Letter XL.—On the celebrated Problem of the Longitude: General Description of the Earth, of its Axis, its two Poles, and the Equator.

You will by this time, no doubt, imagine that enough has been said of electricity; and indeed I have nothing farther to add on that subject; and am, of course, not a little embarrassed about the choice of one worthy of your attention.

In order to determine my choice, I think myself obliged to take into consideration those subjects which most materially interest human knowledge, and which authors of celebrity most frequently bring forward. These are subjects respecting which, it is to be presumed, persons of quality have considerable information.

As you must unquestionably have heard frequent mention made of the celebrated problem of the longitude, for the solution of which the British nation has proposed a most magnificent premium, I presume that my labour will not be wholly thrown away if I employ it in laying before you a fair state of that important question. It has such an intimate connexion with the knowledge of our terraqueous globe, that it were a shame to be ignorant of it. It will accordingly furnish me with an opportunity of explaining a variety of interesting articles, which I flatter myself you would wish to see elucidated.

I begin, then, with a general description of the earth, which may be considered as a globe, though it has been discovered by recent observation, that its real figure is a spheroid, somewhat flattened; but the difference is so small, that it may for the present be altogether neglected.

The first thing to be remarked on the globe of the earth, are two points on its surface, denominated the two poles of the earth. Round these two points the globe of the earth every day revolves, as you turn a ball fixed between the two points of a turning machine. This motion is called the daily or diurnal motion of the earth, each revolution of which is performed in about twenty-four hours; or, to speak according to appearances, you know that the whole heavens, which we consider as a concave ball, within whose circumference the earth revolves, appear to turn round the earth in the same space of twenty-four hours. This motion is likewise performed round two fixed points in the heavens, denominated the poles of heaven; now if we conceive a straight line drawn from one of these poles of heaven to the other, that line will pass through the centre of the earth.

But you will easily comprehend, that the appearance must be the same, whether the earth turns round these poles, while the heavens remain in a state of rest; or whether the heavens revolve round their poles, the earth remaining at rest. On either supposition we are equally led to the knowledge of the poles of the earth, the foundation not only of astronomy, but likewise of geography.

Let Figure 9. of Plate IV. represent the globe of the earth, whose poles are the points A and B; one of these poles, A, is named the *south* or *antarctic pole*, the other, B, is denominated the *north* or *arctic pole*. This last is nearer to the region of the globe which we inhabit.

I remark that these two poles are directly opposite to each other; in other words, were a straight line A B to be drawn directly through the earth, it would pass precisely through the middle C, that is to say, through the centre of the earth. This straight line A B has accordingly its appropriate name, and is called *the axis of the earth*, which being produced in both directions to the heavens, will terminate in the two points which are called the poles of heaven; and to which we give the same names as to those of the earth.

These two poles of the earth are by no means a mere fiction, or a speculation of astronomers and geographers; but are really most essential points marked on the surface of our globe; for it is well known, that the nearer we approach these two points, the colder* and more rugged the face of nature becomes, to such a degree, that the regions adjacent to the poles are absolutely uninhabitable, from the excessive cold which prevails there during the winter. No one instance, accordingly, has been produced of any traveller, whether by land or water, who has reached either of the poles. It may be affirmed, therefore, that these two spots of the earth are altogether inaccessible.

Having thus determined the two poles of the earth A and B, we may conceive the whole globe divided into two hemispheres, DBE and DAE, each of which terminates in one of the poles as its summit. For this purpose we are to suppose the globe bisected through its centre C, so that the section shall be perpendicular to the axis of the earth; this section will mark on the surface a circle encompassing the whole globe, every where equally distant from the two poles. This surrounding circle is denominated the *Equator*. The regions adjacent to it are the hottest, and on that account, as the ancients believed,

* I have lately had occasion to show, that the greatest cold is not at the Poles, but at two points on each side of the Pole, nearly coincident with the Magnetic Poles. The mean temperature of Melville Island, which Captain Parry found to be 1°½ for 1819–1820, is undoubtedly lower than that of the North Pole of our globe.—See *Edinburgh Transactions*, vol. ix. p. 201.—Ed.

almost uninhabitable; but they are now found to be exceedingly populous, though the heat be there almost insupportable.

But as you remove from the equator, on either side, toward the poles, the countries become more and more temperate, till at last, on approaching too near the poles, the cold becomes intolerable.

As the equator divides the earth into two hemispheres, each bears the name of the pole contained in it; thus the half DBE, which contains the north pole, is denominated the *northern hemisphere*, and in it is situated all Europe, almost the whole of Asia, part of Africa, and the half of America. The other hemisphere DAE, is, from its pole, denominated the *southern hemisphere*, and contains the greatest part of Africa, the other half of America, and several isles, which geographers attribute to Asia, as you will recollect to have seen in maps of the world.

18*th August* 1761.

Letter XLI.—Of the Magnitude of the Earth; of Meridians, and the shortest Road from Place to Place.

Having distinctly fixed the idea of the poles of the earth, and of the equator, which you much more easily imagine on a globe, than I can represent by a figure, every other necessary idea will readily follow from these.

I must, however, subjoin a further elucidation of considerable importance. The axis of the earth, passing from one pole to the other, through the centre of the earth, is a diameter of the globe, and consequently is double the length of the radius. A radius of the earth, or the distance from every point on the surface to the centre, is computed to be 3956

English miles; the axis of the earth will therefore contain 7912 English miles. And the equator being a circle whose centre is likewise that of the earth, it will have nearly the same radius, namely 3956 miles; the diameter of the equator will accordingly be 7912 miles, and its whole circumference 23736 miles nearly: so that if you were to make a tour of the globe, following the tract of the equator, you must perform a journey of almost 23736 English miles. This will give you some idea of the magnitude of the earth.

The equator being a circle, it is supposed to be divided into 360 equal parts, named *degrees*; a degree of the equator contains, therefore, 65 English miles,* as 9 times 360 make nearly 24196.

Every degree is again subdivided into 60 equal parts, called *minutes*, so that every minute contains more than an English mile, or 6076 English feet; a *second* being the sixtieth part of a minute, will contain 101 English feet.

It being impossible to represent a globe on paper, any other way than by a circle, you must supply this defect by imagination. Accordingly, AB, (Plate IV. *Fig.* 10.) being the two poles of the earth, B the north, and A the south, DMNE will represent the equator, or rather that half of it which is turned toward us, the other being concealed on the opposite side.

The line DMNE represents, then, a semicircle, as well as BEA and BDA; all these semicircles having their centres at that of the globe, C. It is possible to imagine an infinite number of other semicircles,

* These results are only approximative. As the earth is a spheroid, flattened at the poles like an orange, the circumference of the meridian is about 24855.84 English miles, and the circumference of the equator 24896.16 English miles. A geographical mile of 60 to a degree will therefore contain 6075.6 English feet.—Ed.

all of them drawn through the two poles of the earth A and B, and passing through every point of the equator, as BMA, BNA; these will all be similar to the first, BDA and BEA, though in the figure their form appears very different. Imagination must correct this, and the fact is apparent on a real globe.

All these semicircles drawn from one pole to the other, through whatever point of the equator they may pass, are denominated *meridians*; or rather, a *meridian* is nothing else but a semicircle which, on the surface of the earth, is drawn from one pole to the other; and you can easily comprehend, that taking any place whatever on the surface of the earth, say the point L, you can always conceive a meridian BLMA, which passing through the two poles, takes in its way the point L. This meridian, then, is named the *meridian of L.* Supposing, for example, L to be Berlin, the semicircle BLMA would be the meridian of Berlin; and the same may be said respecting every other spot of the earth.

You can represent to yourself a globe, on the surface of which are described all the countries of the earth, the continent, as well as the sea, with its islands. This artificial globe, denominated the *terrestrial* or *terraqueous globe*, you must no doubt be acquainted with. As to all meridians which can possibly be drawn upon it, and a great number of which actually are traced, I remark, that each, being a semicircle, is divided by the equator into two equal parts, each of which is the fourth part of a circle, that is, an arch of 90 degrees. Accordingly, BD, BM, BN, BE, are fourth parts of a circle, as well as AD, AM, AN, AE; each therefore contains 90 degrees: and it may be farther added, that each is perpendicular to the equator, or forms right angles with it.

Again, were a person to travel from the point of the equator M, to the pole B, the shortest road would be to pursue the track of the meridian MLB, which being an arch of 90 degrees, will contain 6214 English miles; the distance to be passed in going from the equator to either of the poles.

You will recollect, that the shortest road from place to place, is the straight line drawn through any two places; here the straight line drawn from the point M, in the equator, to the pole B, would fall within the earth—a route which it is impossible to pursue, for we are so attached to the surface of the earth, that we cannot remove from it. For this reason, the question becomes exceedingly different, when it is asked, What is the shortest road leading from one spot on the surface of a globe to another? This shortest road is no longer a straight line, but the segment of a circle, described from one point of the surface to another, and whose centre is precisely that of the globe itself. This is accordingly in perfect harmony with the case in question; for to travel from the point M in the equator, to the pole B, the arch of the meridian MLB, which I have represented as the shortest road, is in reality a segment of the circle whose centre is precisely that of the earth.

In like manner, if we consider the spot L situated in the meridian BLMA, the shortest road to go thence to the pole B will be the arch LB; and if we know the number of degrees which this arch contains, allowing 69 English miles to a degree, we shall have the length of the road. But if you were disposed to travel from the same spot to the equator by the shortest track, it would be necessary to pursue the track of the arch of the meridian LM, the number of degrees contained in which, reckoning 69 English miles to a degree, would give the distance.

We must be satisfied with expressing these distances in degrees, it being so easy to reduce them to English miles, or the miles of any other nation. Taking, then, the city of *Berlin* for the spot L, we

find that the arch LM, which leads to the equator, contains 52 degrees and a half; consequently, to travel from Berlin to the equator, the shortest road is 3623 English miles. But if any one were to go from Berlin to the north pole, he must follow the direction of the arch BL, which containing 37 degrees and a half, would be 2591 English miles. These two distances added, give 6214 English miles for the extent of the arch BLM, which is the fourth part of a circle, or 90 degrees, which contain, as we have seen, 24855 English miles.

22d August 1761.

Letter XLII.—Of Latitude, and its Influence on the Seasons, and the Length of the Day.

I begin once more with the same figure (Plate IV. *Fig.* 10.), which must by this time be abundantly familiar to you. The whole circle represents the globe of the earth; the points A and B its two poles; B the north or arctic, and A the south or antarctic; so that the straight line BA, drawn within the earth, and passing through its centre C, is the axis of it. Again, DME is the equator which divides it into two hemispheres, DBE the northern, and DAE the southern.

Let us now take any spot whatever, say L, and draw its meridian BLMA, which, being a semicircle, passes through the point L, and the two poles B and A. This then is the meridian of the place L, divided by the equator at M into two equal parts, making two-fourths of a circle, each of which contains 90 degrees. I remark farther, that the arch LM of this meridian gives us the distance of the place L from the equator, and that the arch LB expresses the distance of the same place L from the pole B.

This being laid down, it is of importance to observe that the arch LM, or the distance of L from the equator, is denominated the *Latitude of the place L;* so that the latitude of any place on the globe is nothing else but the arch of the meridian of that place, which is intercepted between the equator and the given place; in other words, the latitude of a place is the distance of that place from the equator; expressing such distance by degrees, the quantity of which we perfectly know, as each degree contains 69 English miles.

You will readily comprehend, that this distance must be distinguished, according as the given place is in the northern or southern hemisphere. In the former case, that is, if the given place is in the northern hemisphere, we say it has *north latitude;* but if it is in the southern hemisphere, we say it is in *south latitude.*

Taking Berlin as an instance, we say it is in 52 degrees and 32 minutes of north latitude; the latitude of Magdeburg is, in like manner, northern, 52 degrees and 8 minutes. But the latitude of Batavia in the East Indies is 6 degrees 12 minutes south; and that of the Cape of Good Hope in Africa, is likewise south 33 degrees 55 minutes.

I remark by the way, that for the sake of abbreviation, instead of the word *degree* we affix a small cypher (°) to the numeral characters, and instead of the word *minute* a small slanting bar (′), and instead of *second* two of these (″); thus the latitude of the observatory at Paris is 48° 50′ 14″ N., that is, 48 degrees, 50 minutes, and 14 seconds North. In Peru there is a place named Vlo, whose latitude has been found to be 17° 36′ 15″ S., that is, 17 degrees, 36 minutes, and 15 seconds South. Hence you will

understand, that if a place were mentioned whose latitude was 0° 0′ 0″, such a place would be precisely under the equator, as its distance from the equator is 0, or nothing; and in this case it is unnecessary to affix the letter N or S. But were it possible to reach a place whose latitude was 90° N., it would be precisely the north pole of the earth, which is distant from the equator the fourth of a circle, or 90 degrees. This will give you a clear idea of what is meant by the latitude of a place, and why it is expressed by degrees, minutes, and seconds.

It is highly important to know the latitude of every place, not only as essential to Geography, in the view of assigning to each its exact situation on geographical charts, but likewise because on the latitude depend the seasons of the year, the inequalities of day and night, and consequently the temperature of the place. As to places situated directly under the equator, there is scarcely any perceptible variation of the seasons; and through the whole year the days and nights are of the same length, namely, 12 hours. For this reason the equator is likewise denominated the equinoctial line; but in proportion as you remove from the equator, the more remarkable is the difference in the seasons of the year, and the more likewise the days exceed the nights in summer; whereas, reciprocally, the days in winter are as much shorter than the nights.

You know that the longest days, in these northern latitudes, are toward the commencement of our summer, about the 21st of June; the nights, of consequence, are then the shortest; and that toward the beginning of our winter, about the 23d of December, the days are shortest and the nights longest: so that every where the longest day is equal to the longest night. Now in every place the duration of the longest day depends on the latitude of the place.

Here, at Berlin, the longest day is 16 hours and 38 minutes, and consequently the shortest day in winter is 7 hours 22 minutes. In places nearer the equator, or whose latitude is less than that of Berlin, which is 52° 32′, the longest day in summer is less than 16 hours 38 minutes, and in winter the shortest day is more than 7 hours 22 minutes. The contrary of this takes place on removing farther from the equator: at Petersburg, for example, whose latitude is 59° 56′, the longest day is 18 hours 30 minutes, and consequently the night is then only 5 hours 30 minutes: in winter, on the contrary, the longest night is 18 hours 30 minutes, and then the day is only 5 hours 30 minutes. Were you to remove still farther from the equator, till you came to a place whose latitude was 66° 30′, the longest day there would be exactly 24 hours, in other words, the sun would not set at that place at that season; whereas in winter the contrary takes place, the sun not rising at all on the 23d of December, that is, the night then lasting 24 hours. Now at places still more remote from the equator, and consequently nearer the pole, for example, at Warthuys, in Swedish Lapland, this longest day lasts for the space of several days together, during which the sun absolutely never sets; and the longest night, when the sun never rises at all, is of the same duration.

Were it possible to reach the pole itself, we should have day for six months together, and, during the other six, perpetual night. From this you comprehend of what importance it is to know accurately the latitude of every spot of the globe.

22d August 1761.

Letter XLIII.—Of Parallels, of the first Meridian, and of Longitude.

Having informed you, that in order to find the meridian of any given place L, it is necessary to draw on the surface of the earth a semicircle BLMA, passing through the two poles B and A, and through the given place L; I remark (Plate IV. *Fig.* 12.), that there is an infinite number of other places, through which this same meridian passes, and which are consequently all said to be situated under the same meridian, whether in the northern hemisphere, between B and M, or in the southern, between M and A.

Now, all the places situated under the same meridian differ as to latitude, some being nearer to, or more remote from, the equator than others. Thus, the meridian of Berlin passes through the city of Meisse, and nearly through the port of Trieste, as well as many other places of less note.

You will likewise please to observe, that a great many places may have the same latitude, that is, may be equally distant from the equator, but all of them situated under different meridians. In fact, if L is the city of Berlin, whose latitude, or the arch LM, contains 52° 32′, it is possible that there should be under any other meridian BNA, a place I, the latitude of which, or the arch IN, shall likewise be 52° 32′; such are the points F and G, taken in the meridians BDA, BEA. And as a meridian may be drawn through every point of the equator, in which there shall be a place whose latitude is the same with that of Berlin, or the place L, we shall have an infinite number of places, all of the same latitude. They will be all situated in the circle FLIG, all the points of which being equally distant from the equator, it is denominated a *parallel circle* to the equator, or simply a *parallel*. A parallel on the globe, then, is nothing else but a circle parallel to the equator, that is, all the points of which are equidistant from it; hence it is evident, that all the points of a parallel are likewise equidistant from the poles of the earth.

As it is possible to draw such a parallel through every place on the globe, we can conceive an infinite number of them, all differing in respect of latitude, each having a latitude, whether north or south, peculiar to itself.

You must likewise be abundantly sensible, that the greater the latitude is, or the nearer you approach to either of the poles, the smaller the parallels become; till at last, on coming to the very poles, where the latitude is 90°, the parallel is reduced to a single point. But, on the contrary, as you approach the equator, or the smaller the latitude is, the greater are the parallels; till at last, when the latitude becomes 0, or nothing, the parallel is lost in the equator. It is accordingly by the latitude that we distinguish them; thus, the parallel of 30°, is that which passes through every place whose latitude is 30 degrees; but it is necessary to explain yourself, according as you mean north or south latitude.

On consulting an accurate map, you will observe that Hanover is situated under the same parallel with Berlin, the latitude of both being 52° 32′; and that the cities of Brunswick and Amsterdam fall nearly under the same parallel; but that the meridians passing through these places are different. If you know the meridian and the parallel under which any place is situated, you are enabled to ascertain its actual position on the globe. If it were affirmed, for example, that a certain place is situated under the meridian BNA, and the parallel FLG, you would only have to look where the meridian BNA is inter-

sected by the parallel FLG, and the point of intersection I, will give the true position of the given place.

Such are the means employed by geographers to determine the real situation of every place on the face of the globe. You have only to ascertain its parallel, or the latitude, and its corresponding meridian. As to the parallel, it is easy to mark and distinguish it from every other; you have only to indicate the latitude or distance from the equator, according as it is north or south: but how describe a meridian, and distinguish it from every other? They have a perfect resemblance, they are all equal to each other, and no one has a special and distinctive mark. It depends therefore upon ourselves to make choice of a certain meridian, and to fix it, in order to refer all others to that one. If, for example, in Figure 12, referred to at the beginning, we were to fix on the meridian BDA, it would be easy to indicate every other meridian, say BMA, by simply ascertaining on the equator the arch DM, contained between the fixed meridian BDA and the one in question BMA, adding only in what direction you proceed from the fixed meridian toward the other, whether from east to west, or west to east.

This fixed meridian, to which every other is referred, is called the *first meridian*; and the choice of this meridian being arbitrary, you will not think it strange that different nations should have made a different choice. The French have fixed on the isle of Ferro, one of the Canaries, for this purpose, and draw their first meridian through it. The Germans and Dutch draw theirs through another of the Canary islands, called Teneriffe. But whether you follow the French or German geographers, it is always necessary carefully to mark on the equator the point through which the first meridian passes; from this point you afterwards reckon, by degrees, the points through which all other meridians pass; and both French and Germans have agreed to reckon from west to east.

If, therefore, in Figure 12, to which I have already referred, the semicircle BDA be the first meridian, and the points of the equator M and N were situated toward the east, you have only, in order to mark any other meridian, say BMA, to indicate the magnitude of the arch DM; and this arch is what we call the *longitude* of all the places situated under the meridian BMA. In like manner, all the places situated under the meridian BNA have their longitude determined by the arch of the equator DN, expressed in degrees, minutes, and seconds.

29th August 1761.

Letter XLIV.—Choice of the First Meridian.

You have now received complete information respecting what is denominated the latitude and the longitude of a place on the surface of the globe. Latitude is computed on the meridian of the given place, up to the equator; in other words, it is the distance of the parallel passing through that place from the equator; and to prevent all ambiguity, it is necessary to express whether this latitude or distance is north or south.

As to longitude, we must determine the distance of the meridian of the given place from the first meridian; and this distance is computed on the equator, from the first meridian to the meridian of the given place, always proceeding from west to east; in other words, longitude is the distance of the meridian of the given place, from the first, computing the degrees on the equator, as I have just now said.

We always compute, then, from the first meridian eastward; and it is evident, that when we have computed up to 360 degrees, we are brought back precisely to the first meridian, as 360 degrees complete the circumference of the equator. Accordingly, were any particular place found to be in the 359th degree of longitude, the meridian of that place would be only one degree distant from the first meridian, but toward the west. In like manner, 350° of longitude would exactly correspond with a distance of 10° westward. For this reason, in order to avoid all ambiguity in determining longitude, we go on to reckon up to 360° toward the east.

You will no doubt have the curiosity to know, why geographers, in settling the first meridian, have agreed to fix on one of the Canary islands? I beg leave to reply, that the intention was to begin with settling the limits of Europe toward the west; and as these islands, called the Canaries, and situated in the Atlantic ocean, beyond Spain, toward America, were still considered as part of Europe, it was thought proper to draw the first meridian through the most remote of the Canary islands, that we might be enabled to compute the other meridians without interruption, not only all over Europe, but through the whole extent of Asia; from whence, going on to reckon toward the east, we arrive at America, and thence return at length to the first meridian.

But to which of the Canary isles shall we give the preference? Certain geographers of France made choice of the isle of Ferro, and the Germans that of Teneriffe, because the real situation of these isles was not then sufficiently ascertained, and it was not perhaps known which of them was the most remote; besides, the German geographers imagined that the mountain named the Peak of Teneriffe was pointed out, as it were, by the hand of Nature for the first meridian.

Be this as it may, it seems rather ridiculous to draw the first meridian through a place whose real position on the globe is not perfectly determined; for it was not till very lately that the situation of the Canaries was ascertained. For this reason, the most accurate astronomers fix the first meridian precisely 20 degrees distant from that of the observatory at Paris, without regarding through what spot the first may in that case pass; and it is undoubtedly the surest method that can be adopted; and in order to determine every other meridian, the simplest way is to find out its distance from that of Paris: then, if that other meridian is more to the east, you have only to add to it 20 degrees, in order to have the longitude of the places situated under it; but if this meridian be westward to that of Paris, you must subtract the distance from 20 degrees. Finally, if this distance toward the west is more than 20 degrees, you subtract it from 380 degrees, that is, from 20 degrees above 360, in order to have the longitude of the meridian.

Thus, the meridian of Berlin being to the eastward of the meridian of Paris 11° 2′ 0″, the longitude of Berlin will be 31° 2′ 0″; and this is likewise the longitude of all other places situated under the same meridian with Berlin.

In like manner, the meridian of Petersburg being 28 degrees more to the east than that of Paris, the longitude of Petersburg will be 48°.

The meridian of St. James's, London, is more to the west than that of Paris by 2° 25′ 15″; subtracting, therefore, that quantity from 20°, the remainder, 17° 34′ 45″, gives the longitude of St. James's, London.

Let us now take the city of Lima in Peru, the meridian of which is 79° 27′ 45″ to the westward of that of Paris; that distance must be subtracted from 380 degress; which will leave a remainder of 310° 32′ 15″, the longitude of Lima.*

Now, when the latitude and longitude of a place are known, we are enabled to ascertain its true position on the terrestrial globe, or on a map; for as the latitude marks the parallel under which the place is situated, and the meridian gives the meridian of the same place, the point where the parallel intersects the meridian, will be exactly the place in question.

You have but to look at a map, that of Europe, for example; and you will see the degrees of the parallels marked on both sides, or their distances from the equator; above and below are the degrees of longitude, or the distances of the several meridians from the first.

The parallels and meridians are usually traced on maps, degree by degree, sometimes at the distance of 5 degrees from each other. In most maps the meridians are drawn up and down, and the parallels from left to right: the upper part is directed toward the north, the under to the south, the right-hand side toward the east, and the left-hand side toward the west.

It is likewise to be remarked, that as all the meridians meet at the two poles, the more any two meridians approach to either of the poles, the smaller their distance becomes; at the equator their distance always is greatest. Accordingly, on all good maps, where the meridians are traced, you will observe

* This method of reckoning the longitude is now entirely abandoned. The English reckon it from Greenwich, the French from Paris, and so on.—Ed.

that they gradually approximate toward the top, that is the north; and their distances increase as you proceed toward the equator. This is all that seems to be requisite for the understanding of geographical charts, by means of which an attempt is made to represent the surface, or part of the surface, of the globe.

But my principal object was to demonstrate how the real position of every spot on the globe is determined by its latitude and longitude.

1st September 1761.

Letter XLV.—Method of determining the Latitude, or the Elevation of the Pole.

It being a matter of such importance to know the latitude and longitude of every place, in order to ascertain exactly the spot of the globe where you are, you must be sensible that it is equally important to discover the means of certainly arriving at such knowledge.

Nothing can be more interesting to a man, who has been long at sea, or after a tedious journey through unknown regions, than to be informed at what precise spot he is arrived; whether or not he is near some known country, and what course he ought to pursue in order to reach it. The only means of relieving such a person from his anxiety would undoubtedly be to give him the latitude and longitude of the place where he is; but what must he do to attain this most important information? Let us suppose him on the ocean, or in a vast desert, where there is no one whom he can consult. After having ascertained, by the help of a terrestrial globe, or of maps, the latitude and longitude of the

place where he is, he will with ease from them determine his present position, and be furnished with the necessary information respecting his future progress.

I proceed therefore to inform you, that it is by astronomy chiefly we are enabled to determine the latitude and longitude of the place where we are; and that I may not tire you by a tedious detail of all the methods which astronomers have employed for this important purpose, I shall satisfy myself with presenting a general idea of them, trusting that this will be sufficient to convey to you the knowledge of the principles on which every method is founded.

I begin with the latitude, which is involved in scarcely any difficulty; whereas the determination of the longitude seems hitherto to have defied all human research, especially at sea, where the utmost precision is requisite. For the discovery of this last, accordingly, very considerable prizes have been proposed, as an encouragement to the learned to direct their talents and their industry toward a discovery so interesting, both from its own importance, and from the honour and emolument which are to be the fruit of it.

I return to the latitude, and the means of ascertaining it, referring to some future opportunity a more ample discussion of the longitude, and of the different methods of discovering it, especially at sea.

Let the points B and A (Plate IV. *Fig.* 13.) be the poles of the earth; BA its axis, and C its centre; let the semicircle BDA represent a meridian, intersected by the equator at the point D; and BD, AD, will be each the quadrant of a circle, or an arch of 90 degrees; the straight line DC will therefore be a radius of the equator, and DE its diameter.

Let there now be assumed in this meridian BDA, the point L, the given place, of which the latitude is required; or, in other words, the number of degrees contained in the arch LD, which measures the distance of the point L from the equator; or again, drawing the radius CL, as the arch LD measures the angle DCL, which I shall call y, this angle y will express the latitude of the place L, which we want to find.

Now, it being impossible to place ourselves at the centre of the earth, from which we could take the measure of that angle, we must have recourse to the heavens. There the prolongation of the axis of the earth AB terminates in the north pole of the heavens P, which we are to consider as at an immense distance from the earth. Let the radius CL likewise be carried forward till it terminate in the heavens at the point Z, which is called the zenith of the place; then, drawing through the point L the straight line ST, perpendicular to the radius CL, you will recollect that this line ST is a tangent of the circle, and that consequently it will be horizontal to the place L; our horizon always touching the surface of the earth at the place where we are.

Let us now look from L toward the pole of the heavens P, which being infinitely distant, the straight line L Q directed to it will be parallel to the line ABP, that is, to the axis of the earth: this pole of the heavens will appear, therefore, between the zenith and the horizon LT; and the angle TLQ, indicated by the letter m, will show how much the straight line LQ, in the direction of the pole, is elevated above the horizon; hence this angle m is denominated the *elevation of the pole.*

You have undoubtedly heard frequent mention made of the elevation of the pole, or, as some call it, the *height of the pole,* which is nothing else but the angle formed by the straight line LQ in the direction of the pole, and the horizon of the place

where we are. You have a perfect comprehension of the possibility of measuring this angle m, by means of an astronomical instrument, without my going into any farther detail.

Having measured this angle m, or the height of the pole, it will give you precisely the latitude of the place L, that is, the angle y. To make this appear, it is only necessary to demonstrate that the two angles m and y are equal.

Now the line LQ being parallel to CP, the angles m and n are alternate, and consequently equal. And the line LT being perpendicular to the radius CL, the angle CLT of the triangle CLT must be a right angle, and the other two angles of that triangle, n and x, must be together equal to a right angle. But the arch BD being the quadrant of a circle, the angle BCD must likewise be a right angle; the two angles x and y, therefore, are together equal to the two angles n and x. Take away the angle x from both, and there will remain the angle y equal to the angle n; but the angle n has been proved equal to the angle m, therefore the angle y is likewise equal to the angle m.

It has already been remarked, that the angle y expresses the latitude of the place L, and the angle m the elevation or height of the pole at the same place L; the latitude of any place, therefore, is always equal to the height of the pole at that same place. The means which astronomy supplies, for observing the height of the pole, indicate therefore the latitude required.

Astronomical observations made at Berlin have accordingly informed us, that there the height of the pole is 52° 32′, and hence we conclude that the latitude of that city is likewise 52° 32′.

This is one very remarkable instance to demonstrate how the heavens may assist us in the attainment of the knowledge of objects which relate only to the earth.

5th September 1761.

Letter XLVI.—Knowledge of the Longitude, from a Calculation of the Direction, and of the Space passed through.

I now proceed to the longitude; and remark, that on taking a departure, whether by land or water, from a known place, it would be easy to ascertain the spot we had reached, did we know exactly the length of the road, and the direction which we pursued. This might, in such a case, be effected even without the aid of astronomy; and this obliges me to enter into a more particular detail on the subject.

We measure the length of a road by feet; we know how many feet go to a mile, and how many miles go to an arch of one degree upon the globe: thus we are enabled to express in degrees the distance we have travelled.

As to the route or direction in which we travel, it is necessary accurately to know the position of the meridian at every place where we are. As the meridian proceeds in one direction toward the north pole, and in the other toward the south, you have only to draw, on the horizon of the spot where you are, a straight line from north to south, which is called the *meridian line* of that place. All possible care must be taken to trace this meridian line very accurately, and here the heavens must again perform the office of a guide.

You know it is mid-day when the sun is at his greatest elevation above the horizon; or, which is the same thing, the direction of the sun is then exactly south, and the shadow of a staff fixed perpendicularly on a horizontal plane will fall, at that instant, precisely northward. Hence it is easy to comprehend, how an observation of the sun may furnish us with the means of accurately tracing a meridian line, wherever we may be.

Having traced a meridian, every other direction is very easily determined.

Let the straight line NS (Plate IV. *Fig.* 14.) be the meridian, one of the extremities N being directed toward the north, and the other S toward the south. With this meridian let there be drawn at right angles the straight line EW, whose extremity E shall be directed toward the east, and the other extremity W toward the west. Having divided the circle into 16 equal parts, we shall have so many different directions, denominated according to the letters affixed to them; and in case of not pursuing a direction which exactly corresponds with some one of the sixteen, the angle must be marked which that deviating line of direction makes with the meridian NS, or with EW, which is perpendicular to it.

It is thus we are enabled to determine exactly the direction which we pursue in travelling; and so long as we are assured of the length of the way, and of the direction pursued, it will be very easy to ascertain the true place at which we have arrived, and to indicate both its longitude and latitude. We employ for this purpose an accurate map, which contains the point of departure, and that which we have reached; and by means of the scale, which gives the quantity of miles or leagues that go to a degree, it is easy to trace, on such map, the track pursued and completed.

Figure 15. of Plate IV. represents a map, on which are marked from left to right the degrees of longitude, and those of latitude from top to bottom; it is likewise visible on the face of it, that the meridians con-

verge as they approach toward the north, and retire from each other toward the south, as is the actual case on the globe.

This map contains part of the surface of the earth, from the 53d degree of north latitude to the 59th degree; and from the 13th degree of longitude to the 26th.

Suppose, then, I take my departure from the place L, the longitude of which is 16°, and the latitude 57° 20′, and that I proceed in the direction ESE, and have travelled a space of 345 English miles. In order to determine the longitude and latitude of the place I have reached, I draw from the place L the straight line LM, making with the meridian an angle of 67° 30′, the same angle which the direction ESE in the preceding figure makes with NS. Then on that line I take, according to the scale marked on the chart, LM equal to 345 English miles, and the point M shall be the place which I have reached.

I have then only to compare this place with the meridians and parallels traced on the map, and I find that its longitude is 24° nearly; and on measuring more exactly the part of the degree to be added to the 24th degree, I find the longitude of the point M to be 24° 4′. As to the latitude, I observe it to be between the 55th and 56th degree, and by an easy computation I find it to be 55° 25′; so that the latitude of the place M, which I have reached, is 55° 25′, and its longitude 24° 4′.

It has here been supposed that I have invariably pursued the same direction, ESE, from first to last; but if I have from time to time deviated from that direction, I have only to perform the same operation on each deviation, to find the place where I then was; from this I take a fresh departure, and trace my direction till another deviation takes place; and so on, till I reach my object. By these means it is

always in my power, whether travelling by sea or land, to ascertain the place I have reached; provided I know exactly, through my whole progress, the direction I pursue, and measure with equal accuracy the length of the way.

We might in this case dispense even with the assistance of astronomy, unless we had occasion for it accurately to determine our direction, or the angle which it makes with the meridian; but the magnetic needle or compass may, in many cases, supply this want.

You must be sensible, however, that it is possible to make a very considerable mistake, both in the computation of the direction, and of the length of the way, especially in very long voyages. How often is it necessary to change the direction in travelling even from hence to Magdeburg? and how is it possible to measure exactly the length of the way? But when we travel by land we are not reduced to this expedient; for we are enabled to measure by geometrical experiments the distance of places, and the angles which the distances make with the meridian of every place; and thus we can determine, with tolerable accuracy, the true situation of all places.

8th September 1761.

Letter XLVII.—Continuation. Defects of this Method.

A method of observing the direction pursued, and the length of the course, seems to be of singular utility in sea voyages, because there we are not under the necessity of deviating from the direction every moment, as in travelling by land; for, with the same wind, we can proceed in the same direction.

Pilots are accordingly very attentive in exactly observing the course of the vessel, and in measuring the progress she has made. They keep an accurate journal of all these observations, at the close of every day, nay still more frequently; they trace on their sea-charts the progress they have made, and thus are enabled to mark on the charts, for every period of time, the point where they are, and of which they consequently know the latitude and longitude. Accordingly, so long as the course is regular, and the vessel is not agitated by a tempest, good pilots are seldom mistaken; but when they are in doubt, they have recourse to astronomical observations, from which they discover the elevation of the pole; and this being always equal to the latitude of the place where they are, they compare it with that which they have marked on the chart, conformably to the computation of their progress. If these are found to coincide, their computation is just; if they discover a difference, they conclude with certainty that some error has been committed in the computation of the distance and of the course; in that case they re-examine both the one and the other more carefully, and endeavour to apply the necessary corrections, in order to make the computation agree with the observation of the height of the pole, or of the latitude, which is equal to it.

This precaution may be sufficient in short voyages, as the errors committed can in these be of no great importance; but in very long voyages, these slight mistakes may accumulate to such a degree, that at last a very gross mistake may be committed, and the place where the vessel actually is may differ considerably from what it was supposed to be on the chart.

I have hitherto gone on the supposition that the voyage proceeded quietly; but should a storm arise, during which the vessel is subjected to the rudest concussions of wind and waves, it is evident that the

computation of distance and course is entirely deranged, and that it is impossible to trace on the chart the progress she has made.

It would be very easy, after this derangement, to ascertain by astronomical observations the latitude of the ship's place; but this would determine only the parallel of that place, and it would remain totally uncertain at what point of the parallel she actually was.

It is necessary, therefore, to discover likewise the longitude of the place, which shows us the meridian under which it is situated; and then the intersection of that meridian with the parallel found, will give the vessel's true place. This will make you sensible of what importance it is to assist mariners, in discovering likewise the longitude of the place where they are.

This necessity is imposed not only from the consideration of the tempests to which navigation is liable; for it is possible, supposing the voyage to proceed ever so quietly, to be grossly mistaken in the computation of both course and distance. Could we suppose the sea to be at rest, it might be possible to invent various methods of ascertaining, with tolerable exactness, the way which the vessel has made; but there are rapid currents in many places of the ocean, which have the resemblance of a river running in a certain direction. Thus it is observed, that the Atlantic ocean has a perpetual current into the Mediterranean sea, through the straits of Gibraltar; and that the ocean between Africa and America has a very considerable current from east to west, so that a voyage to America is performed in much less time than a voyage from America to Europe.

Were such currents constant and well known, we should have considerable assistance toward forming our calculations; but it has been observed, that they are sometimes more, sometimes less rapid, and that they frequently change their direction; which deranges the calculations of the most skilful navigator to such a degree, that it is no longer safe to trust them. We have but too many fatal instances of ships dashed on concealed rocks, and lost, because these were computed to be still at a considerable distance. It was afterwards discovered, when too late, that these calamities had been occasioned by the currents of the ocean, which deranged the calculations of navigators.

In fact, when the ocean has a current which makes it flow like a river, following a certain direction, vessels caught in it are carried away imperceptibly. In a river we clearly perceive that the current is carrying us along, by observing the banks or the bottom; but at sea no land is visible, and the depth is too great to admit of our making any observation from the bottom. At sea, then, it is impossible to discern the currents; and hence so many dreadful mistakes respecting both course and distance. Whether, therefore, we take tempests into the account or not, we are always under the necessity of falling on other methods of ascertaining the longitude of the places where we may arrive; and of the various methods hitherto employed for acquiring this knowledge of the longitude, I now proceed to inform you.

12*th September* 1761.

Letter XLVIII.—Second Method of determining the Longitude, by Means of an exact Time-Piece.

A very sure method of finding the longitude, would be a clock, watch, or pendulum, so perfect, that is to say, which should always go so equally,

and so exactly, that no concussion should be able to affect its motion.

Supposing such a time-piece constructed, let us see in what manner, by means of it, we should be enabled to solve the problem of the longitude. We must return, for this purpose, to the consideration of meridians, which we are to conceive to be drawn through every place on the surface of the globe.

You know that the sun seems to describe every day a circle round the earth, and that, of consequence, he passes successively over all the meridians in the space of twenty-four hours.

Now, the sun is said to pass *over*, or *through* a given meridian, if a straight line drawn from the sun to the centre of the earth C (Plate IV. *Fig.* 12.), pass precisely through that meridian. If, therefore, in the present case, the line drawn from the sun to the centre of the earth pass through the meridian BLMA, we would say that the sun was in that meridian, and then it would be mid-day to all the places situated under this meridian; but under every other, it would not be mid-day at that precise instant; it would there be before noon or after it every where else.

If the meridian BNA is situated to the eastward of the meridian BMA, the sun, in making his circuit from east to west, must pass over the meridian BNA before he reaches the meridian BMA; consequently, it will be mid-day under the meridian BNA earlier than under the meridian BMA: when, therefore, it shall be mid-day under this last meridian, mid-day under every other meridian to the eastward will be already past, or it will be afternoon with them. On the contrary, it will be still forenoon under every meridian, say BDA, situated to the westward, as the sun cannot reach it till he has passed over the meridian BMA.

And as the motion of the sun is regular and uniform, and he completes his circuit of the globe, that is 360 degrees, in twenty-four hours, he must every hour describe an arch of 15 degrees. When, therefore, it is noon at Berlin, and at every other place situated under the same meridian, noon will be already past under meridians situated to the eastward; and more particularly still under the meridian situated 15 degrees to the eastward of that of Berlin, it will already be one o'clock; under the meridian 30 degrees eastward, two o'clock; under that of 45 degrees, three o'clock afternoon, and so on. The contrary will take place under meridians situated to the westward of that of Berlin; when it is noon there, it will be only eleven o'clock forenoon under the meridian 15 degrees to the westward, ten o'clock under the meridian of 30, nine o'clock under the meridian of 45 degrees westward, and so on; a difference of 15 degrees between two meridians always amounting to an hour of time.

To elucidate still more clearly what has now been remarked, let us compare the two cities Berlin and Paris. As the meridian of Berlin is 11° 17′ 15″ to the eastward of that of Paris, reckoning an hour to 15 degrees, this difference of 11° 17′ 15″ will give 44 minutes and 29 seconds of time, or three quarters of an hour nearly. When, therefore, it is midday at Paris, it will be 44 minutes and 29 seconds after mid-day at Berlin; and reciprocally, when it is mid-day at Berlin, it will only be 15 minutes and 31 seconds after eleven o'clock at Paris; so that it will not be noon at this last city till 44 minutes and 29 seconds afterwards. Hence it is evident, that the clocks at Berlin should always be faster than those of Paris, and that this difference ought to be nearly 44 minutes and 29 seconds.

The difference between the meridians of Berlin and Magdeburg is nearly 1° 40′; Berlin therefore is to the eastward of Magdeburg; and this difference reduced to time gives 6 minutes and 40 seconds, which the clocks of Berlin ought to indicate more than that of Magdeburg. Consequently, if it is just now noon at Magdeburg, and the clocks there, which I suppose well regulated, point to XII., the clocks at Berlin should, at the same instant, indicate 6 minutes and 40 seconds after XII., that is, noon there is already past.

Hence you see, that in proportion as places differ in longitude, or as they are situated under different meridians, well regulated time-pieces ought not to point out the same hour at the same instant, but the difference ought to be a whole hour when that of the longitude is 15 degrees.

In employing a time-piece, then, for ascertaining the longitude of the places through which we pass, it would first be necessary to regulate it exactly at some place where we actually were. This is done by observing the instant of noon, that is, the instant when the sun passes over the meridian of that place; and the time-piece ought then to point precisely to XII. It ought afterwards to be adjusted in such a manner, that always after a revolution of 24 hours, when the sun returns to the meridian, the index, after having made two complete circuits, should again point exactly to XII. If this is carefully observed, such well regulated time-pieces will not coincide in different places, unless these be situated under one and the same meridian; but if they are situated under different meridians, that is, if there be a difference of longitude, the time indicated by the clock or watch, at the same moment, will likewise be different; at the rate of one whole hour of time for every 15 degrees of longitude.

Knowing, then, the difference of time indicated by well regulated time-pieces, at different places, and at the same instant, we are enabled exactly to compute the difference of longitude at these two places, reckoning always 15 degrees for an hour, and the fourth part of a degree for a minute.

15th September 1761.

Letter XLIX.—Continuation, and Farther Elucidations.

You will be less surprised at the difference of time which well regulated time-pieces must indicate under different meridians, when you recollect, that while it is noon with us, there are countries toward the east where the sun is already set, and that there are others toward the west where he is but just rising. It must therefore be already night with the one, and still morning with the other, at the same instant that it is noon with us. You know, besides, that with our antipodes, who are under the meridian diametrically opposite to ours, it is night, while it is day with us; so that our noon corresponds exactly to their midnight.

It will be an easy matter, after these elucidations, to show how an exact time-piece may assist us in discovering the difference of meridians, or that of the longitude, at different places.

Supposing me possessed of such an excellent time-piece, which, once exactly regulated, shows me every day the precise time it is at Berlin, so that whenever it is noon at Berlin, it points precisely to XII.; supposing farther, that it goes so regularly, that once adjusted, I have no farther occasion to touch it, and that its motion is not to be deranged either by the shaking of a carriage, or the agitation of a vessel on

the ocean, or by any concussion whatever to which it may be exposed.

Provided thus with a time-piece of this description, I set out to travel, whether by land or by sea; perfectly assured, that go where I will, its motion will be steady and uniform, as if I had remained at Berlin: it will every day point to XII. at the very moment it is noon at Berlin, and that wherever I may happen to be. On this journey, I arrive first at Magdeburg: there I observe the sun when he passes the meridian, and this happens when he is exactly south; and it being then noon at Magdeburg, I consult my time-piece, and observe it points to 6 minutes and 40 seconds after XII.: whence I conclude, that when it is noon at Magdeburg, noon at Berlin is already past, and that the difference is 6′ 40″ of time, which correspond to 1° 40′ of distance; therefore the meridian of Magdeburg is to the westward of that of Berlin. The longitude of Berlin, therefore, being nearly 31° 7′ 15″, the longitude of Magdeburg will be 1° 40′ less, that is, it will be 29° 27′ 15″.

I thence proceed to Hamburgh, accompanied by my time-piece, which I never touch; and there observing when it is noon by the sun, for I cannot depend on the public clocks which there announce the hour, I find my time-piece already announces 13′ 33″ after XII.; so that at Berlin noon is passed 13′ 33″ when it is exactly noon at Hamburgh: hence I conclude, that the meridian of Hamburgh is 3° 23′ 15″ to the westward of that of Berlin; reckoning 15° to an hour, that is one degree for every four minutes of time: accordingly, I find that 13′ 33″ of time give 3° 23′ 15″ of distance for the difference of the meridians. The longitude of Hamburgh will be, of course, 27° 44′.

At Hamburgh I go to sea, still accompanied by my time-piece, and after a long voyage I arrive at a place where, waiting for noon, the moment of which I ascertain by observing the sun, I find that my time-piece indicates only 58′ 15″ after X.; so that then it is not yet noon at Berlin, and the difference of time is 1 hour 1′ 45″, from which I conclude, that the place at which I have arrived is to the eastward of Berlin; and as one hour gives 15 degrees, one minute of time 15′, and 45 seconds of time 11′ 15″, the difference of the meridians will therefore be 15° 26′ 15″. I find, then, that I am at a place to the eastward of Berlin, whose longitude is greater than that of Berlin by 15° 26′ 15″; now the longitude of that city being nearly 31° 7′ 15″, the longitude of the place where I am must be 46° 33′ 30″. Thus I have discovered under what meridian I now am; but I am still uncertain as to the point of the meridian. In order to ascertain this I have recourse to astronomical observations, and find the height of the pole to be precisely 41°. Knowing likewise that I am still in the northern hemisphere, as I have not passed the equator, I discover that I actually am at a place whose latitude is 41° north, and longitude 46° 33′ 30″. I take therefore my globe or maps, and trace the meridian whose longitude is 46° 33′ 30″; I look for the place whose latitude is 41°, and at the point of intersection I find I have got to the city of Constantinople, without having occasion to apply for information to any person whatever.

Thus, at whatever place of the globe I may arrive, possessed of a time-piece so exact, I am able to ascertain the longitude of it; and then an observation of the height of the pole will show me its latitude. All that remains, therefore, is to take the terrestrial globe, or a good map, and it will be easy for me to ascertain where I am, however unknown to me the country may in other respects be.

It is much to be regretted, that artists of the greatest ability have hitherto been unsuccessful in the construction of time-pieces, such as I have described, and such as the case requires. We meet with a great many very good pendulum machines, but they go regularly only when fixed in undisturbed situations; the slightest concussion is apt to derange their motion; they are therefore totally useless in long sea voyages. It is obvious that the pendulum, which regulates the motion, is incapable of resisting the shocks to which it is exposed in navigation. About ten years ago, however, an English artist pretended that he had constructed a time-piece proof against the motion of a ship at sea, and that after having tried it a long time together in a carriage on the road, it was impossible to perceive the slightest derangement; on which the inventor claimed and received part of the parliamentary reward proposed for the discovery of the longitude, and the rest was to be paid after it had been put to the proof of a long voyage. But since that time we have heard no more of it; from which it is to be presumed that this attempt too has failed, like many others which had the same object in view.*

19th September 1761.

Letter L.—Eclipses of the Moon, a Third Method of finding the Longitude.

From want of the exquisite time-piece, of which I have endeavoured to give you an idea, the eclipses of the moon have hitherto been, considered as the

* The success of these attempts has been very great. The chronometers of Harrison, Earnshaw, Arnold, &c. in England, and those of M. Breguet in Paris, and of M. Jurgensen at Copenhagen, enable the navigator to determine his longitude at sea with an extraordinary degree of accuracy. —Ed.