

**XXIX.** *Astronomical Observations relating to the Mountains of the Moon. By Mr. Herchel of Bath. Communicated by Dr. Watson, Jun. of Bath, F. R. S.*

Read May 11, 1780.

**A**T the time when the telescope was first invented this noble instrument was immediately applied to astronomical observations with the most surprising success. Several very eminent persons have given us an account of their discoveries; and, notwithstanding the imperfect state of telescopes in those times, we still owe a great deal of our knowledge of the heavenly bodies to the observations that were made by those first telescopic observers, who made amends for the deficiencies of their instruments by their uncommon diligence and attention.

It may, perhaps, be esteemed to be a mere matter of curiosity to search after the height of the lunar mountains. I grant that there are more necessary and more useful objects of inquiry in the science of astronomy; but when we consider that the knowledge of the construction of the Moon leads us insensibly to several con-

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quences, which might not appear at first; such as the great probability, not to say almost absolute certainty, of her being inhabited, we shall soon agree, that these researches are far from being trifling.

My reason for repeating observations that have been made by very good astronomers was not that I doubted either their veracity or diligence. The names of GALILEO, HEVELIUS, KIRCHER, and several more, will always deserve to be mentioned with particular respect for the eminent services they have rendered to astronomy; but as we know that their instruments were far from being arrived to that degree of perfection we have now obtained, I thought it by no means improper or useless to repeat their observations on the lunar mountains, and to extend them to other parts of the Moon's visible hemisphere, and thereby to establish this theory on the firmest evidence of a survey taken by a very excellent instrument.

The method used by HEVELIUS and others to find the height of a mountain in the Moon is this. Let a ray of light *SLM* (fig. 1.) proceeding from the Sun, pass by the Moon at *L*, and touch the top of a mountain at *M*: then the space between *L* and *M* will appear dark, and the top of the mountain will be seen to stand at some distance from the illuminated part of the Moon's disk. With a

good micrometer let the distance LM be taken by observation <sup>(a)</sup>. Draw LC perpendicular to LM; draw also MC from the top of the lunar mountain to the center of the Moon: then in the triangle MLC, rectangled at L, we have given the side LC, which is the Moon's radius, and the side LM taken by observation. Therefore, by trigonometry, we can find the hypotenuse MC <sup>(b)</sup>, from which, subtracting the part pc or radius, there remains the perpendicular height of the mountain mp. I have followed the same method, as being the least liable to error.

GALILEO takes the distance of the top of a lunar mountain from the line that divides the illuminated part of the disk from that which is in the shade to be equal to a 20th part of the Moon's diameter; but HEVELIUS affirms, that it is only the 26th part of the same.

When we calculate from thence the height of such a mountain it will be found, in English measure, according to GALILEO, almost  $5\frac{1}{2}$  miles; and, according to HEVELIUS, something more than  $3\frac{1}{4}$  miles, admitting the Moon's diameter to be 2180 miles.

(a) I do not recollect that HEVELIUS mentions in what manner he took the distance LM; but I am apt to believe it was by a micrometer.

(b)  $\sqrt{LC^2 + LM^2} = MC.$

He says, in his *Selenography*, p. 266. “ Vera distantia illustratarum cuspidum, à confinio luminis et umbræ, præsertim tempore quadraturæ, invenitur, unâ vigesimâ sextâ parte, totius Lunæ dimetientis consistare; quando nimirum sunt remotissimæ: quemadmodum hoc ex phasi trigesimâ secundâ, monteque Apennino; ex phasi trigesima prima, monteque Didyme; et trigesimâ phasi, monteque Tauro et Anti-tauro, manifestissimè demonstratur.” Having afterwards mentioned that GALILEO makes the distance LM to be the 20th part of the Moon’s diameter, HEVELIUS proceeds, “ Quamobrem, cum distantia a nobis designatæ, paululum sint minores, idcirco et montes aliquantum depressores inveniuntur, quàm GALILÆUS æstimavit: neque non tamen illi terrenis nostris montibus, quoad altitudinem, non solum æquiparari possunt merittissimò; sed et multo certe sunt excelsores, quàm nostri omnium maximi; prout confestim, ex adjecto diagrammate patebit.” He gives us then his calculation according to German and Italian measure; and having found, in the manner above mentioned, the hypotenuse MC, he adds: “ Semidiameter Lunæ erit 1976 octav. part. Si igitur hæc à totâ hypotenusâ aufertur, restabunt adhuc sex, hoc est sex octavæ unius miliaris, vel tres quartæ unius miliaris Germanici, five

“ tria

“ tria milliaria Italica: quæ est vera, et genuina altitudo  
“ istius montis.” As a German mile in the time of HEVELIUS was a very uncertain measure, we may suppose that he meant geographical miles, 15 of which make a degree of latitude. The observations of HEVELIUS have always been held in great esteem; and this is most probably the reason why later astronomers have not repeated them. M. DE LA LANDE, who is one of our most eminent modern astronomers, agrees to the sentiments above cited.

In his *Abrégé d'Astronomie*, p. 435. he says, “ Je terminerai ce qui concerne la selenographie, en disant un  
“ mot de la hauteur des montagnes de la lune, qui étoient  
“ quelquefois éclairées, quoiqu' éloignées de la ligne de  
“ lumière de la treizième partie du rayon de la Lune; de  
“ la on peut conclure que ces montagnes ont de hauteur  
“ la 338<sup>ième</sup> partie du rayon Lunaire, ou une lieue de  
“ France. He then gives us a particular calculation, and the result is: “ Avec ces données on trouve la hauteur de  
“ 2643 toises, c'est à dire, plus d'une lieue commune.”

He also mentions the opinion of GALILEO, and adds:  
“ Mais on doit préférer à cet égard les observations  
“ d'HEVELIUS, qui ont été plus répétées, plus détaillées  
“ et plus exactes.”

Mr. FERGUSON says (Astronomy explained, § 252.)  
 “ Some of her mountains, by comparing their height  
 “ with her diameter, are found to be three times higher  
 “ than the higheft hills on our earth.”

KEILL, in his Astronomical Lectures, has calculated the height of St. Katherine's hill, according to the observations of RICCIOLUS, and finds it nine miles.

Before I report my own observations, it will be necessary to explain by what method I have found the height of a lunar mountain from observations that were made when the Moon was not in her quadrature; for the method laid down by HEVELIUS will only do in that one particular case: in all other positions the projection of the hills must appear much shorter than it really is. Let  $SLM$ , or  $slm$  (fig. 2.) be a line drawn from the Sun to the mountain, touching the Moon at  $L$  or  $l$ , and the mountain at  $M$  or  $m$ . Then, to an observer at  $E$  or  $e$  the lines  $LM$ ,  $lm$ , will not appear of the same length, though the mountains should be of an equal height; for  $LM$  will be projected into  $on$ , and  $lm$  into  $on$ . But these are the quantities that are taken by the micrometer when we observe a mountain to project from the line of illumination. From the observed quantity  $on$ , when the Moon is not in her quadrature, to find  $LM$  we have the following analogy. The triangles  $oOL$ ,  $rML$ , are similar; therefore,

therefore,  $Lo : LO :: Lr : LM$ , or  $\frac{Lo \times on}{Lo} = LM$ ; but  $Lo$  is the radius of the Moon, and  $Lr$ , or  $on$ , is the observed distance of the mountain's projection; and  $LO$  is the sine of the angle  $ROL = oLS$ , which we may take to be the distance of the Sun from the Moon without any material error, and which therefore we may find at any given time from an ephemeris.

I will now give an account of my own observations relating to the mountains in the Moon; but, perhaps, it may not be amiss to mention the instrument they were made with, and a few of the circumstances, that it may appear how far their accuracy may be depended upon.

The telescope I used was a Newtonian reflector of six feet eight inches focal length, to which a micrometer was adapted consisting of two parallel hairs, one of which was moveable by means of a fine screw. The value of the parts shewn by the index was determined by a trigonometrical observation of a known object at a known distance, and was verified by several trials. The power I always used, except when another is mentioned, was 222 times, also determined by experiment, which I have often found to differ somewhat from theory, on account of some little errors in the *data*, hardly to be avoided. The moon having sufficient light, I used no more

more aperture of the object speculum than four inches; and, I believe, that for distinctness of vision this instrument is perhaps equal to any that was ever made.

## OBSERVATIONS.

November 30, 1779, six o'clock in the morning, a rock, situated near what HEVELIUS calls *Lacus niger major*, was measured to project  $41'';56$ . To reduce this quantity into miles, put  $R$  for the semi-diameter of the Moon in seconds, as given by the Nautical Almanac at the time of observation, and  $Q$  for the observed quantity, also in seconds and centesimals; then it will be in general  $R : 1090 :: Q : \frac{1090Q}{R} = on$ , in miles. Thus it is found that  $41'';56$  is 46,79 miles. This distance of the Sun and Moon at the same time was, by the Nautical Almanac, about  $93^{\circ} 57\frac{1}{2}$ . The sine of which to the radius  $R$  is .9985, &c. and  $\frac{on}{Lo}$  in this case, is  $LM = 46,85$  miles. Then, by HEVELIUS's method the perpendicular height of the rock is found to be about one mile.

The same morning, a great many rocks, situated about the middle of the disk, projected from  $25'';93$  to  $26'';56$ . This gives  $on$  about 29,3 miles, and these rocks are all less than half a mile high.

January



January 13, 1780, 7 o'clock, I examined the mountains in the Moon; but there was not one of them that was fairly placed on level ground, which is a condition very necessary for an exact measurement of the projection. If there should be a declivity on the Moon before the mountains, or a tract of hills placed so as to cast a shadow on that part before them which would otherwise be illuminated, it is plain that the projection would appear too large; and, on the contrary, should there be a rising ground before them, it would appear too little.

As far as I was able to judge of the direction of the line of illumination, the highest hill projected  $25''31$ , or 30,36 miles: from thence we find, as before that the perpendicular height is (.42 mile) less than half a mile.

January 14, 11 o'clock, I took the projection of the highest mountain which was situated at the Western edge. It measured  $24''68$ , or about 27 miles; and the perpendicular height comes out less than half a mile. There was not one mountain in the edge of the disk so high as this.

January 17, 7 o'clock, a very high mountain projected no less than  $40''625$ . Its situation is in the South-east quadrant. The Moon's semi-diameter, at the time of

observation, by the Nautical Almanac, was 16' 2",6; therefore,  $\frac{10900}{R} = 45,98$  miles = *on*.

Sun's longitude at	7h.	.	.	.	.	9	27	39	0
Moon's longitude at	7	.	.	.	.	2	2	46	52
Their nearest distance,		.	.	.	.	4	5	7	52

or about 125° 8'; the sine of which is .8104: thence we find LM 56,73 miles; and the perpendicular height of the mountain is 1m. 47, or less than a mile and a half.

January 22, 8h. 20'. the highest mountain, situated near Snell or Petavius, projected 11",437, which is 12',34; and LM comes out to be 35,3 mile: therefore the perpendicular height is ,57 mile.

Another, just behind Mare Crisium, measured only 7", therefore is less than half a mile high.

January 25, 7h. 30'. in the morning, a mountain near Aristoteles measured 18",59 which gives 20,6 miles; and LM is found 28,53 miles; the perpendicular height is therefore only ,37 mile.

Other mountains about Mare Nectaris measured about 23",5; but they had hills before them, and their situation was not so proper for my purpose. However, it is evident they were of no considerable height.

January 28, 6 o'clock in the morning, the highest mountain in the disk measured  $30''$ ,937; the Moon's semi-diameter at that time  $15'$  40''; and  $on$  therefore equal 31,37 miles: but as the Moon is within four hours of her quadrature we may be assured that this mountain is less than half a mile high.

February 19, Mons Sinopium projected  $5''$ ,781; therefore  $on = 6,26$  miles, and the quantity LM 56,54 miles; and consequently the height of this mountain, which it seems proves to be a very high one, is not much less than a mile and a half. However, my journal observes, that the measure was very full; therefore the mountain in all probability does not exceed a mile and a quarter. Moreover, I think that observations made so near the full or new Moon are less to be depended upon, because a small error in measuring will produce a great one in the height of a mountain.

From these observations I believe it is evident, that the height of the lunar mountains in general is greatly over-rated; and that, when we have excepted a few, the generality do not exceed half a mile in their perpendicular elevation. It is not so easy to find any certain mountain exactly in the same situation it has been measured in before; therefore some little difference must be expected in these measures. Hitherto I have not had an

opportunity of particularly observing the three mountains mentioned by HEVELIUS; nor that which RICCIOLUS found to project a sixteenth part of the Moon's diameter. If KEILL had calculated the height of this last mentioned hill according to the theorem I have given, he would have found (supposing the observation to have been made, as he says, on the fourth day after new Moon) that its perpendicular could not well be less than between eleven and twelve miles.

I shall not fail to take the first opportunity of observing these four, and every other mountain of any eminence; and if other persons, who are furnished with good telescopes and micrometers, would take the quantity of the projection of the lunar mountains, I make no doubt, but that we should be nearly as well acquainted with their heights as we are with the elevation of our own. One caution I would beg leave to mention to those who may use the excellent  $3\frac{1}{2}$  feet refractors of Mr. DOLLOND. The admirable quantity of light, which on most occasions is so desirable, will probably give the measure of the projection somewhat larger than the true, if not guarded against by proper limitations placed before the object glass. I have taken no notice of any allowance to be made for the refraction a ray of light must suffer in passing through the atmosphere of the Moon, when

when it illuminates the top of the mountain, whereby its apparent height will be lessened, as we are too little acquainted with that atmosphere to take it into consideration. It is also to be observed, that this would equally affect the conclusions of HEVELIUS, and therefore the difference in our inferences would still remain the same.

Bath, February 28, 1780.

*Continuation of the same observations.*

March 11, 1780, 7h. Promontorium Archerusia projected  $17''$ , 187. It is very properly situated for measuring. By a proper deduction from the Moon's semi-diameter, as given by the Nautical Almanac, at the time of observation, we find the quantity  $on = 20.1$  miles, and  $LM = 22,6$  miles; from which it appears, that the perpendicular height of this mountain is a little less than a quarter of a mile.

Antitaurus, the mountain measured by HEVELIUS was badly situated, because Mount Mofchus and its neighbouring hills cast a deep shadow, which may be mistaken for the natural convexity of the Moon. A good, full, but just measure,  $25''$ , 105; in miles 29,27: therefore;

LM 31,7 miles, and the perpendicular height not quite half a mile.

7h. 45'. I was desirous of being very exact in this measure, therefore I repeated it. I took two different observations. A narrow measure 21",562; quite full enough 24",062. These measures give the perpendicular height less than half a mile.

8h. I measured Lipulus, 19"063. It is also badly situated, though rather better than Antitaurus. I found that the projection increased, therefore concluded that this was not the highest part of the mountain, and waited some time when I measured it again.

9h. Lipulus now projected 28",75.

10h. It measured 28",75: this gives  $on = 33,64$  miles. Distance of Sun and Moon about  $63^{\circ} 23'$ : therefore, LM 37,54 miles. From hence we find the perpendicular height, 64 mile, or very near two-thirds of a mile.

March 12, 1780, 7h. One of the Apennine mountains, between Lacus Trafimenus and Pontus Euxinus projected 44",062. This gives us  $on = 51,11$  miles; and LM = 52,9 miles: therefore the perpendicular height of these mountains, which I know to be very high, comes out to be  $1\frac{1}{4}$  mile.

Mons Armenia (near Taurus) projected  $31''406 = 36,43$  miles; LM = 38 miles nearly, and the height two-thirds of a mile.

Mons Leucopetra  $34''479$  or 40 miles; LM = 41,4 miles, and the perpendicular height three quarters of a mile.

There was a very fine shade of a high rock near it, which shewed the direction of the illuminating ray, and thereby assisted me in measuring to a great exactness; but the mountain itself is not very favourably situated.

March 16, 10h. 30'. Mons Lacer projected  $45''625$ ; but I am almost certain that there are two very considerable cavities or places where the ground descends below the level of the convexity, just before these mountains, so that these measures must of course be a good deal too large: but supposing them to be just, it follows, that *oz* is 50,193 miles, LM = 64 miles, and the perpendicular height above  $1\frac{3}{4}$  miles.

Another of the same mountains situated on the borders of S. Sirbonis measured  $41''875$ . This ridge of mountains is the same of which I measured one on January the 17th, which was then found to be 1,47 miles high.

*The following additional Memoranda of the Manner in which Mr. HERSCHEL made his Observations are taken from a Letter of his to the rev. Dr. MASKELYNE, Astronomer Royal.*

IN the second figure of my observations, the points  $L, s, E, r$ , are all supposed to be in one plane; and as the illuminating ray  $sL$  is also in this plane, it follows, that the line  $Ln (= on)$  will always be perpendicular to the right line which joins the cusps of the Moon<sup>(c)</sup>; and the truth of the theorem there delivered depends upon this circumstance.

For this reason I have taken care in all my observations to measure the line, which in fig. 3. (taken from your letter to Dr. WATSON) is marked  $on$ , parallel to the line  $CD$ , or perpendicular to  $AB$ , and not the line  $rn$ , perpendicular to the elliptical curve  $AroB$ .

The manner of taking it is easy enough: however, I have occasionally used three different methods, and will de-

(c) It is here supposed, that rays from the Sun  $s$ , and the eye of the observer  $E$ , to any part of the Moon  $L$ , may be taken for parallel; and therefore, that different planes, made by several sections of the Moon, according as the point  $L$  is taken North or South of the diameter of the Moon, which is at rectangles to the line joining the cusps, may also be taken to be parallel to that diameter.



scribe them all, which I should have done in the paper delivered by Dr. WATSON, had I not feared to be too particular.

The first method I used was to set the immoveable hair *bb* (fig. 4.) of my micrometer parallel to a line *AB*, joining the cusps of the Moon; then, by opening the moveable parallel hair till it included the projection *on*, intended to be taken, I marked that down as the measure of *on*. As this method required some attention (that part of the ellipsis of illumination *AVB* which is the vertex *v* of the lesser axis may serve as a direction) and took up some time, on account of the small field of view of my telescope, I used occasionally these two following ways.

When there was any remarkable figure on the disk of the Moon near the line of illumination, I put on a compound eye-piece whose magnified field of view is full  $40^{\circ}$ , and power about 90 times, so that it takes in the greatest part of the whole Moon; by this means I was enabled to view the projection intended for measuring at the same time with the rest of the Moon, and to fix upon some mark in the disk very near to its edge towards which I judged the line *on* should be directed; then putting on the eye-piece which carries the micrometer I

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took the distance according to this judgment as well as I could.

The third method I took was the following, which, indeed, I look upon as the best of all, and which I therefore most frequently put in practice. I took a view of some neighbouring shades of rocks or mountains, if there happened to be any near, and directed the measure of the micrometer by them, as they plainly pointed out the direction of the illuminating ray; or, which is the same thing, indicated the line perpendicular to a line joining the cusps.

Mons Leucopetra was measured by this last method, which circumstance I have mentioned in my observations of the 12th of March, where I saw the whole rock and its highest point, as well as the whole shade, and its last termination, upon very even ground, at the same time that I directed my micrometer in that line, to take the projection *on*, of the above mentioned mountain.

Sometimes I compared together a measure taken in the direction *on*, and one taken in the direction *rn*; but as most of my observations were made upon mountains not situated near the cusps or limb of the Moon, I never found so much difference between these two measures, that it could have occasioned any very material error, if I had intirely neglected it.

By the nature of the ellipsis it will appear, that, when we do not come too near the limb or cusps of the Moon, a tangent drawn to a point in the curve of illumination will seldom make with the subtangent an angle that exceeds (or is so much as)  $26^{\circ}$ ; and in all such cases the error that can arise from taking the line  $rn$  instead of  $on$  will be less than the tenth part of the whole measure: but, if the angle the tangent makes with the subtangent is only about  $18^{\circ}$ , the error will be less than a 20th part; and all the measures I have taken, I believe, will be found to be much within these last-mentioned limits. From this consideration it will appear, that if I had not been aware of this circumstance, my observations would still be sufficiently accurate to disprove the usually assigned great height of the lunar mountains; but as I took all the precaution the situation of each mountain would afford, by using any one of the above mentioned three methods, which suited best, I believe there can hardly be a possibility of any error that should amount to a 40th part of the whole height of any mountain I have measured.

The figure ABCD (fig. 5.) contained by the diameter AB, the arch CD, and the two curves AD, BC, shews in what portion of the Moon's semi-disk we may safely measure the line  $rn$ , instead of  $on$ , without being liable

to fo great an error as one tenth part of the whole, and the figure  $ABcd$  contains that part wherein the meafure  $rn$  being taken inftead of  $on$ , the error will be lefs than the 20th part of the whole meafure. In a portion fomething more confined the error will foon vanifh, fo that the difference may be fafely neglected intirely. Thus in the fpace  $ABxy$  the error cannot amount to a hundredth part. Thefe figures may be conftructed by taking the feveral points  $D, d, y$ , and  $C, c, x$ ,  $26^\circ, 18^\circ, 8^\circ$ , refpectively, from the vertex, the curves  $AD, Ad, Ay, BC, Bc, Bx$ , being the loci of thofe points of the tangents which touch the feveral ellipfes of illumination that may be contained in the femi-difk of the Moon, when thefe tangents make thofe feveral angles of  $26^\circ, 18^\circ, 8^\circ$ , with their fubtangents.

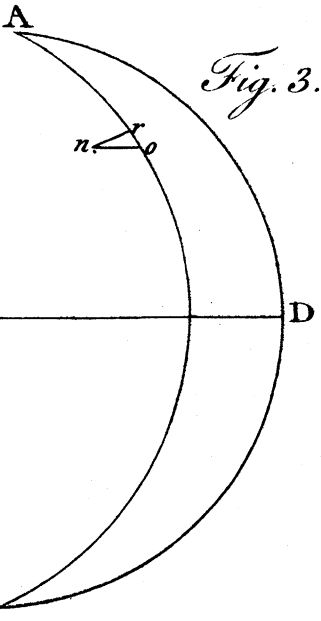
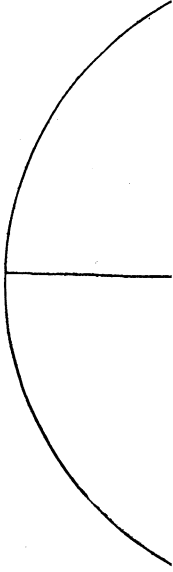
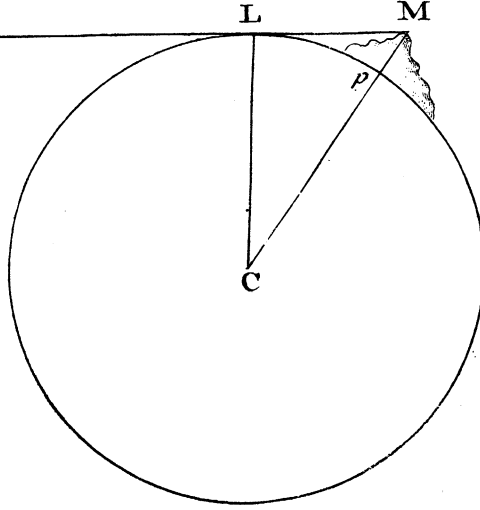


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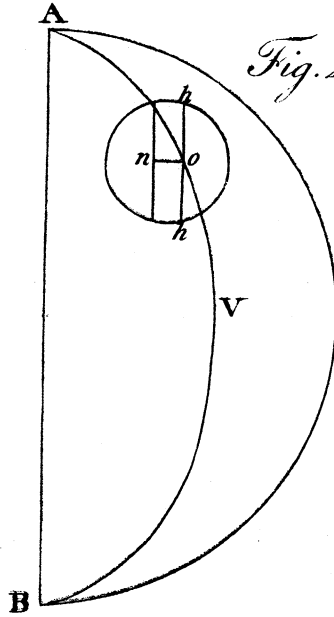
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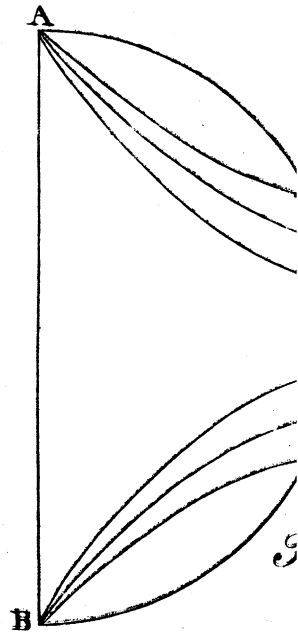
*Fig. 1.*

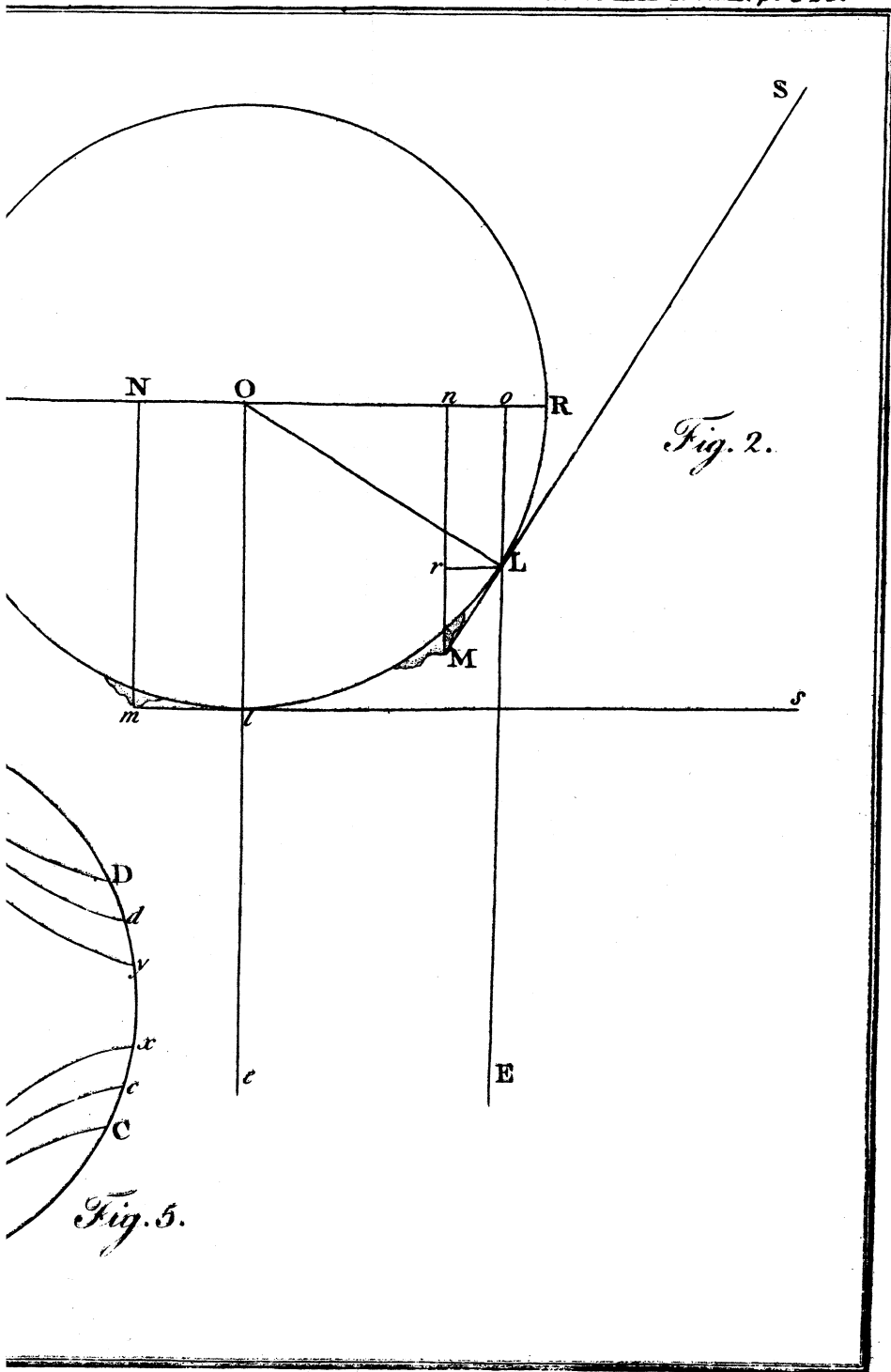


*Fig. 3.*



*Fig. 4.*





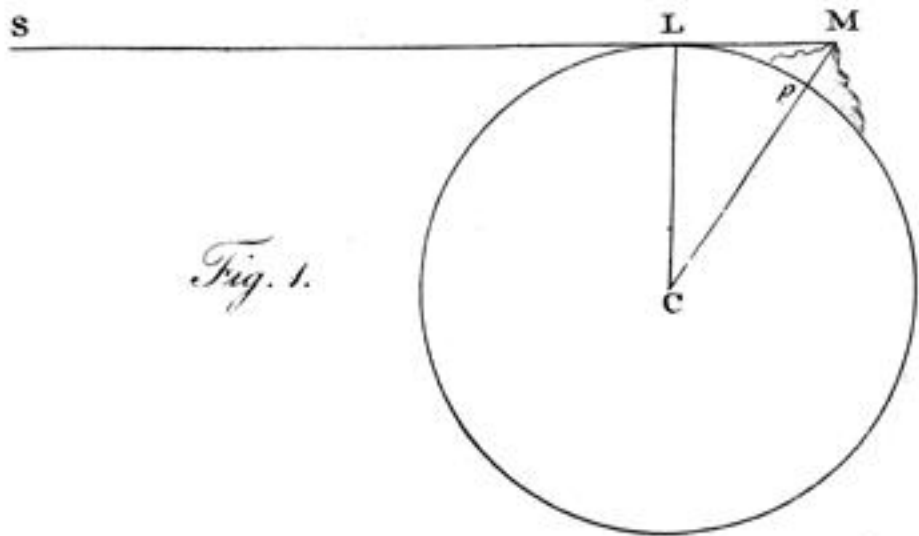


Fig. 1.

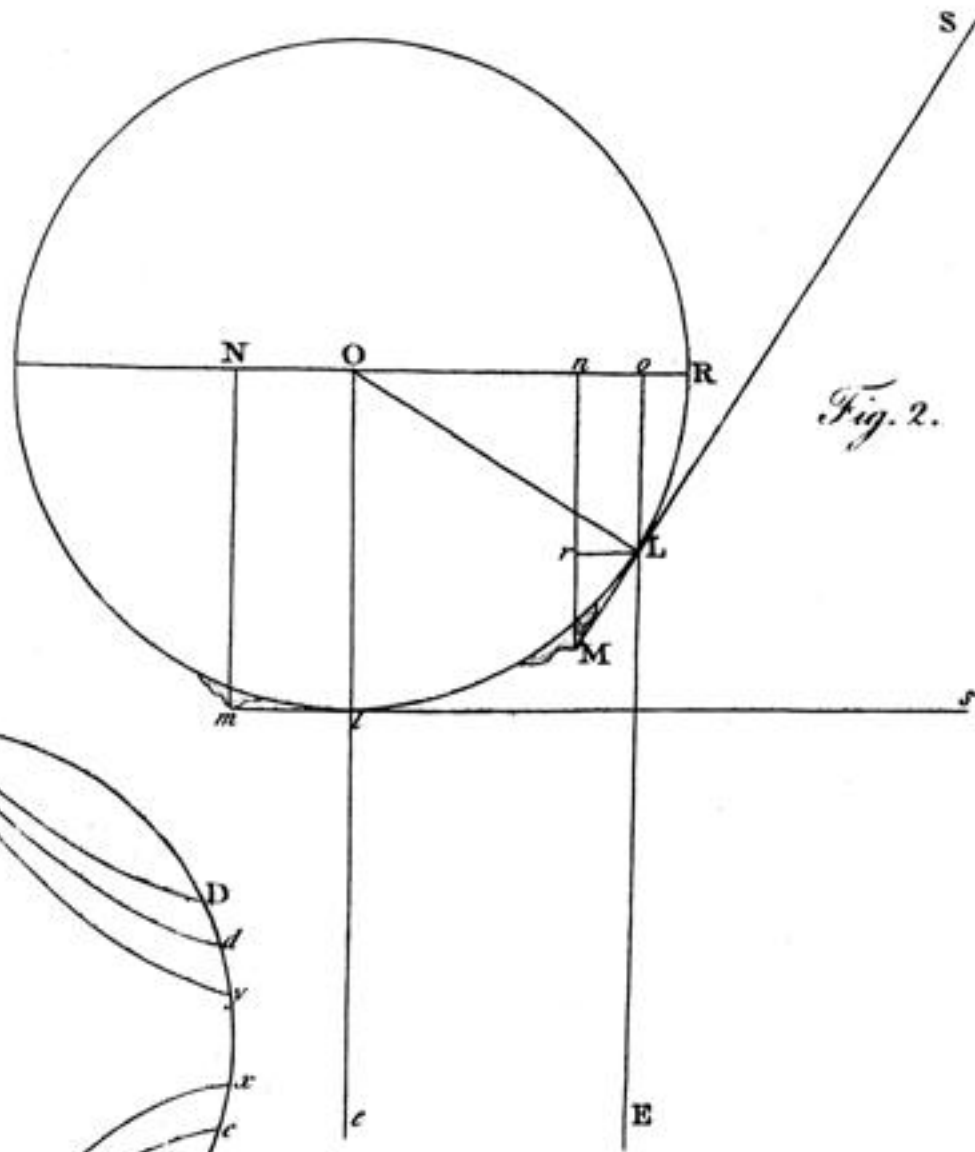


Fig. 2.

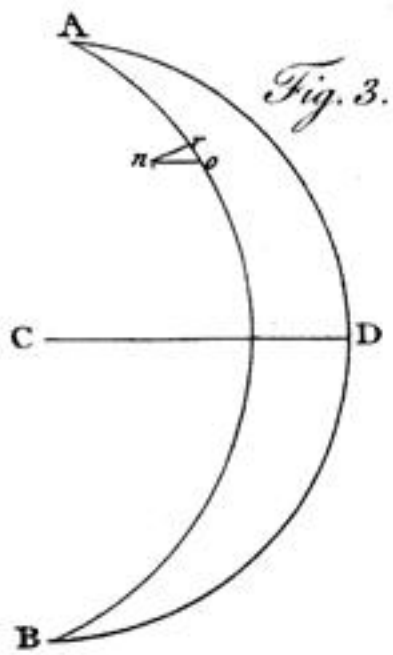


Fig. 3.

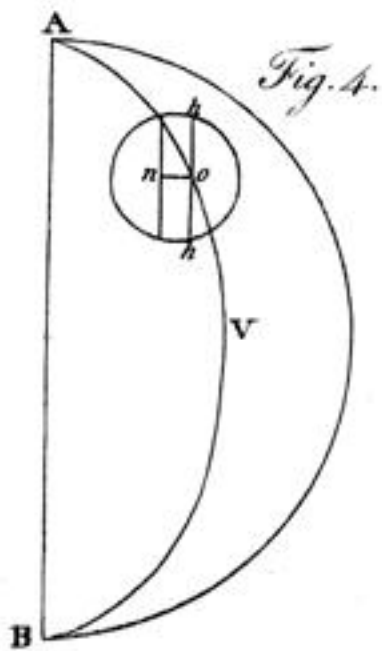


Fig. 4.

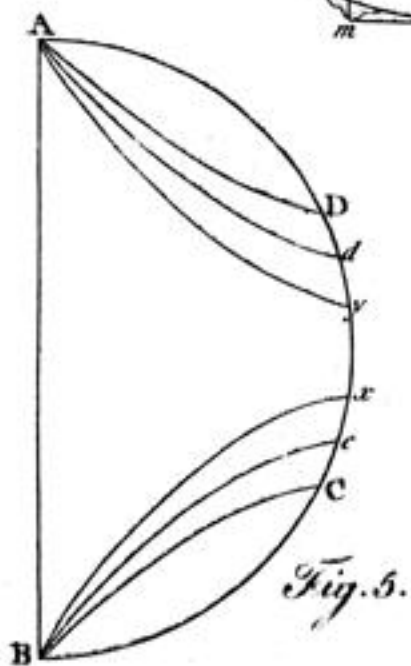


Fig. 5.