; then keeping the globe in that poſition, turn the quadrant quite round upon it, and the degree of the quadrant that touches the ſecond place, will paſs over all the other places which are equally diſtant with it from the given place.

This is the ſame as if one foot of a pair of compaſſes was ſet in the given place, and the other foot extended to the ſecond place, whoſe

* Any circle that divides the globe into two equal parts, is called a *great circle*, as the equator or meridian. Any circle that divides the globe into two unequal parts (which every parallel of latitude does) is called a *leſſer circle*. Now, as every circle, whether great or ſmall, contains 360 degrees, and a degree upon the equator or meridian contains 60 geographical miles, it is evident, that a degree of longitude upon the equator, is longer than a degree of longitude upon any parallel of latitude, and muſt therefore contain a greater number of miles. So that, although all the degrees of latitude are equally long upon an artificial globe (though not preciſely ſo upon the earth itſelf) yet the degrees of longitude decreaſe in length, as the latitude increaſes, but not in the ſame proportion. The following table ſhews the length of a degree of longitude, in geographical miles, and hundredth parts of a mile, for every degree of latitude, from the equator to the poles: a degree on the equator being 60 geographical miles.

Great circles. *Leſſer circles.*

diſtance

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 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 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

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 which the sun is (or his place) on that day at noon. Find the same degree of that sign in the ecliptic line upon the globe, and having brought it to the brasen meridian, observe what degree of the meridian stands over it; for that is the sun's declination, reckoned from the equator.

PROBLEM XI.

The day of the month being given, to find all those places of the earth over which the sun will pass vertically on that day.

Find the sun's place in the ecliptic for the given day, and having brought it to the brasen meridian, observe what point of the meridian is over it; then, turning the globe round its axis, all those places which pass under that point of the meridian, are the places required: for as their latitude is equal, in degrees and parts of a degree, to the sun's declination, the sun must be directly over head to each of them at its respective noon.

* 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.

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 brasen meridian, and mark the degree of latitude that is exactly over it on the meridian; then turn the globe round its axis, and observe the two degrees of the ecliptic which pass exactly under that degree of latitude: lastly, find on the wooden horizon, the two days of the year in which the sun is in those degrees of the ecliptic, and they are the days required: for on them, and none else, the sun's declination is equal to the latitude of the given place: and consequently, he will then be vertical to it at noon.

PROBLEM XIII.

To find all those places of the north frigid zone, where the sun begins to shine constantly without setting, on any given day, from the 21st of March to the 23d of September.

On these two days, the sun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and so make equal day and night to all places of the earth. But as the sun declines from the equator, towards either pole, he will shine just as many degrees round that pole, as are equal to his declination from the equator; so that no place within that distance of the pole will then go through any part of the dark, and consequently the sun will not set to it. Now, as the sun's declination is northward, from the 21st of March to the 23d of September, he must constantly shine round the north pole all that time; and on the day that he is in the northern tropic, he shines upon the whole north frigid zone; so that no place within the north polar circle goes through any part of the dark on that day. Therefore,

* 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 23½ on each side of the equator: the *temperate zones* lie between the tropics and polar circles, or from 23½ degrees of latitude, to 66½, on each side of the equator; and are each 43 degrees in breadth: the *frigid zones* are the spaces included within the polar circles, which being each 23½ degrees from their respective poles, the breadth of each of these zones is 47 degrees. As the sun never goes without the tropics, he must every moment be vertical to some place or other in the torrid zone.

Having

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

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

PROBLEM XIV.

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

Having found the ſun's declination for the given day (by Prob. IX.) mark it with a chalk on the braſen meridian: then bring the place where you are (ſuppoſe London) to the braſen meridian, and ſet the index to the given hour; which done, turn the globe on its axis, until the index points to XII at noon; and the place on the globe, which is then directly under the point of the ſun's declination marked upon the meridian, has the ſun that moment in the zenith, or directly over head.

PROBLEM XV.

The day and hour at any place being given, to find all thoſe places where the ſun is then riſing, or ſetting, or on the meridian: conſequently, all thoſe places which are enlightened at that time, and thoſe which are in the dark.

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

Having found the place to which the ſun is vertical at the given hour, if the place be in the northern hemiſphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of

 that

that place; if the place be in the southern hemisphere, elevate the south pole accordingly; and bring the said place to the brasen meridian. Then, all those places which are in the western semicircle of the horizon, have the sun rising to them at that time; and those in the eastern semicircle have it setting: to those under the upper semicircle of the brass meridian, it is noon; and to those under the lower semicircle, it is mid-night. All those places which are above the horizon, are enlightened by the sun, and have the sun just as many degrees above them, as they themselves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the brasen meridian over the place to which the sun is vertical; and then, laying it over any other place, observe what number of degrees on the quadrant are intercepted between the said place and the horizon. In all those places that are 18 degrees below the western semicircle of the horizon, the morning twilight is just beginning; in all those places that are 18 degrees below the eastern semicircle of the horizon, the evening twilight is ending; and all those places that are lower than 18 degrees, have dark night.

If any place be brought to the upper semicircle of the brasen meridian, and the hour-index be set to the upper XII or noon, and then the globe be turned round eastward on its axis; when the place comes to the western semicircle of the horizon, the index will shew the time of sun-rising at that place; and when the same place comes to the eastern semicircle of the horizon, the index will shew the time of sun-set.

To those places which do not go under the horizon, the sun sets not on that day: and to those which do not come above it, the sun does not rise.

PROBLEM XVI.

The day and hour of a lunar eclipse being given; to find all those places of the earth to which it will be visible.

The moon is never eclipsed but when she is full, and so directly opposite to the sun, that the earth's shadow falls upon her. Therefore, whatever place of the earth the sun is vertical to at that time, the moon must be vertical to 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

place to the upper part of the brafen meridian, as in the former problem: then, as the fun will be vifible to all thofe parts of the globe which are above the horizon, the moon will be vifible to all thofe parts of the globe which are below it, at the time of her greateft obfcuration.

But with regard to an eclipfe of the fun, there is no fuch thing as fhewing to what places it will be vifible, with any degree of certainty, by a common globe; becaufe the moon's fhadow covers but a fmall portion of the earth's furface, and her latitude, or declination from the ecliptic, throws her fhadow fo varioufly upon the earth, that to determine the places on which it falls, recourfe muft be had to long calculations.

PROBLEM XVII.

*To rectify the globe for the latitude, the * zenith, and the fun's place.*

Find the latitude of the place (by Prob. I.) and if the place be in the northern hemifphere, raife the north pole above the north point of the horizon, as many degrees (counted from the pole upon the brafen meridian) as are equal to the latitude of the place. If the place be in the fouthern hemifphere, raife the fouth pole above the fouth point of the horizon, as many degrees as are equal to the latitude. Then, turn the globe till the place comes under its latitude on the 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 graduated fide of the brafen meridian, and fet the hour-index to XII at noon, which is the uppermoft XII on the hour-circle; and the globe will be rectified.

The latitude of any place, is equal to the elevation of the neareft Remark. 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

* The *zenith*, in this fenfe, is the higheft point of the brafen meridian above the horizon; but in the proper fenfe, it is that point of the heaven which is directly vertical to any given place, at any given inftant of time.

over

over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view: if we go from the equator, towards either pole of the earth, we ſhall ſee the correſponding pole of the heaven riſing gradually above our horizon, juſt as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the correſponding pole of the heaven would be directly over our head. Conſequently, the elevation or height of the pole in degrees above the horizon, is equal to the number of degrees that the place is from the equator.

PROBLEM XVIII.

*The latitude of any place, not exceeding * 66½ 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.

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 66½ degrees of latitude: and the nearer to 66½, 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.

* All places whoſe latitude is more than 66½ degrees, are in the frigid zones: and to thoſe places the ſun does not ſet in ſummer, for a certain number of diurnal revolutions, which occaſions this limitation of latitude.

Rectify

Rectify the globe, and bring the fun's place in the ecliptic to the eaftern fide of the horizon; then mark that point of the ecliptic with a chalk which is in the weftern fide of the horizon, it being the point oppofite to the fun's place: this done, lay the quadrant of altitude over the faid point, and turn the globe eaftward, keeping the quadrant at the chalk-mark, until it be juft 18 degrees high on the quadrant; and the index will point out the time when the morning twilight begins: for the fun's place will then be 18 degrees below the eaftern fide of the horizon. To find the time when the evening twilight ends, bring the fun's place to the weftern fide of the horizon, and the point oppofite to it, which was marked with the chalk, will be rifing in the eaft: then, bring the quadrant over that point, and keeping it thereon, turn the globe weftward, until the faid point be 18 degrees above the horizon on the quadrant, and the index will fhew the time when the evening twilight ends; the fun's place being then 18 degrees below the weftern fide of the horizon.

PROBLEM XX.

To find on what day of the year the fun begins to fhine conftantly without fetting, on any given place in the north frigid zone; and how long he continues to do fo.

Rectify the globe to the latitude of the place, and turn it about until fome point of the ecliptic, between *Aries* and *Cancer*, coincides with the north point of the horizon where the brafen meridian cuts it: then find, on the wooden horizon, what day of the year the fun is in that point of the ecliptic; for that is the day on which the fun begins to fhine conftantly on the given place, without fetting. This done, turn the globe until fome point of the ecliptic, between *Cancer* and *Libra*, coincides with the north point of the horizon, where the brafen meridian cuts it; and find, on the wooden horizon, on what day the fun is in that point of the ecliptic; which is the day that the fun leaves off conftantly fhining 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 conftantly 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 juft as much of the oppofite part of

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the ecliptic that never rises; therefore, the sun will keep as long constantly below the horizon in winter, as above it in summer.

Whoever considers the globe, will find, that all places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the opposite season.

PROBLEM XXI.

To find in what latitude the sun shines constantly without setting, for any length of time less than * $182\frac{1}{2}$ *of our days and nights.*

Find a point in the ecliptic half as many degrees from the beginning of *Cancer* (either toward *Aries* or *Libra*) as there are † natural days in the time given; and bring that point to the north side of the 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.

PROBLEM XXII.

The latitude of a place, not exceeding $66\frac{1}{2}$ *degrees, and the day of the month being given; to find the sun's amplitude, or point of the compass on which he rises or sets.*

Rectify the globe, and bring the sun's place to the eastern side of the horizon; then observe what point of the compass on the horizon stands right against the sun's place, for that is his amplitude at rising. This done, turn the globe westward, until the sun's place comes to the western side of the horizon, and it will cut the point of his amplitude at setting. Or, you may count the rising amplitude in degrees, from the east point of the horizon, to that point where the sun's place cuts it; and the setting amplitude, from the west point of the horizon, to the sun's place at setting.

* The reason of this limitation is, that $182\frac{1}{2}$ 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 XXIII.

*The latitude, the sun's place, and his * altitude, being given; to find the hour of the day, and the sun's azimuth, or number of degrees that he is distant from the meridian.*

Rectify the globe, and bring the sun's place to the given height upon the quadrant of altitude; on the eastern side of the horizon, if the time be in the forenoon; or the western side, if it be in the afternoon: then, the index will shew the hour; and the number of degrees in the horizon, intercepted between the quadrant of altitude and the south point, will be the sun's true azimuth at that time.

N. B. Always when the quadrant of altitude is mentioned in working any problem, the graduated edge of it is meant.

If this be done at sea, and compared with the sun's azimuth, as shewn by 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 is the sun's azimuth, reckoned from the south.

PROBLEM XXV.

The latitude, the sun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and hour of the day, though they had all been lost.

Rectify the globe for the latitude and † zenith, and set the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn

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

† By rectifying the globe for the zenith, is meant screwing the quadrant of altitude to the given latitude on the brass meridian.

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the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the ſun's place; and the day of the month anſwering thereto, will be found over the like place of the ſun on the wooden horizon. Keep the quadrant of altitude in that poſition, and having brought the ſun's place to the braſen meridian, and the hour-index to XII at noon, turn back the globe, until the ſun's place cuts the quadrant of altitude again, and the index will ſhew the hour.

Any two points of the ecliptic which are equidiſtant 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,

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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 the north pole to about 66½ degrees; but if the latitude be ſouth, bring the beginning of *Capricorn* to the meridian, and elevate the ſouth pole to about 66½ degrees; becauſe the longeſt day in north latitude, is when the ſun is in the firſt point of *Cancer*; and in ſouth latitude, when he is in the firſt point of *Capricorn*. Then ſet the hour-index to XII at noon, and turn the globe weſtward, until the index points at half the number of hours given; which done, keep the globe from turning on its axis, and ſlide the meridian down in the notches, until the aforeſaid point of the ecliptic (viz. *Cancer* or *Capricorn)* comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

PROBLEM XXVIII.

*The latitude of any place, not exceeding 66½ degrees, being given; to find in what * climate the place is.*

Find the length of the longeſt day at the given place by Prob. XXVI. and whatever be the number of hours whereby it exceedeth twelve, double that number, and the ſum will give the climate in which the place is.

PROBLEM XXIX.

The latitude, and the day of the month, being given; to find the hour of the day when the ſun ſhines.

Set the wooden horizon truly level, and the braſen meridian due north and ſouth by a mariner's compaſs: then, having rectified the

* A *climate*, from the equator to either of the polar circles, is a tract of the earth's ſurface, included between two ſuch parallels of latitude, that the length of the longeſt day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the ſun keeps long above the horizon without ſetting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and ſix from each polar circle to its reſpective pole.

 globe,

globe, ſtick a ſmall ſewing-needle into the ſun's place in the ecliptic, perpendicular to that part of the ſurface of the globe: this done, turn the globe on its axis, until the needle comes to the braſen meridian, and ſet the hour-index to XII at noon; then, turn the globe on its axis, until the needle points exactly towards the ſun (which it will do when it caſts no ſhadow on the globe) and the index will ſhew the hour of the day.

PROBLEM XXX.

A pleaſant way of ſhewing all thoſe places of the earth which are enlightened by the ſun, and alſo the time of the day when the ſun ſhines.

Take the terreſtrial ball out of the wooden horizon, and alſo out of the braſen meridian; then ſet it upon a pedeſtal in ſun-ſhine, in ſuch a manner, that its north pole may point directly towards the north pole of the heaven, and the meridian of the place where you are be directly towards the ſouth. Then, the ſun will ſhine upon all the like places of the globe, that he does on the real earth, riſing to ſome when he is ſetting to others; as you may perceive by that part where the enlightened half of the globe is divided from the half in the ſhade, by the boundary of the light and darkneſs: all thoſe places, on which the ſun ſhines, at any time, having day; and all thoſe, on which he does not ſhine, having night.

If a narrow ſlip of paper be put round the equator, and divided into 24 equal 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.

The principles of dialing ſhall be explained farther on, by the terreſtrial globe. At preſent we ſhall only add the following obſervations upon it; and then proceed to the uſe of the celeſtial globe.

1. *The latitude of any place is equal to the elevation of the pole above the horizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the latitude wants of* 90 *degrees.*

2. *Thoſe places which lie on the equator, have no latitude, it being there that the latitude begins; and thoſe places which lie on the firſt meridian*

have no longitude, it being there that the longitude begins. Consequently, that particular place of the earth where the first meridan intersects the equator, has neither longitude nor latitude.

3. *In all places of the earth, except the poles, all the points of the compass may be distinguished in the horizon: but from the north pole, every place is south; and from the south pole, every place is north. Therefore, as the sun is constantly above the horizon of each pole for half a year in its turn, he cannot be said to depart from the meridian of either pole for half a year together. Consequently, at the north pole it may be said to be noon every moment for half a year; and let the winds blow from what part they will, they must always blow from the south; and at the south pole, from the north.*

4. *Because one half of the ecliptic is above the horizon of the pole, and the sun, moon and planets, move in (or nearly in) the ecliptic; they will all 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 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 quadrant, and thence ascending, it will cross the*

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

quadrant

quadrant towards the south; but before it arrives at the meridian, it will cross the quadrant again, and pass over the meridian northward of Barbadoes. And if the quadrant be set about 18 *degrees north of the west, the sun's place will cross it twice, as it descends from the meridian towards the horizon, in the afternoon.*

8. *In all places of the earth between the equator and poles, the days and nights are equally long, viz.* 12 *hours each, when the sun is in the equinoctial: for, in all elevations of the pole, short of* 90 *degrees (which is the greatest) one half of the equator or equinoctial will be above 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 ecliptic, the circle of the sun's daily motion is divided into two unequal parts by the horizon.*

10. *The nearer that any place is to the equator, the less is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the sun describes in the heaven every* 24 *hours, being cut more nearly equal in the former case, and more unequally in the latter.*

11. *In all places lying upon any given parallel of latitude, however long or short the day or night be at any one of these places, at any time of the year, it is then of the same length at all the rest; for in turning the globe round its axis (when rectified according to the sun's declination) all these places will keep equally long above or below the horizon.*

12. *The sun is vertical twice a year to every place between the tropics; to those under the tropics, once a year, but never any where else. For, there can be no place between the tropics, but that there will be two points in the ecliptic, whose declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the sun never goes without the tropics, he can never be vertical to any place that lies without them.*

13. *To all places in the* * *torrid zone, the duration of the twilight is least, because the sun's daily motion is the most perpendicular to the horizon. In the frigid* † *zones, greatest; because the sun's daily motion is nearly parallel to the horizon; and therefore he is the longer of getting* 18 *degrees below it (till which time the twilight always continues.) And in the*

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

*the * temperate zones it is at a medium between the two, because the obliquity of the sun's daily motion is so.*

14. *In all places lying exactly under the polar circles, the sun, when he is in the nearest tropic, continues 24 hours above the horizon without setting; because no part of that tropic is below their horizon. And when the sun is in the farthest tropic, he is for the same length of time without rising; because no part of that tropic is above their horizon. But, at all other times of the year, he rises and sets there, as in other places; because all the circles that can be drawn parallel to the equator, between the tropics, are more or less cut by the horizon, as they are farther from, or nearer to, that tropic which is all above the horizon: and when the sun is not in either of the tropics, his diurnal course must be in one or other of these circles.*

15. *To all places in the northern hemisphere, from the equator to the polar circle, the longest day and shortest night is when the sun is in the northern tropic; and the shortest day and longest night is when the sun is in the southern tropic; because no circle of the sun's daily 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 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*

* Between the tropics and polar circles.

following

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.

LECT. IX.

The uſe of the celeſtial globe, and armillary ſphere.

The *celeſtial globe.* HAVING done for the preſent with the terreſtrial globe, we ſhall proceed to the uſe of the celeſtial; firſt premiſing, that as the equator, ecliptic, tropics, polar circles, horizon, and braſen meridian, are exactly alike on both globes, all the former problems concerning the ſun are ſolved the ſame way by both globes. The method alſo of rectifying the celeſtial globe is the ſame as rectifying the terreſtrial, viz. Elevate the pole according to the latitude of your place, then ſcrew the quadrant of altitude to the zenith, on the braſs meridian; bring the ſun's place in the ecliptic to the graduated edge of the braſs meridian, on the ſide which is above the ſouth point of the wooden horizon, and ſet the hour-index to the uppermoſt XII, which ſtands for noon.

To rectify it.

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,*

* *The great circle* that paſſes through the *equinoctial points* at the beginning of