XX. *An improved method of dividing Astronomical Circles and other Instruments.* *By Capt.* Henry Kater. *Communicated by* Thomas Young, *M. D. For. Sec. R. S.*

Read May 5, 1814.

THE art of dividing astronomical circles and other instruments for taking angles, has ever been thought highly important to the improvement of astronomy and geography, and has consequently, at different periods, formed a subject of much attention and inquiry. The method of dividing, which until very lately was in general use, was that practised so successfully by the late Mr. BIRD; but the laborious and delicate operation by the scale and beam compasses, has recently been superseded by the invention of Mr. TROUGHTON, of the excellency of which the mural circle at the Royal Observatory at Greenwich affords a noble proof. But this method, though decidedly superior to Mr. BIRD's, seems yet to leave somewhat more to be done with respect to simplicity and facility of execution; and it is with the hope of having in some measure attained these desirable objects, that I am induced to lay before the Royal Society a mode of dividing, which, I am led to believe, will not be found inferior in accuracy to any that has hitherto been proposed.

In the essential principle on which this method is founded, I find that I have been anticipated by the Duc de CHAULNES; but some parts of the apparatus which he has described are so

complicated, and others so incapable of the necessary adjustments, that his method of dividing never has been, nor ever can be introduced into practice, and indeed was intended by its author merely to form a model, which was to be employed as part of a dividing engine.

The method which I am about to describe requires no other apparatus than two pieces easily made, which I shall call *adjustable dots;* three microscopes, (two furnished with micrometers) and a cutting point with its frame.

The general principle of this method consists in viewing the two micrometer microscopes, as the points of a pair of beam compasses, and the moveable dots as divisions, capable of the nicest adjustment previously to their being transferred to the limb of the instrument. Its principal advantages are its simplicity, and the exclusion of all errors, excepting such as may arise from careless execution, the imperfection of vision, or the instability of the apparatus employed.

The *adjustable dots* are represented at plate XV. figs. 1, 2, and 3. *a*, *a*, *a*, *a*, fig. 1. is a flat piece of brass, intended to rest on the face of the arc to be divided, and to be clamped to it by means of the screw C, fig. 3, where the adjustable dot is represented in perspective. The piece *c c*, slides smoothly in a dove-tail groove, formed by the pieces *b*, *b*, and is moveable by the screw *d*. *e*, *f*, slides in like manner in a dove-tail groove beneath, and at right angles to the piece *c c*, and is moveable by the screw *g*. That part of the clamp which bears against the edge of the arc, should be curved in such a manner as to have only its two extremes in contact with the edge, by which means the motion of the sliding piece *c c*, will always be in the proper direction. A very thin and narrow tongue

of silver or gold, on which is a well defined circular dot, is soldered to the lower surface of *ef*, beneath, and projecting from *e*: the lower surfaces of this tongue, of the piece *ef*, and of *a*, *a*, *a*, *a*, are all in the same plane. It is evident from this construction, that the tongue with the circular dot is moveable on the surface of the limb of the instrument, both to and from its centre, and in a direction at right angles to the radius. The screws *d*, and *g*, are to be turned by a key with a handle of wood or ivory, in order to avoid any change of temperature which might arise from the near approach of the hand; the sliding pieces should move easily, and yet be perfectly free from shake.

There is another mode of constructing the adjustable pieces, which I conceive may be found far preferable to that I have just described, though in the use of them greater care and nicety will be required. It is to draw two fine lines at right angles to each other on the silver tongue of the piece *ef*, fig. 1. which lines may be used instead of the dot, by causing them to bisect the angles formed by the cross wires of the microscopes, and thus ensuring, as far as vision is concerned, as great a degree of accuracy in dividing as can afterwards be attained in reading off.

The line in the direction of the piece *ef*, must be drawn when the adjustable piece is fixed on a circle, and when the piece *cc*, is placed about half way between the limits of its adjustment; in which position this line will be directed towards the centre of the instrument, and, unless the circle to be divided is very small, the difference from this direction within the limits of its adjustments will scarcely become sensible. This will be better understood when the manner of using the

adjustable dots has been described. The silver tongue with its cross lines is represented at A, plate XV. fig. 1.

The three microscopes are similar to those used in reading off the divisions of astronomical instruments of modern construction, and therefore need not be very particularly described. Two of these microscopes are furnished with micrometers in the usual manner, each having a set of cross wires as represented at fig. 6, moveable in the direction *ab*, by means of the micrometer screw.

The two micrometer microscopes have adjustable supports, one of which is seen at fig. 4. in which *a*, *a*, are two pieces of brass forming a dovetail groove for the sliding piece A, which carries the microscope, and which is moveable by the screw represented in the plate. In the circular opening formed in the sliding piece A, a piece of brass tube is soldered, in which the microscope slides rather stiffly, in order to be adjusted to distinct vision. The supports are made very strong, and are furnished beneath with clamps, by which, or by any other equivalent contrivance, they may be firmly fixed to an arc, hereafter to be described. One of the microscopes with its support is represented at fig. 5, from which its construction will be readily understood; the micrometer head is omitted in the engraving, as it would only occasion confusion. The object glass of each microscope is fixed in a tube having a fine screw cut on its outside, by means of which, after the microscope has been adjusted as nearly as possible to distinct vision, any remaining parallax may be removed, when the object glass is to be secured by the nut *a*, in the usual manner.

Fig. 7, represents the support for the third microscope, and also the cutting point, the frame of which is attached to this

support. ABCDE, is a thick plate of brass, having a tube soldered in the opening C, to receive the microscope. The projecting square pieces B, D, receive the conical points of the screws F, F, of the cutting frame, the general construction of which will be readily understood from the engraving. The cutting point which is elliptical, as recommended by Mr. TROUGHTON, passes obliquely at an angle of about fifty degrees through the flat piece of brass G. The pieces *a*, *a*, project half an inch or more beyond the piece G, and to their under surfaces a thin slip of silver or gold is soldered, or otherwise securely fastened, on which a well defined circular dot is made, as represented in the plate. The sides HI, HI, of the cutting frame, must be of a sufficient length for the ends I, I, to reach nearly to the surface of the instrument to be divided when the frame hangs perpendicularly from B, D; by this construction of the cutting frame, it is evident that the circular dot may be adjusted so that its image may pass through the point of intersection of the wires of the microscope when carried through its field of view, and that the cutting point may be seen through the same microscope when employed in tracing the divisions on the limb of the instrument. A profile of the cutting point and frame is given at fig. 8.

As every thing depends on the rectilineal motion of the cutting point when tracing a division, too much care cannot be employed in its use, and it is greatly to be wished some better mode of giving it motion could be adopted in place of the inflexible projecting handles at present employed, as a lateral deviation of only $\frac{1}{16000}$ of an inch, in a circle of two feet diameter, would occasion an error in the division amounting to about a whole second. Perhaps an universal joint applied to

the upper surface of the piece G, and connected with a handle, might be used with advantage. The length of that part of the cutting point which projects beneath the piece G, may also prove a source of error; but this may be easily obviated by making the piece G, much thicker, and passing the screw through it, as represented in the profile.

An arc of cast iron or brass must be provided, of about 120 degrees in length, and of a radius rather greater than that of the instrument to be divided. Its breadth may be about two inches, and its thickness should be fully sufficient to ensure its not bending. This arc, which is designed to carry the three microscopes, is to be fastened at its extremities by clamps, screws, or otherwise, to the framework of the instrument to be divided, in such a manner as that the microscopes may project over its limb, and be at a proper distance above it for distinct vision, and that the surface of the arc may be parallel to the face of the instrument. The manner of fastening this arc must be left to the ingenuity of the artist. In some instances it may perhaps be found convenient to construct a temporary frame for the reception of the instrument during the operation of dividing, but in whatever manner the arc is applied, it is absolutely necessary that it should be so secured as to be perfectly immoveable.

I shall now proceed to detail the manner in which this apparatus is to be employed in dividing a circle, which I shall suppose to be two feet in diameter. The first operation necessary is to describe on the face of the instrument the circles which are to limit the divisions. This may readily be done by causing a fixed point to press on the surface of the circle, whilst it is made to revolve on its axis. The support carrying

the third microscope and cutting frame, which microscope I shall in future distinguish by calling it *the fixed microscope*, is then to be firmly screwed to the arc, as near to its right extremity as conveniently may be, and so that the intersection of the cross wires of the microscope may be a little without the exterior circle described on the face of the instrument, and yet that both the circles that limit the divisions may pass through the field of view. The support of the fixed microscope must also be so placed, as that the cutting point may move in the direction of the diameter of the circle to be divided. The moveable microscopes are to be attached to the arc by their clamps, and to be always so adjusted that the intersections of their wires may appear half way between the circles intended to limit the divisions. The microscope which is placed next to the fixed microscope I shall distinguish by the letter A, and the other by the letter B. The micrometer head of A must be placed to the right, and that of B to the left, of their respective microscopes.

It will, perhaps, be found most convenient to commence by dividing the circle into five equal parts of *seventy-two degrees* each. For this purpose, having fixed the circle by means of the clamp attached to its tangent screw (with which every instrument is provided), draw a fine line with the cutting point from the exterior circle described on the face of the instrument to the edge of its limb: this line I shall call *the line of reference.* Adjust the fixed microscope to distinct vision, by sliding it in its support, and cause the line of reference accurately to bisect the vertical angles formed by the cross wires of the microscope, by moving the circle, and by turning the microscope in the tube of its support. Move the eye to the right and left, and observe

whether the line of reference appears to change its position. If it is perfectly stationary in every situation of the eye, the adjustment of the microscope is correct; if not, the remaining parallax must be destroyed by moving the object glass, which must afterwards be secured by means of its nut.

The next step is to adjust the cutting frame. To this end, place the projecting pieces *a*, *a*, of the cutting frame on the face of the limb of the instrument, when the dot will be at a proper distance from the microscope for distinct vision. Slide it through the field of view, and examine whether its centre passes accurately through the intersection of the cross wires, and if not, cause it to do so by means of the screws F and F.* This adjustment should be most carefully examined in every part of the process of dividing, as it is essentially necessary to the accuracy of the operation.

Place the microscope A, as near to the fixed microscope as conveniently may be (leaving, however, sufficient space to use the cutting point), and clamp it firmly to the arc. Fix the microscope B at the distance of seventy-two degrees by estimation from A,† and bring the intersections of their wires between the circles which are to limit the divisions. Place an adjustable dot under A, with its centre precisely in the intersection of the cross wires. Unclamp the circle, and turn it on its axis till the adjustable dot arrives at the intersection of the cross wires of B; and should the centre of the dot not pass

* The same thing might, perhaps, be as conveniently effected by giving a motion to the cross wires of the fixed microscope, and fine lines intersecting each other at right angles may be used instead of the dot (as in the adjustable pieces) should it be thought preferable.

† This may be readily done by means of the figures usually engraved on the limb previous to the operation of dividing.

accurately through their intersection, cause it to do so by means of the screw of the moveable support of the microscope B. The intersections of the cross wires of both microscopes will now be equidistant from the centre of the circle. Adjust both microscopes to distinct vision, in the manner described for the fixed microscope, using the adjustable dot instead of the line of reference. Return the line of reference to the fixed microscope, clamp the circle, and, by means of the tangent screw, bring the line of reference again accurately under the intersection of the cross wires. Place the second adjustable dot precisely under the intersection of the wires of the microscope B. When all has been thus arranged, the line of reference, and the two adjustable dots, should appear in the intersection of the wires of their respective microscopes, and the dot of the cutting frame, if moved through the field of view, should pass through the intersection of the wires of the fixed microscope. This arrangement of the microscopes is represented in plate XVI. from which the manner of placing them in the subsequent parts of the operation will also be readily understood.

Turn the circle on its axis till the dot which was under A, arrives under B. Clamp the circle, and, by means of the tangent screw, bring the centre of this dot under the intersection of the wires of the microscope B. Take off the adjusttable dot which was under B, and which will now be found to the left of that microscope, place it beneath A,* and, by means of its adjusting screws, bring its centre under the intersection of the cross wires, carefully remarking whether the circle has

* The artist will perceive, that five dots in this stage of the process will be more convenient than two, and obviate the necessity of removing the dots.

in the mean time suffered any change of position, which may be known by the centre of the dot which is under B, being no longer found precisely under the intersection of its wires; and, should this have happened, the dot must be restored to its former position by moving the circle, previous to the final adjustment of the dot which is under the microscope A. The adjustable dots must thus be made successively to change places, till the line of reference arrives again in the field of the fixed microscope, when it is evident, if the intersections of the wires of the microscopes A and B are precisely distant seventy two degrees from each other, the line of reference will again be found accurately in the intersection of the cross wires of the fixed microscope, as it was at the commencement; but should this not be the case, its distance from it will be equal to five times the error in the distance of the wires of the microscopes A and B, and this error is to be corrected by the micrometer of the microscope A,* and the whole operation repeated, always remembering to bring, in the first instance, the line of reference accurately to the intersection of the wires of the fixed microscope, and carefully to repeat the various adjustments which have been detailed.

When, by repeated trials, the wires of the microscopes A and B are found to be at the required distance from each other, the divisions are to be cut on the limb of the instrument, the eye being assisted by viewing the cutting point through the fixed microscope. The first line, or zero, is to be made when

* The line of reference may be brought to the intersection of the wires of the fixed microscope and the distance of the dot which is under A, from the intersection of its wires be measured by its micrometer screw, and this will be equal to five times the error in the distance of A and B.

the line of reference and the two dots are under the intersections of the wires of their respective microscopes, and each of the other divisions, successively after the dots have been made to change their places; and thus the circle will be divided into five equal parts, which seem to be subject to no other error than what may be attributed to the imperfection of vision, or inaccurate execution.

Each division of *seventy-two degrees* is next to be subdivided into three parts. To effect this, bring the line of reference to the intersection of the wires of the fixed microscope, and verify the adjustment of the cutting frame. Place the microscope B, above the first division from the fixed microscope, and the microscope A, at the distance of one third of a division, or twenty-four degrees by estimation from B. Cause the division which is under B, to bisect the vertical angles of the cross wires, by means of the micrometer screw, and by turning the microscope in its tube, and adjust both microscopes to distinct vision. Place an adjustable dot under the intersection of the wires of A; unclamp the circle, and turn it till the adjustable dot is under B; when, if it does not pass precisely through the intersection of the cross wires, it must be made to do so, as before described, by means of the screw attached to the support of the microscope. Bring back the line of reference to the wires of the fixed microscope, when the adjustable dot should be precisely in the intersection of the wires of A, and the first division (seventy-two degrees from zero) accurately bisecting the vertical angles of the cross wires of B. Turn the circle round till the adjustable dot arrives under B, and by means of the tangent screw bring it accurately to the intersection of the cross wires. Place another adjustable

dot in the intersection of the cross wires of A, taking care, by examining the dot under B, to ascertain that the circle has not in the mean time suffered any change of position. Bring the dot which was last placed, and which is now under A, to the intersection of the wires of B, when it is evident if the wires of the microscopes A and B, are at the required distance from each other, the next division of the instrument, or zero, will now pass precisely through the intersection of the cross wires of A. But should this not be the case, the distance may be measured by means of the micrometer, and the cross wires of A must be removed one third of this distance from their first position towards the side opposite to that on which the division appears in the microscope. The line of reference must then be brought again to the wires of the fixed microscope, and the whole operation repeated as before, till the intersections of the wires of A and B, are at the proper distance from each other.

In order to cut the divisions; having ascertained that the line of reference, the division which is under B, and the adjustable dot under A, are accurately in the intersection of the wires of their respective microscopes; turn the circle till A and B, have each an adjustable dot in the intersection of their cross wires, and cut a division; move the circle till an adjustable dot is in the intersection of the wires of B, and a division in that of A, and trace another line with the cutting point. It is now evident, that one of the primary divisions of seventy-two degrees is trisected. Take off the adjustable dots, which are now no longer necessary, and bringing each of the new divisions, as well as the primary ones, successively under the intersection of the wires of the microscope A, trace a new

division with the cutting point, and proceed in this manner round the whole circle, remembering that when a division is in the intersection of the wires of A, another division should be found precisely in that of B, and this affords a very severe test of the accuracy of the work as it proceeds.

Having thus obtained divisions of *twenty-four degrees*, these are again to be trisected precisely in the same manner, and with all the precautions before detailed, placing, should it be necessary, the microscope B, at the distance of two divisions, or forty-eight degrees, from the fixed microscope, and transferring the adjustable dots through two divisions instead of one, which will bring the new divisions under the microscope A, when the adjustable dots may be taken off.

The circle is now divided into portions of *eight degrees* each, and these are to be continually bisected, till we arrive at divisions of *half a degree;* but as it is presumed that the centres of the microscopes A and B, cannot be brought nearer to each other than eight degrees, it becomes necessary to take distant divisions, and to bisect twenty-four degrees. For this purpose, having brought the line of reference to the intersection of the wires of the fixed microscope, and verified the adjustment of the cutting point, place the microscope A, as near to the fixed microscope as convenient, with the intersection of its cross wires half way by estimation between any two divisions, and at the distance of twelve degrees place the microscope B, causing the angles of its cross wires, by means of the micrometer screw, to be bisected by the division under it. Fix an adjustable dot beneath the intersection of the wires of A, and see that it passes through that of B, as formerly directed. Adjust for distinct vision, &c. in the manner which has already

been minutely detailed, and on bringing the adjustable dot to the intersection of the wires of B, if the distance of the microscopes be accurate, a division will be found precisely in the intersection of the wires of A, but should it not be so, the error in the distance of A and B, must be determined and corrected by means of the micrometer, as before described. The line of reference is then to be brought back to the intersection of the wires of the fixed microscope, and the trial repeated.

When the distance of A and B, is found to be correct; the line of reference being brought to the intersection of the cross wires of the fixed microscope, and a division being in that of the microscope B, it is evident that the intersection of the wires of A must accurately bisect a division, or be four degrees distant from the next division on the instrument. Bring up this division therefore to the intersection of the wires of A, and trace a line with the cutting point; do the like with each division, or every eighth degree successively, and the circle will be divided into parts of *four degrees* each, and by continuing to bisect in the same manner, the division of the circle is to be carried to *thirty minutes*.

The last operation consists in trisecting the divisions of thirty minutes.* Bring the line of reference to the fixed microscope, and examine the adjustment of the cutting frame as before. Place the intersections of the wires of B and A, on any two divisions of the instrument, say ten degrees from each other, and increase their distance by advancing the intersection of the wires of A, by means of its micrometer screw, one third of a division, or *ten minutes*. Place an adjustable dot under

* The method by which this trisection is effected is of very general application, and may be used with equal facility to divide an arc into any other number of parts.

A, adjusting the cross wires, and using all the various precautions which have been before minutely detailed. Bring the dot under B, and place a second dot under A: turn the circle till this second dot arrives at B, when if A and B are accurately at the required distance from each other, it is evident that a division will be seen precisely in the intersection of the wires of A; but if not, the error must be corrected as before described, by means of the micrometer. The line of reference is then to be brought back to the fixed microscope, in which position of the circle the intersection of the wires of A will be accurately one third of a division, or ten minutes in advance. Turn the circle, and *bring every division both of thirty minutes and those newly cut*, successively, as they arrive in the microscope, to the intersection of the wires of A, tracing a new division with the cutting point wherever there does not appear to have been one previously made, and continue this till the whole circle is divided into parts of ten minutes each.

In the example of the process of dividing which I have given, the diameter of the circle was supposed to be two feet, but should the instrument be of a smaller size, the microscopes cannot be brought so near to each other as eight degrees, and it then becomes necessary to choose a different series of numbers for the divisions. For this purpose, I have added a small table containing several series which appear to be most convenient, and from among which the artist may select that which may best suit the size of his instrument, and his own ideas of accuracy.

It may not be useless briefly to recapitulate the precautions which are absolutely requisite to the success of this mode of dividing.

The microscopes must be perfectly free from parallax, and the vertical angles formed by the intersections of their cross wires, accurately bisected by the divisions which pass through them. The intersections of the cross wires of A and B must appear between the circles which limit the divisions, and be equidistant from the centre of the instrument to be divided.

The dot on the cutting frame, if moved through the field of view, must always pass through the intersection of the wires of the fixed microscope; and the motion of the cutting point must be in the diameter of the circle to be divided.

When the line of reference is in the intersection of the wires of the fixed microscope, a division should always appear precisely in the intersection of the wires of the microscope B.

Lastly, previous to cutting each new division, if two divisions do not appear precisely in the intersections of the wires of A and B, it is an immediate proof, (unless the microscopes may have suffered any accidental change of position) of inaccurate execution in the former part of the work.

From what has been said, it is evident that the microscope B might have remained stationary after having been placed over one of the primary divisions of seventy-two degrees, and perhaps in practice this may be preferable. My only reason for directing it to be removed was to obviate the effect of any expansion which might take place in that part of the arc which is between the tracing point and the microscope, by placing it as near as possible to the cutting frame; this, however, will probably be found to be an unnecessary refinement.

This method of dividing is not confined to circles, but may be applied with equal facility and advantage to the division of straight lines and zenith sectors. For the last, it is necessary

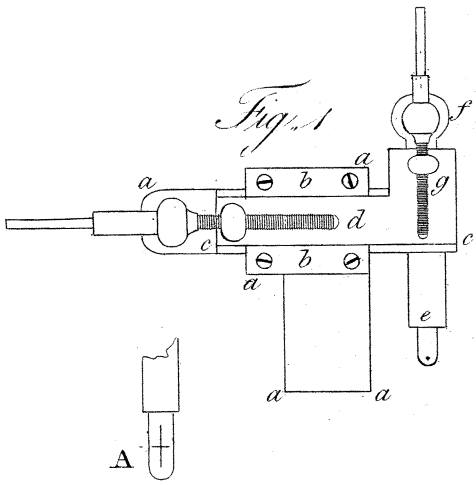


Fig. 1

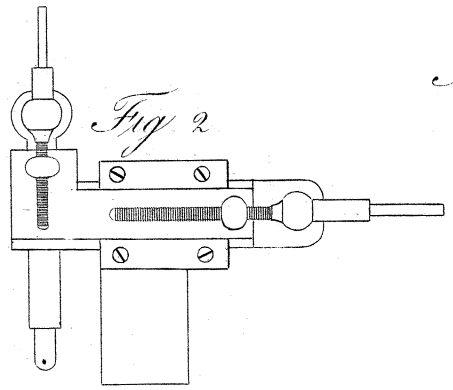


Fig. 2

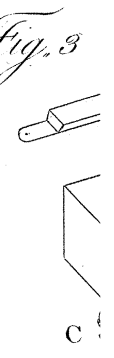


Fig. 3

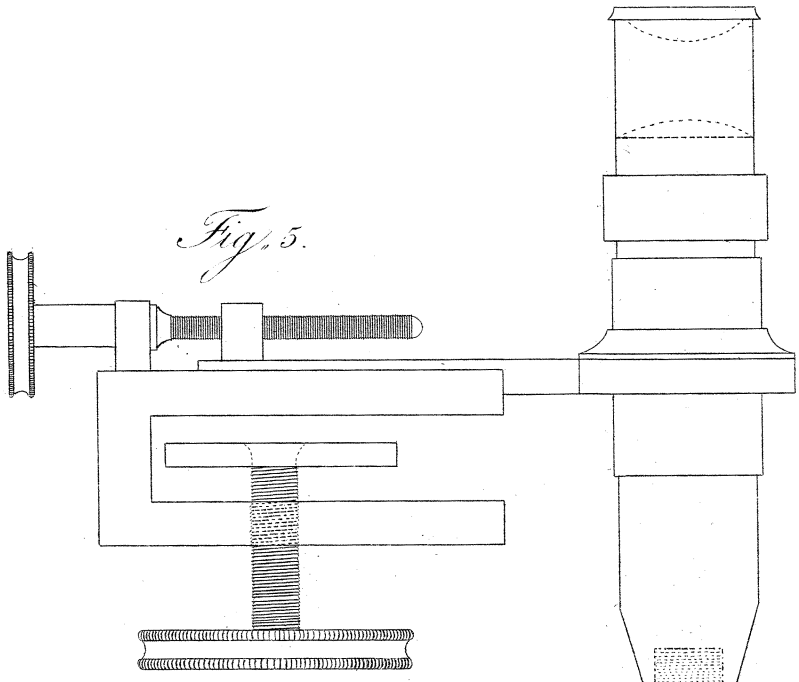
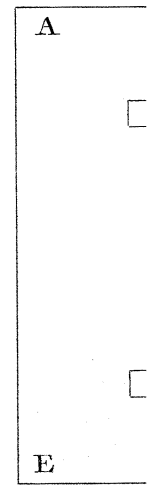


Fig. 5.



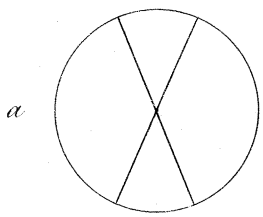


Fig. 6.

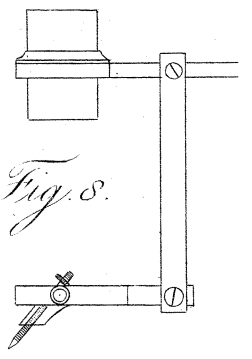
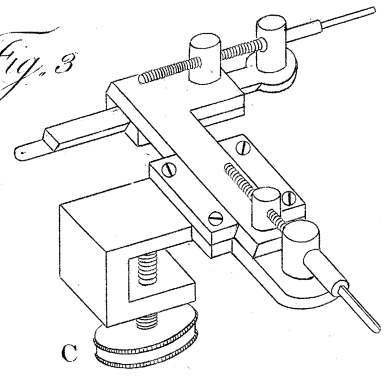


Fig. 8.

Fig. 3



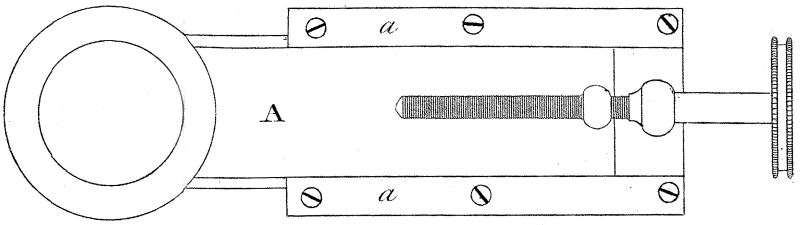
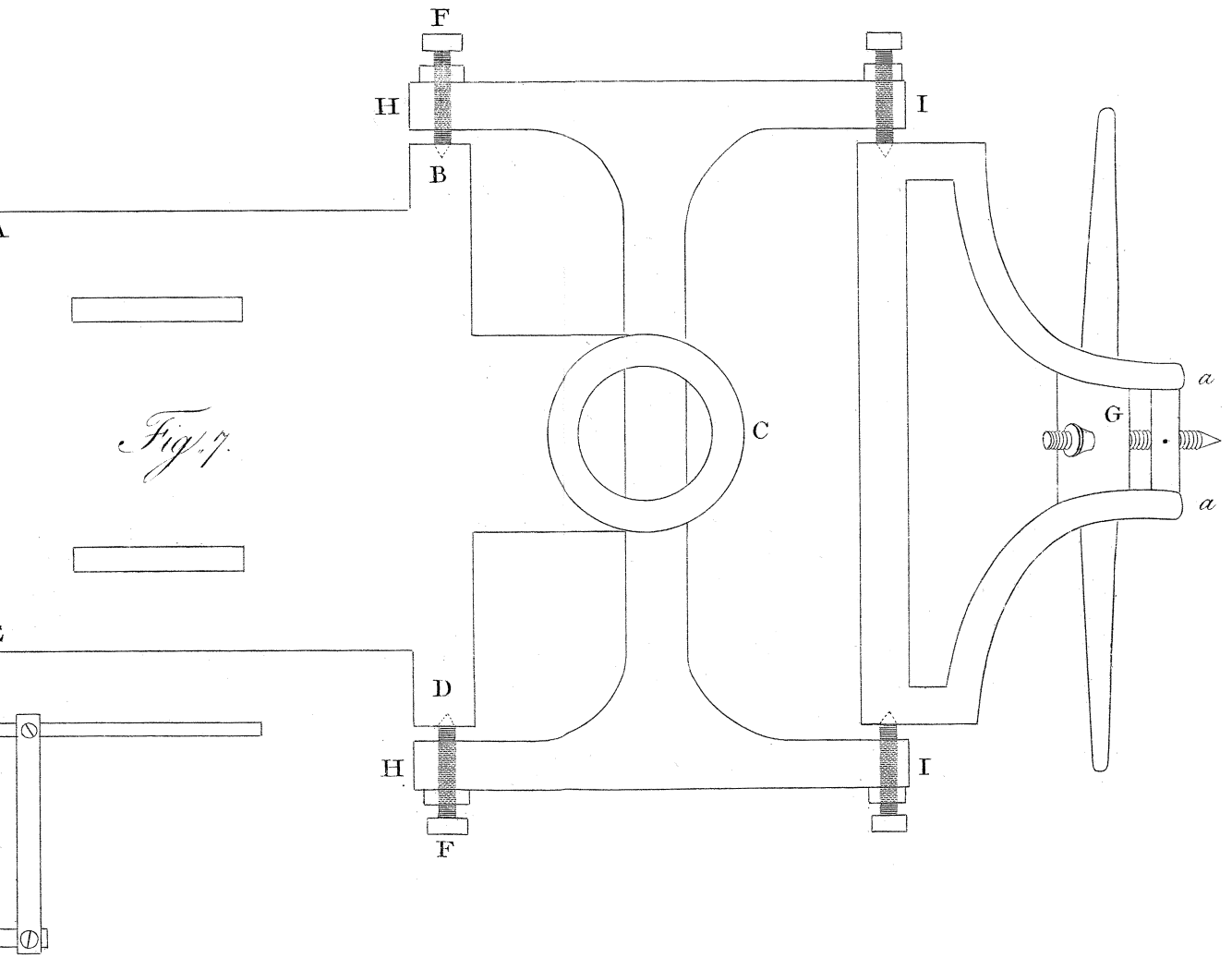
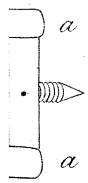


Fig. 4.

Fig. 7.

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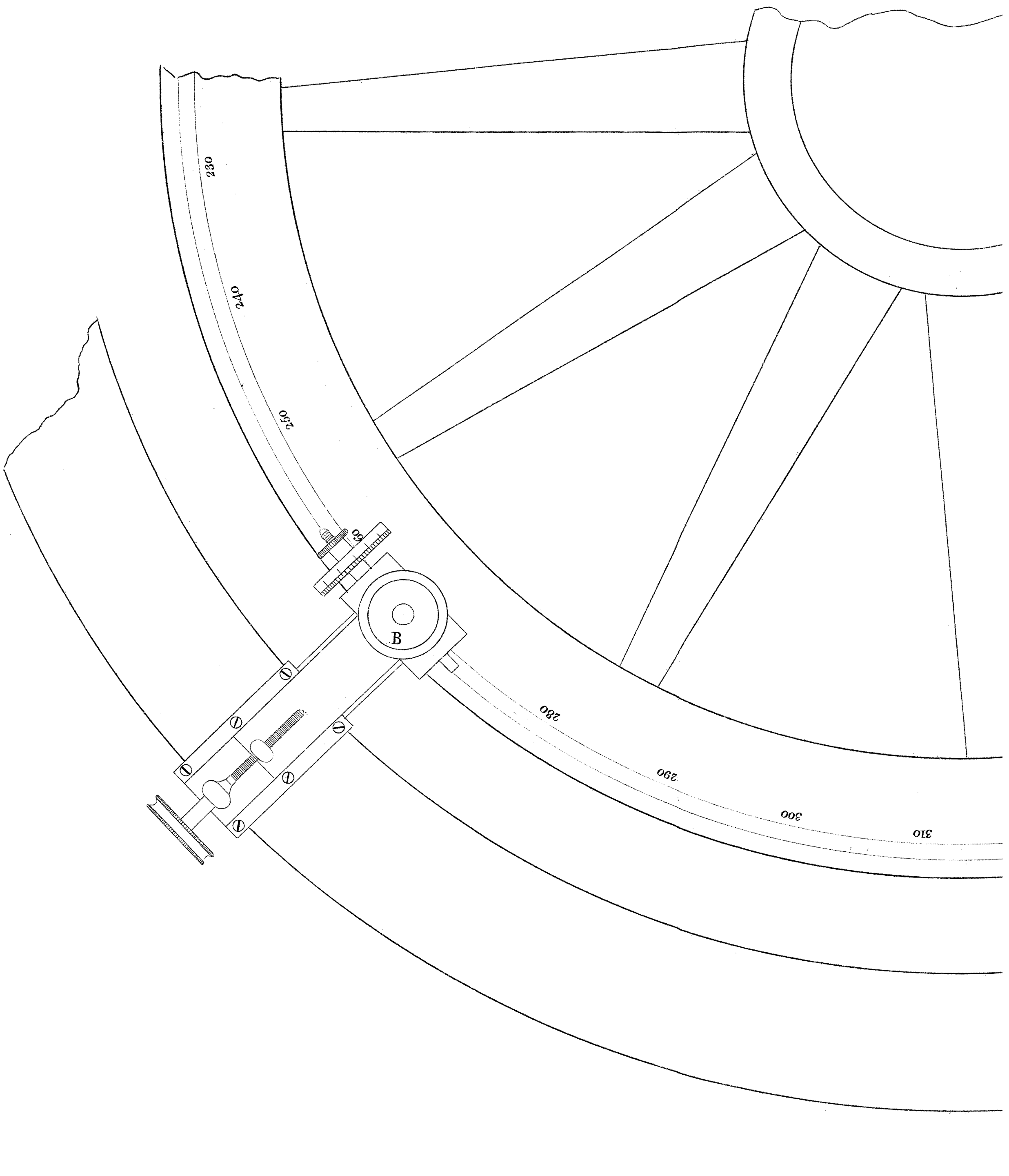

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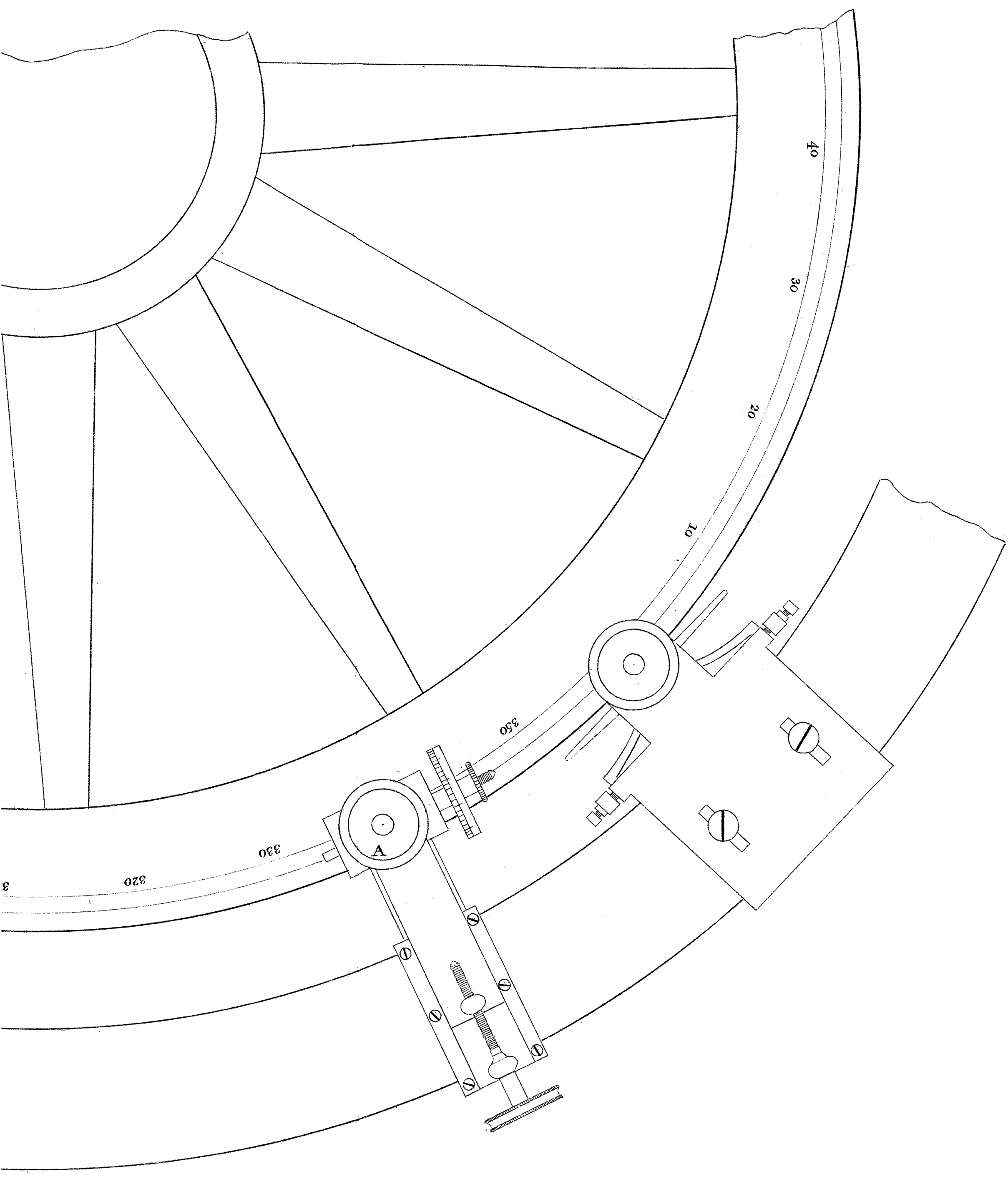

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to obtain the radius of the instrument to be divided, and by continual bisection its eighth part, which is the chord of seven degrees ten minutes. This chord is to be faintly set off on a part of the arc, and the fixed microscope being placed over the middle point of the arc, or zero, the division may be carried to five or ten minutes, precisely in the same manner as has already been directed for the circle.

Finally, whether the operation of dividing is performed by daylight, or by the light of a lamp, I would strongly recommend the use of shades made of thin oiled paper without wire marks, placed very near the limb of the instrument. The accuracy, and, if I may be allowed the expression, the luxury which they afford in delicate observations, can be fully appreciated only by those, who, like myself, have been in the frequent habit of using them.

No. 1. For a circle of two feet and upwards.	No. 2.	No. 3.	No. 4. For a smaller circle.
$\frac{360}{5}$ will give 72° 0′	$\frac{360}{2}$ will give 180° 0′	$\frac{360}{3}$ will give 120° 0′	$\frac{360}{5}$ will give 72° 0′
$\frac{72}{3}$ - 24 0	$\frac{180}{2}$ - 90 0	$\frac{120}{3}$ - 40 0	$\frac{72}{3}$ - 24 0
$\frac{24}{3}$ - 8 0	$\frac{90}{2}$ - - 45 0	$\frac{40}{5}$ - - 8 0	$\frac{24}{2}$ - - 12 0
$\frac{24}{2}$ - - 4 0	$\frac{45}{3}$ - 15 0	(See No. 1.)	$\frac{36}{2}$ - 6 0
$\frac{20}{2}$ - 2 0	$\frac{30}{3}$ - - 5 0		$\frac{42}{3}$ - - 2 0
$\frac{8}{2}$ - - 1 0	$\frac{15}{2}$ - 2 30		$\frac{26}{2}$ - 1 0
$\frac{19}{2}$ - 0 30	$\frac{32° 30′}{3}$ - { 0 50 and 0 10		$\frac{25}{2}$ - - 0 30
$\frac{31° 30′}{3}$ - 0 10			$\frac{24° 30′}{2}$ - 0 15

London, January, 1814.

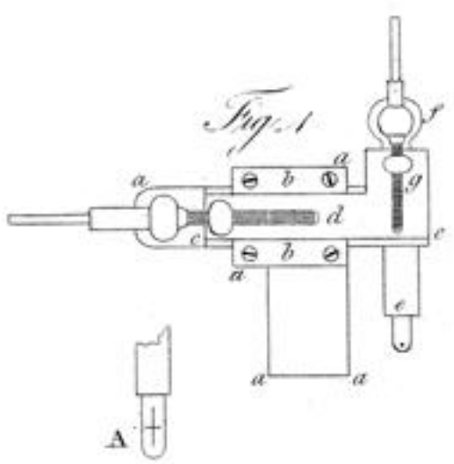


Fig. 1

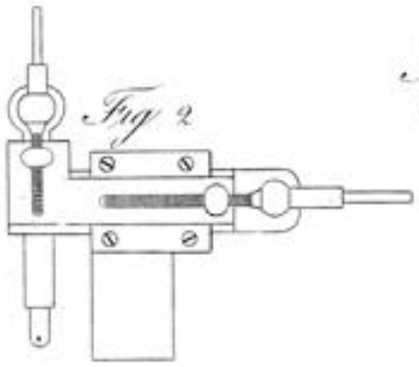


Fig. 2

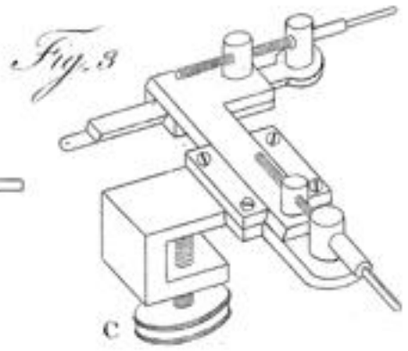


Fig. 3

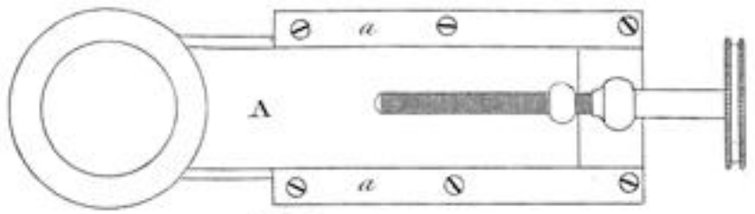


Fig. 4.

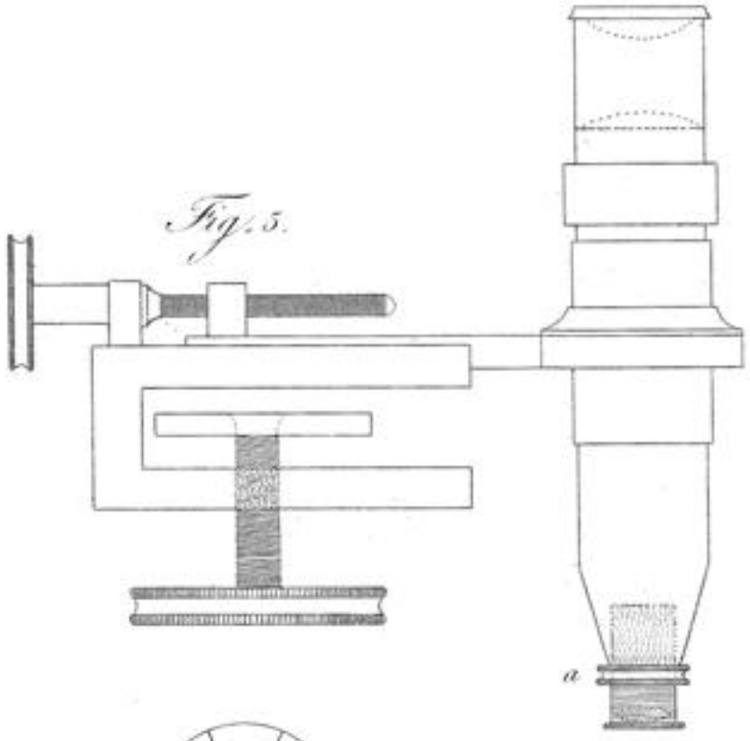
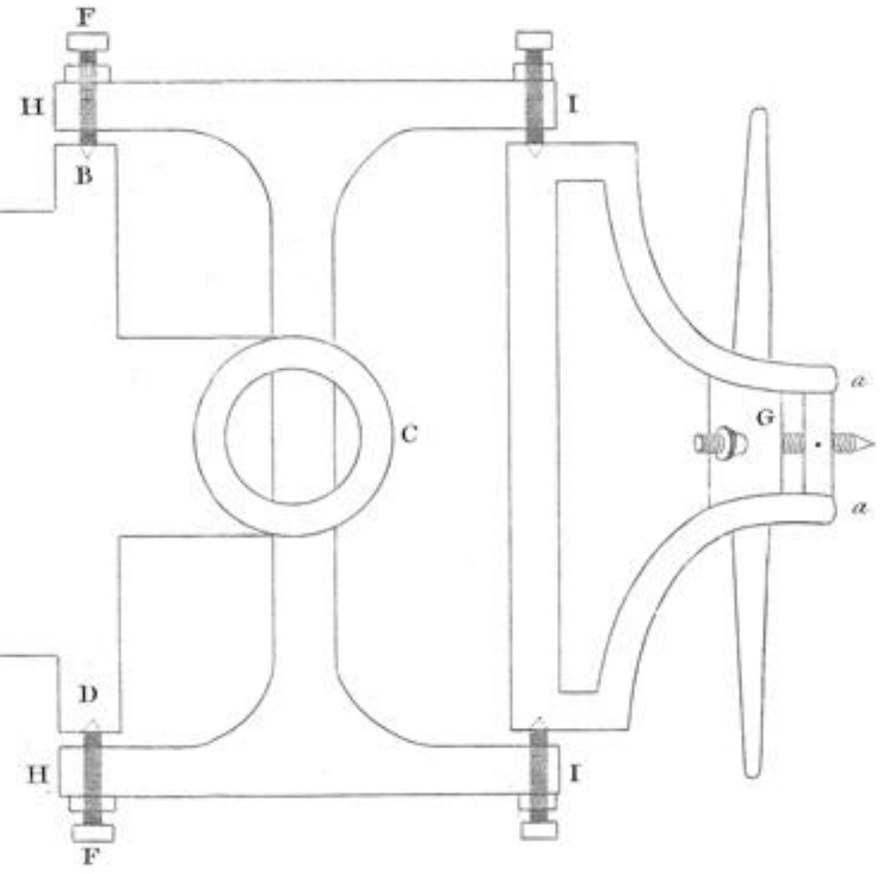


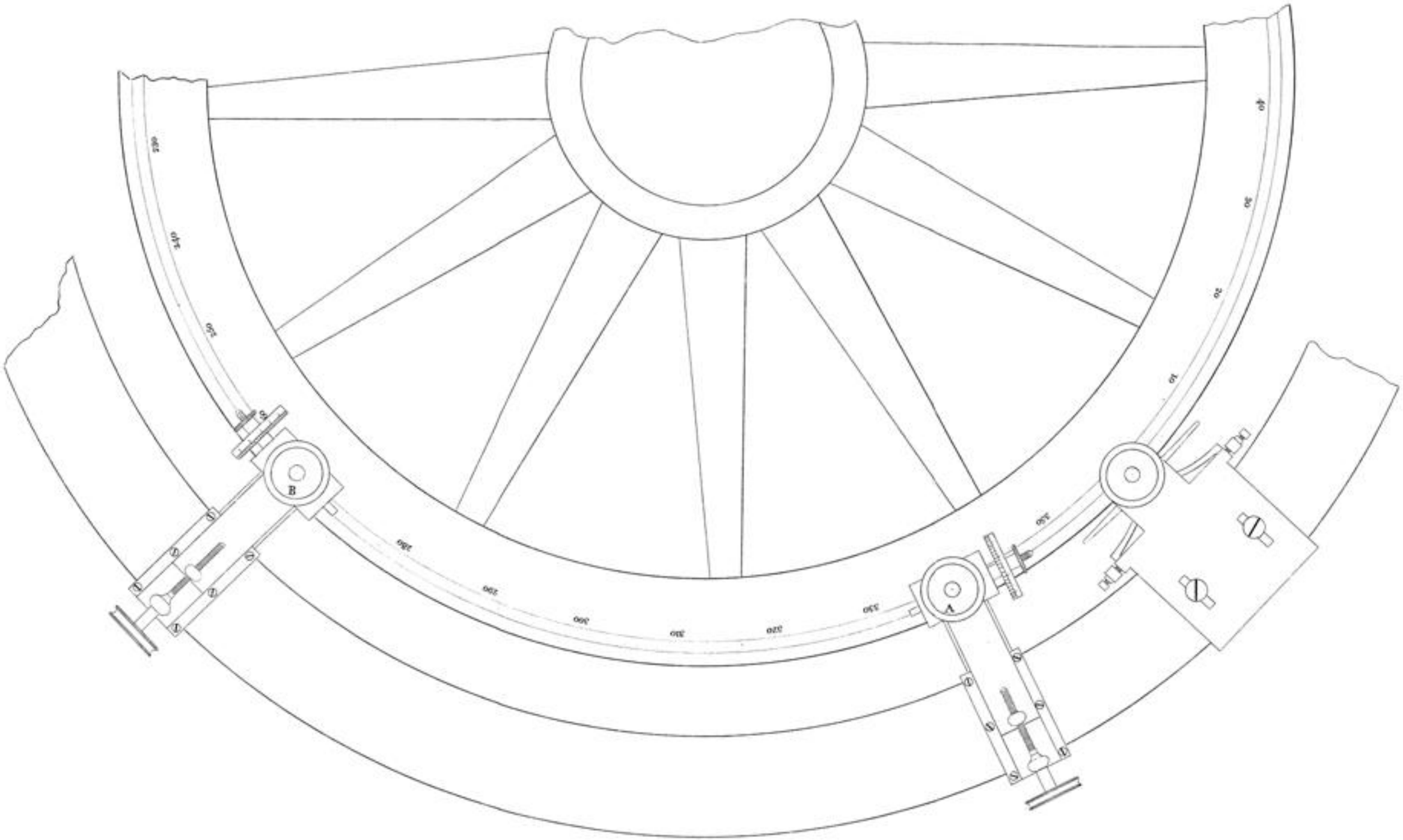
Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.




B
A