II. *Account of a new Pendulum.* *By* George Fordyce, *M. D. F. R. S.; being the* Bakerian *Lecture.*

Read November 7, 1793.

LET AB and CD be two rods of any solid of the same species, and of a simple or uniform texture. Let these two rods be exactly of the same length; let them be connected at the top with a rod BC, which is perfectly inflexible, let the angles ABC, and DCB, be both right angles, so that AB and DC shall be parallel to each other, and in the same plane; let the rod AB be fixed at the point A, and perpendicular to the horizon: then the rod CD shall likewise be perpendicular to it, excepting for the curvature of the earth between B and C, which in a foot or two may be considered as nothing: let the rod CD be loose at the end D, so as to be capable of rising up or falling down; in this case, if heat be applied equally to both rods, so as to expand them both, and lengthen them, the rod AB will raise up the rod BC, and lift up the rod DC; but the rod DC being equally lengthened by heat with the rod BA, the point D will be brought downwards by the lengthening of the rod DC, as much as the point C is raised by the lengthening of the rod AB by the heat. In consequence, the rod DC will have its end D in a line exactly parallel to the horizon, and cutting the end of the rod AB at A, as it did before the heat was applied; and the same thing will be true if the rods AB, DC, be shortened by exposure to cold; so that in all cases of heat or cold the end of the rod CD at D, and the end of the rod BA at A, shall be in a line parallel to the horizon.

Take a point E near any part of the rod CD, and let that point E be connected with the point A, where the end A of the rod AB is fixed, and let the matter which unites them be perfectly inflexible, and incapable of being altered by heat; then, I say, that the part of the rod CD, intercepted at the point E, and forming ED, will always be of the same length whether the temperature of heat is greater or less. For supposing a point F be taken near the rod AB, and of the same perpendicular height with E, so that a line drawn from E to F shall be parallel to the horizon; if the part of the rod AB, opposite to F, should rise up in consequence of being expanded by heat above F, it will carry up the point of the rod DC, which was opposite to E, to an equal height with itself, and therefore would cut off from the length of that part of the rod which was formerly opposite to E, a length equal to that which was added to what was formerly ED, by the heat. Therefore the point opposite to E, in the rod DC, will form ED, which will always continue of the same length, if the heat be increased; and by similar reasoning, it will likewise continue of the same length if the part of the rod AB AF is shortened by cold; therefore the part of the rod DC cut off by the point E, so as to form ED, will always be of an equal length, and the point D will always be of an equal height.

At the point E let there be an apparatus which will render that part of the rod DC which is opposite to the point E flexible, whatever part of it shall be opposite to the point E. Then the part of the rod DC, cut off at the point E, and forming DE, may become a pendulum. Thus we shall procure a pendulum of the same length, whatever be the degree of heat.

Let the rod AB and the rod DC be of different species of matter, so that the rod AB shall be lengthened by being heated to the same degree, more than the rod DC; then, if they be both of the same length, heat would carry up the end of the rod CD, at D, higher than the fixed point A; but if a part be cut off from AB at G, so that the whole of the expansion of the remaining part GB, shall be equal to the whole of the expansion of the whole rod DC, and that in every increase of heat, then the same thing would happen; and the part of the rod DC, cut off by the apparatus at E, would always remain of the same length. If, therefore, it is wished to render DE always equal in length, the fixed point A must be brought nearer to B, so as to shorten the rod AB, that is at G, so that the whole of the expansion of GB by heat, shall be equal to the whole of the expansion of DC by the same degree of heat.

Hitherto I have supposed that the substance which connected the points A and E was incapable of being expanded or contracted by heat: but no such substance is to be found.

I shall now suppose that the substance which connects the points A and E is capable of being expanded by heat. If it was capable of expansion equal to the matter of which the rods AB and CD consist, then it is evident that no advantage could be gained so as to render the part of the rod CD opposite to the point E down to D always equal. But it is clear that the expansion of AE, supposing the point A a fixed one, would carry the point E higher up towards C, if the heat was greater, so that ED would by this means be rendered longer; and the contraction of AE, when exposed to a greater degree of cold, would bring down the point E so as to render ED shorter, just as much as the expansion of AB would raise up the rod ED, or as its contraction lower it. But if the materials connecting the points A and E were less expansile and contractile by heat and cold, than the matter of the rods AB and CD, then upon the whole expanding, although the point E would be raised higher towards C, yet it would not be raised so high as the expansion of AB would raise the point C, and the whole rod CD. The same is true if the whole of them contract, but in an opposite direction. That is to say, the point E would not descend so far towards D, as the point C would descend towards D, and with it the whole rod CD; by this means, although the part ED would not be always equal, yet it will be much more equal than if the point C were a fixed point, and not capable of being affected with the contraction or expansion of the rod AB.

If then the part of the rod CD, from opposite to the point E to D was a pendulum, it would not be always of the same length, but it would be more nearly so than a simple pendulum made of the same materials of which the rod CD consists; and it would be nearly of the same length as if the pendulum had been made of the materials which connect A and E.

In order then to render ED always of an equal length, some other principle must be employed. Now let BA and CD consist of the same materials; and the matter connecting A and E consist of a substance that expands by heat, and contracts by cold, less than the materials of which AB and CD are formed; if the rod AB be brought down to H, and the fixed point be at H, and the points HE be connected together by the same materials which formerly connected the points AE in the rod EH, take a point K, equal in height with the points A D, and in the line AD which is parallel to the horizon, as it has already been taken in the construction; then the rod AH shall expand, upon being heated, in perpendicular height more than the rod HK, and therefore the expansion of AH shall carry the point B, and in consequence the point C, higher than the expansion of the rod HK shall carry the point E; but if the expansion of the rod AH be as great as the expansion of the whole rod HE, then the point C will be carried as much higher than the point E, as the point E is carried higher than it was before the heat was applied, and therefore the point E shall be at as great a distance from the point C, as it would have been if the materials connecting AE had been incapable of being altered by heat: and therefore if ED be a pendulum, it will be rendered of the same length. If then the rods AB, and CD, be of the same materials, and the substance connecting A and E is capable of expanding and contracting less by heat than the matter of the rods AB and CD, then, by adding to the rod AB, a part AH, under the circumstances already described, and making the fixed point at H, we can obtain a pendulum always of equal length; or if the materials of which the rod AB consists be capable of being expanded by heat as much as the materials of which CD consists, together with the expansion of the materials that connect A and E, in that case likewise the point C shall be carried as much higher than the point E, as it would be when they are expanded by heat, as if the materials connecting A and E had not been affected by heat at all. Or, lastly, if we take a rod GB, of materials which expand much more than the expansion of the matter of the rod CD, and the connecting matter of the rod EG by heat, then likewise upon the rod GB expanding, it will carry the point B, and consequently the point C, as much higher than the point E, as it would have been if the materials connecting G and E had been incapable of being expanded by heat, and therefore ED will always continue of the same length. The same reasoning will hold in cases of contraction from cold.

Therefore, if materials be employed in the rod GB, which contract considerably more than those which compose the rod CD, then the fixed point G is to be taken at a distance from B, in an inverse ratio to the inferior expansile power of the materials of which the rod CD consists, and in a direct ratio of the expansile power of the materials which connect E and G. That is, supposing that it was taken in the inverse ratio of the inferior expansile power of CD, then it would be at G; but to counteract the expansile power of the materials GE, it must be somewhat lower at I.

If then the proportion of the expansion of the materials of the rod AB, or GB, the rod CD and the materials which connected AE or GE were known, and the length of a pendulum swinging any proportion of time, in that case the distance and perpendicular height between GE and IE might be taken at once, and a pendulum might be always made which would always be of the same length, therefore swing equal arches in equal times. But these not being perfectly known, and it being extremely difficult, if not impossible, to measure off length perfectly, it is necessary to have the power of varying the distances and perpendicular height between I and E, A and E, or H and E, so that it may be found from trial whether these fixed points I, A, or H, be properly taken. For if, on construct-ing a pendulum on these principles, either of the fixed points, according to the circumstances, I A or H be placed too high or too low, then the pendulum will vary in its length, and of consequence swing different times in different degrees of heat.

That is to say, suppose the case be taken where the rod BG is made of materials which expand more than CD, if instead of rendering I the fixed point, it is made G, nearer to B, then the point C will not be raised sufficiently above the point E, the pendulum will become longer by heat, and make fewer vibrations in a given time. But if the fixed point in this case be brought lower than I, to the point L, then the point C will be raised higher when the whole is expanded by heat from the point E, ED will be rendered shorter, more vibrations will be performed in a given time, and *e contra*. Therefore if there be a power in the apparatus of altering the fixed point I, if found too high or too low by experiment, we shall be able to find out a true point, and make an adjustment accordingly. That is, if heat occasions a pendulum to make fewer vibrations, the fixed point is too high; if, on the contrary, it makes too many vibrations, then the fixed point will be too low.

I come now to show how these principles may be applied in structure.

As it is more convenient in practice to have the fixed point higher than A, which is equal in height to D the bottom of the pendulum, a substance should be chosen for the rod AB which expands and contracts more by heat and cold than the matter of which the rod CD consists, so that the fixed point should be at G, if the materials connecting A and E were incapable of being expanded or contracted by heat or cold:

but if their expansion and contraction is to be compensated for, the fixed point will be at I, as has already been shewn.

If the expansion and contraction of the rod IB by heat and cold, in proportion to the expansion and contraction of CD, were known, and the expansion and contraction in perpendicular height of IE, then the length IB should be to the length DC, as the contraction of the materials of CD is to the contraction of the materials of which IB is constructed, added to the contraction in perpendicular height of the materials of which IE is constructed. These lengths, in this case, might be taken at once; but it is much more convenient to have the power of fixing them by experiment, after taking them from measure as nearly as may be.

Therefore, to have a means of raising the point I higher or lower in proportion to ED, whose ends are always to be at the same distance from one another, fig. 2. represents the means of altering the point I in proportion in height to E. The frame AAAA is fixed to the substance which connects the points I and E by any means. In the clock which I have constructed, the material which connects I and E is wood, as will be described afterwards. The frame is brass; it is fixed to the wood by the screws B B, and two other opposite ones which are hid in the drawing. They are so fixed that the point I shall be nearly in the middle between the upper screw B, and the lower screw B, and so that the part of the frame DDDD shall project backwards, and carry the part of the frame EEEE behind the frame which forms the connection between I and E, so as to be parallel to it; of consequence perpendicular to the horizon. In this frame there is seen, at the upper part, in the drawing, a dove-tail groove, in which, on both sides, another frame

GGGG slides, in the same manner as in that part of a transit instrument which renders one end of the axis higher or lower. This second frame is brought higher or lower by the screw HH. The rod IB, fig. 1, is a brass tube, represented by II. There is a semicylindric cavity in the frame GGGG of the same diameter with the brass tube; a piece is applied over this frame, which is likewise a semicircular cavity, forming with the other cavity a whole cylinder, equal in diameter to the tube I I. This piece is attached to the frame GGGG by the screws L L; when these are screwed in tight, they occasion the tube I I to be embraced perfectly by the piece KK, and the semicylindric cavity in the frame G, so that the screw HH could not act if the tube I I was fixed; but if the screws L L are loosened, then they would leave the frame GGGG capable of being heightened or lowered by the screw HH. Now, if I I represent the rod IB, fig. 1, then if the centre of the screws L L be in an horizontal line, that line will cut the point I in an horizontal direction. The centres of these screws, therefore, may be considered as the point I in perpendicular height; wherefore if the point B, fig. 1, should become a fixed point, the point I may be lowered or heightened by bringing up or carrying down the centres of the screws L L by the screw HH.

If it be wished, therefore, by this apparatus to raise or depress the point I, fig. 1, it is necessary during the time of altering its height by the screw HH, that B, fig. 1, should become a fixed point; but that at all other times it should be a part perfectly free in its motion upwards or downwards.

In order to fix the point B fig. 1, in fig. 3 AAAA represents the frame of the clock, BB another frame fixed to this frame, and projecting backwards to such a distance as to carry a tube fixed to it CC so far back, and in such direction, as to exactly coincide on its inside with the cylinder formed by the semicircular cavity in the frame GG, fig. 2, and the cylindric part of the piece KK, so that if they were continued they would form the same cylinder when the screws L L, fig. 2, are screwed home. This tube is made exactly to fit the tube I I, in the same manner that the outer brass tube of a telescope is fitted to the inner one. This tube CC is split open on one side, and is of such a degree of elasticity as to open when left to itself at this slit, so as to leave the tube I I entirely free. To the frame B is fitted a piece D, which consists of two semicylinders, connected together by one being screwed to the piece B at E, the other to the frame B at E on the other side. They are also connected by a part F, where they can be brought together or separated by the screw G. Now if the screw G be undone, then the two semicylinders will separate from one another, and allow the tube CC to open by its elasticity, and the tube I I to be at perfect liberty in expanding upwards or downwards. But if the screw G be screwed home, then the two sides of the piece F will embrace the tube C, and shut it upon the tube I, so that it shall become fixed at this point. This apparatus may be placed any where between B and I, fig. 1. In the clock I have constructed, it is placed at the point F opposite to E, fig. 1.

If the point I be placed then too high, the clock will be found to go too slow if the heat be greater, too fast if it be less. If this should be found the case, then the screw G, fig. 3, is to be screwed home, the screws L L, fig. 2, are to be loosened, and the frame GGGG must be screwed downward by the screw H, which will carry along with it the piece KK, therefore the centres of the screws L L which form the point I, fig. 1, in perpendicular height. Then the screws L L, fig. 2, are to be screwed home, the screw G, fig. 3, is to be loosened so as to leave the tube I I, which is the same in both figures, perfectly free and untouched by any of the apparatus excepting at the point I, the fixed point. The same thing is to be done, only in the reverse, if the clock be found to go too fast in a greater degree of heat, too slow in a greater degree of cold.

In the clock which I have constructed, the bar BC, fig. 1, is considered as inflexible. If it were flexible, a weight hung at C would occasion it to fall lower, and in consequence bring the rod CD lower, and a greater part of it below the point E; thus the pendulum would be lengthened. It is therefore necessary to make this rod as inflexible as possible; for this reason it is made of a strong brass bar, HK, fig. 3, which is farther strengthened by a brass bar LK, supported by the upright HL.

If a weight were hung at K, it would tend to draw the tube I out of the perpendicular towards K. To prevent this, another bar HM is carried exactly opposite, so that M H K shall form the same bar, the under surface of which is parallel to the horizon. At the end of this bar M, is appended a weight O, so that, supposing the line LH to be the axis of the tube I I continued, and perpendicular to the horizon, then the whole of the weight on the side of LH towards M, shall be equal to the whole of the weight on the side of LH towards P. P is the head of a screw, to the centre of which the rod CD, fig. 1, is attached; this screw passes through the end of the bar HP, in the same manner as the wire sustaining the weight O passes through the end of the bar HM at N. The uses of this screw are to be seen in fig. 4, where HK represent the end of the bar HK, fig. 3, through which the screw A passes. The head of this screw P is toothed and divided. To the teeth there is a catch at K, which allows it to be turned backwards and forwards with a tolerable force, but keeps it in the same place until that force be applied to it. The upper part of the screw C, fig. 4, is a cylinder, which passes through a cylindric hole in the end of the bar HK, fitted to it so as to allow of being turned round without shaking. The screw itself passes through a female screw at D in the frame EF.

This frame, as well as the screw itself, is made of brass, and consists of a bar EF, which is perpendicular to the horizon; from which arise two pieces GG and EL, at right angles, therefore parallel to the horizon. In the upper piece EL is a female screw, through which the screw A passes; so that the head P, being turned round, will raise the frame EF or depress it. In the bottom part GF there is a slit MM, through which the rod NO passes. This rod passes through a piece of brass PP at Q, where it is fixed, so that by screwing forward the screw A, the point Q, and the rod NO consequently, will be raised up, and *e contra.* The point Q is placed exactly under the centre of the screw A.

This point Q is to be considered as the point C, fig. 1. For although in fact the part of the rod HK where the screw A passes, and rests upon the end of the rod HK, be the point C, fig. 1; yet if a part of the tube I I, fig. 3, at the point C be taken at an equal height with Q, fig. 4, as they are both of brass, both will expand equally. If the whole should be heated, the expansion of CH, fig. 3, will raise up the bar HK, and the expansion of the screw A, and the frame EF, will carry down the point Q, so that it shall always be at an equal height with the point C, fig. 3. The points C and Q, fig. 3, 4, therefore, being always of the same height, may be considered as the points B C, fig. 1. The rod CD, fig. 1, is steel wire, the whole length of which weighs 13 grains. It is watch pendulum wire, No. 3. The point E is at R, fig. 4.

SSSS, fig. 4, is the frame which connects the points I and E, fig. 1; to this frame the square brass bar I I is firmly fixed, so as to rise perpendicular from the frame SSSS; on the side VV of this bar a semicylindric piece of crystal is attached, so that the cylindric part shall be towards R, and so that a number of lines perpendicular to the horizon, tangents to this cylinder, shall pass through the slit MM.

WX is another square rod, with a crystal semicylinder also attached to the frame SSSS, so as to rise perpendicular to it, but sliding in the dove-tail groove XY so as that it is capable of being brought nearer or farther from the cylinder attached to the rod I I. This may be done by a screw. It is clear then that the wire NO will pass between the cylindric parts of these two cylinders.

If the screw Y was screwed so as to make the cylinders touch one another, all but the exact thickness of the wire NO, then it is clear that the under part of the wire, from V to O, would become flexible at V, but then the expansion of the tube I I, fig. 3, would not lower or raise the part of the wire VO so as to keep it always of an equal length; but if the cylinders were opened the least farther, then the expansion or contraction of the tube I I, fig. 3, would raise or depress the part of the wire between the cylinder, and render the pendulum always of the same length, whatever be the heat; and thus a pendulum may be formed, according to what has been demonstrated, always of one length.

On considering the several different methods of finding a measure of lengths which could be always and universally ascertained, I am persuaded that the taking the difference of the length of two pendulums, vibrating different times, appears not only to be the most perfect, but the easiest attainable. Mr. WHITEHURST contrived an apparatus for the purpose of ascertaining this difference, an account of which was read in the Royal Society, and afterwards withdrawn and published by the author himself. After his death, I purchased this apparatus.

There was no means in it whatever of keeping the pendulum of the same length when the heat should vary; consequently it was impossible that any accurate admeasurement of the different lengths of two pendulums keeping different times could be ascertained. Mr. WHITEHURST, indeed, had endeavoured to keep his pendulum of the same degree of heat; but I know from many experiments, among which some were for hatching eggs, how extremely difficult it is to maintain the same heat in any considerable mass, and that the means which may be employed to keep it within four or five degrees are almost totally inapplicable to pendulums; so that his experiments must have been defective. I therefore endeavoured to contrive a means of rendering the pendulum in his machine always of the same length, whatever the heat might be, by some addition to it. I thought of the principle, and formed the apparatus above described for this purpose.

It would be improper for me to repeat what has already been laid before this learned Society; therefore I shall only mention briefly, that the frame of Mr. Whitehurst's machine was formed of two pieces of very clean well seasoned deal, to which was fixed the apparatus for rendering the wire flexible of which his pendulum was formed at the point Q, fig. 4, but there were no semicylindric pieces; the two square pieces came together, so as to make the top of the pendulum at their under surface; these pieces could be brought away from one another by the screw Y, so as to leave the wire free. The use of this was, by the screw L, fig. 4, to adjust the pendulum to its proper length, which has in this apparatus a considerable advantage, as it is not necessary, in the form I have given to this apparatus, to stop the clock in order to adjust it. These pieces of wood are mortised into a transverse piece of deal at the top and at the bottom firmly. Before I attempted to make a very perfect machine on these principles, I resolved to try how far this frame of wood might serve to connect the points I and E, fig. 1, and procured the apparatus for altering the point I, screwed on to one of these perpendicular pieces of wood on one side, and to the other on the other side. The pendulum itself serves as a plummet to place them perpendicular. In Mr. Whitehurst's machine the screw at L, fig. 4, went through a piece of brass, and rested upon it, fixed to the top of the clock-case. But in my construction of it, when the length of the rod IB, fig. 1, is adjusted, the clock has nothing to do with the clock-case, excepting with that part of the wooden frame which connects the point I with the point E, fig. 1. If I had been, or were to construct a machine for this purpose *ab origine*, instead of these two pieces of fir, I should employ a solid piece of brass, and make two cylindric cavities into it, parallel to one another, and in these cavities place two glass tubes, about two inches diameter, perpendicularly upwards, which may be done by various means; and, while in this situation, having heated them gradually to the heat of melted lead, I should pour in melted lead, so as to fix them in their places when it cooled. The apparatus for fixing the point I, and that for fixing the tube I I, fig. 2 and 3 at F, fig. 1, being also of brass, in heat they would always expand, and in cold contract, equally; so that the glass tubes would keep always at an equal distance from one another, and equally perpendicular. Glass is not only very little apt to contract and expand by heat, but free from any such disposition from moisture or dryness, which is not the case with wood.

Having added the apparatus I have described to Mr. WHITEHURST's machine, I set it a going, expecting, in the situation I placed it, only some approach towards accuracy in the length of the pendulum. I fixed beside it a transit which belonged to Mr. LUDLAM, the principal parts of which were made by Mr. RAMSDEN, the object-glass was a four-feet focus achromatic by DOLLOND. I found my meridian mark at about three quarters of a mile distance. I likewise borrowed, from my friend Mr. STEVENS, a clock with a gridiron pendulum, made by GRAHAM for his father Dr. STEVENS, in order to compare them together when I had no observations. There were several trivial circumstances, which baffled the experiments for some time, not worth relating, one only excepted; which was, that the curvature of the wire, acquired by its being wound round a pirn, was not entirely unfolded for some months, so that the clock went slower and slower during that time. At length this difficulty was overcome; I then began to observe with

GRAHAM's clock, in order to adjust the length of the pendulum, but found irregularities frequently take place. I then adjusted it by observation, and soon found that GRAHAM's clock went much more irregularly than my own. I adjusted it by turning the head of the screw at L, fig. 4, until the clock came to lose seven-tenths of a second in 24 hours. I did not think it worth while to bring it nearer; I then began to observe, and carried on the observations, when the weather permitted, for about nine months, during which the thermometer had fallen so low as 15° of FAHRENHEIT, in the clock case, and risen as high as 84; and with considerable variations. Unfortunately I have mislaid or lost the particulars of each observation; but I have preserved the greatest difference from the rate of its going. Counting on, according to the rate of its going, during the whole time it never exceeded the sum, half a second, nor was ever less than half a second, whether it was taken from day to day, month to month, or from any one to any other period during the observation.

Undoubtedly, therefore, notwithstanding the errors that might have arisen from the expansion of the wood by moisture, and from the unsteadiness of the building in which it was placed, it certainly performed better than any other time-piece that has been made; and perhaps affords a principle which may be used in fixed observatories for keeping time with certainty, by easy and not very expensive means; and of determining, with the rest of Mr. WHITEHURST's apparatus, the difference between the lengths of two pendulums swinging equal arches of circles of different diameters, in any two given different times.

The astronomer royal has also suggested an improvement:

viz. instead of grinding the two crystalline pieces in a cylindric form, the lower part should be ground in a cycloidal form; then it would have the advantage of cycloidal cheeks, which no contrivance hitherto has been able to attain.

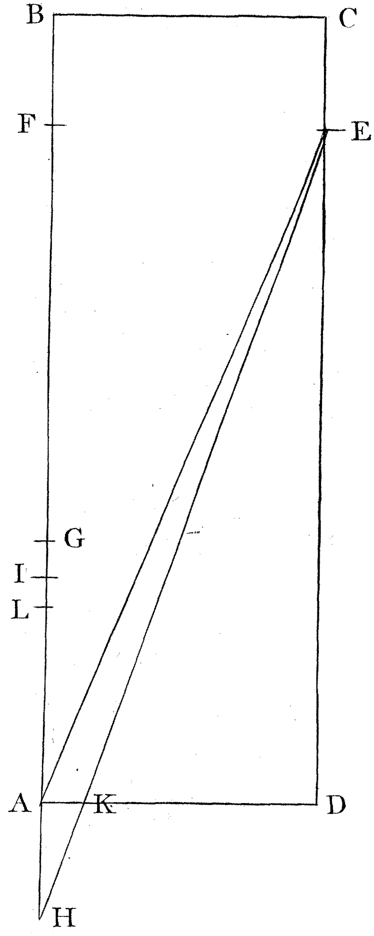
There are some farther observations necessary to be made, to enable workmen to construct clocks according to this principle, and some reflections upon its operation.

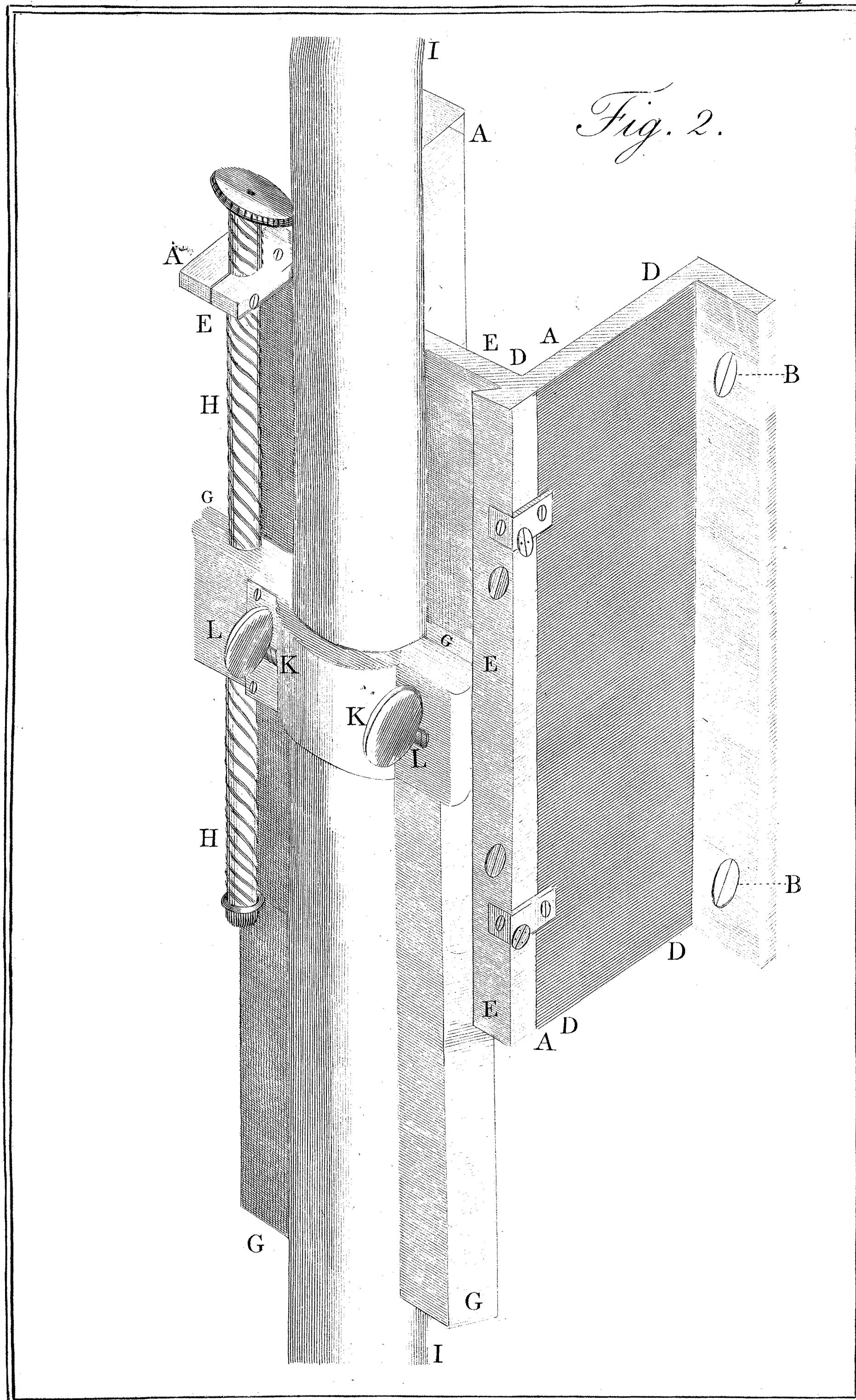
The manner of hanging a leaden weight to the pendulum, its proportion to the maintaining power, the manner of applying the pendulum to the clock, and the structure of the clock, are to be found in Mr. WHITEHURST's pamphlet; with only this difference, that the steel wire should go through a tube placed in the axis of the spherical lead weight, and be fixed at the bottom instead of the top of it. This, however, is of no great consequence if there be a power of altering the height of the fixed point I, fig. 1; because Mr. WHITEHURST's pendulum consisting partly of steel, partly of lead, therefore the point I must be adjusted to the joint expansions of lead and steel, if the wire be fixed at the top of the ball.

The first reflection that I shall make is, that the steel wire, the brass tube, and the materials which connect the points I E, being of different sizes, and different in their disposition to be heated or cooled, some one of them might be heated or cooled faster than another. But where good clocks are kept, the changes of the heat of the atmosphere are so slow, that no great difference can take place in the time that each of the parts rises to the heat of the atmosphere in the room where the clock is kept; none that could make any sensible error. As the difference of the time when they acquired the heat, would be compensated by the difference of the time when they acquired the cold, it could hardly happen that any sensible difference in the going of the clock could arise in any period of twenty-four hours, whether transits of the sun or of any of the fixed stars were taken.

The wire in each vibration hangs, during a certain portion of that vibration, between the two cylinders, and touches neither of them: during that time, the point Q must be considered as the top of the pendulum, not the slit between the cylinders; but this part of the vibration may be so very small a proportion of it, as not to make any sensible error; and it is accompanied on the other hand by a very great advantage. Except in Mr. ARNOLD'S compensation for heat in watches, in all the other modes a surface or surfaces necessarily slide over one another; whenever this happens, if heat, by expanding one of the bodies, is to make its surface slide over the other, it has two things to accomplish, to overcome the *vis insita* of the matter, and the attraction of the two surfaces to one another. When then there is heat enough applied just to overcome the *vis insita*, it would not be sufficient to overcome the attraction likewise, excepting the matter was infinitely hard and inelastic. Although the heat therefore be increased, the compensating parts at first do not move so much as to overcome both these resistances, afterwards the parts jerk on suddenly, and in many cases go beyond what they otherwise would have done. As none of the expanding parts are to slide upon one another in Mr. ARNOLD'S compensation, and there is a time in every vibration, in the apparatus above described, when none of the expanding parts slide over any thing, this disadvantage is avoided.

Fig. 1.





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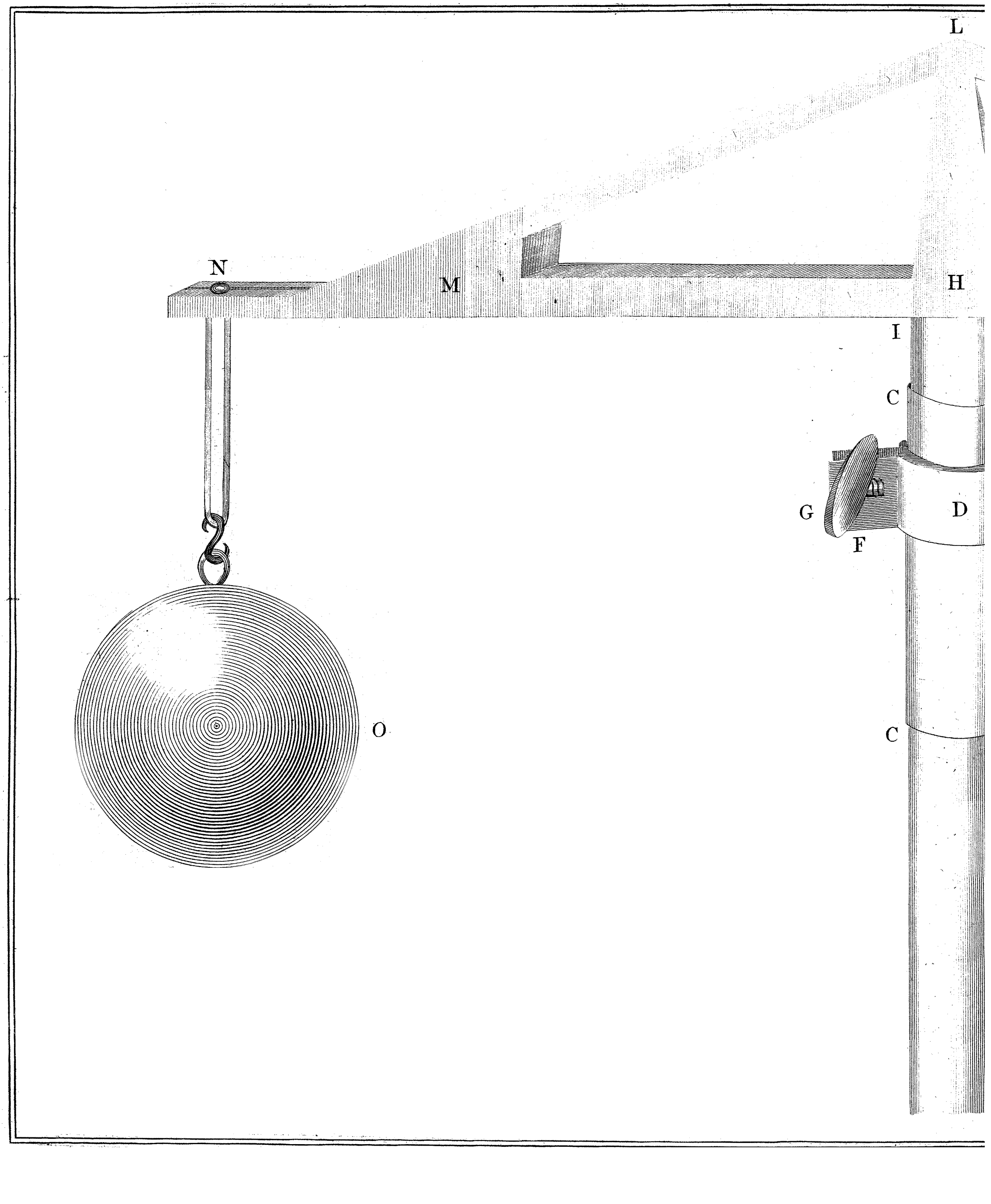
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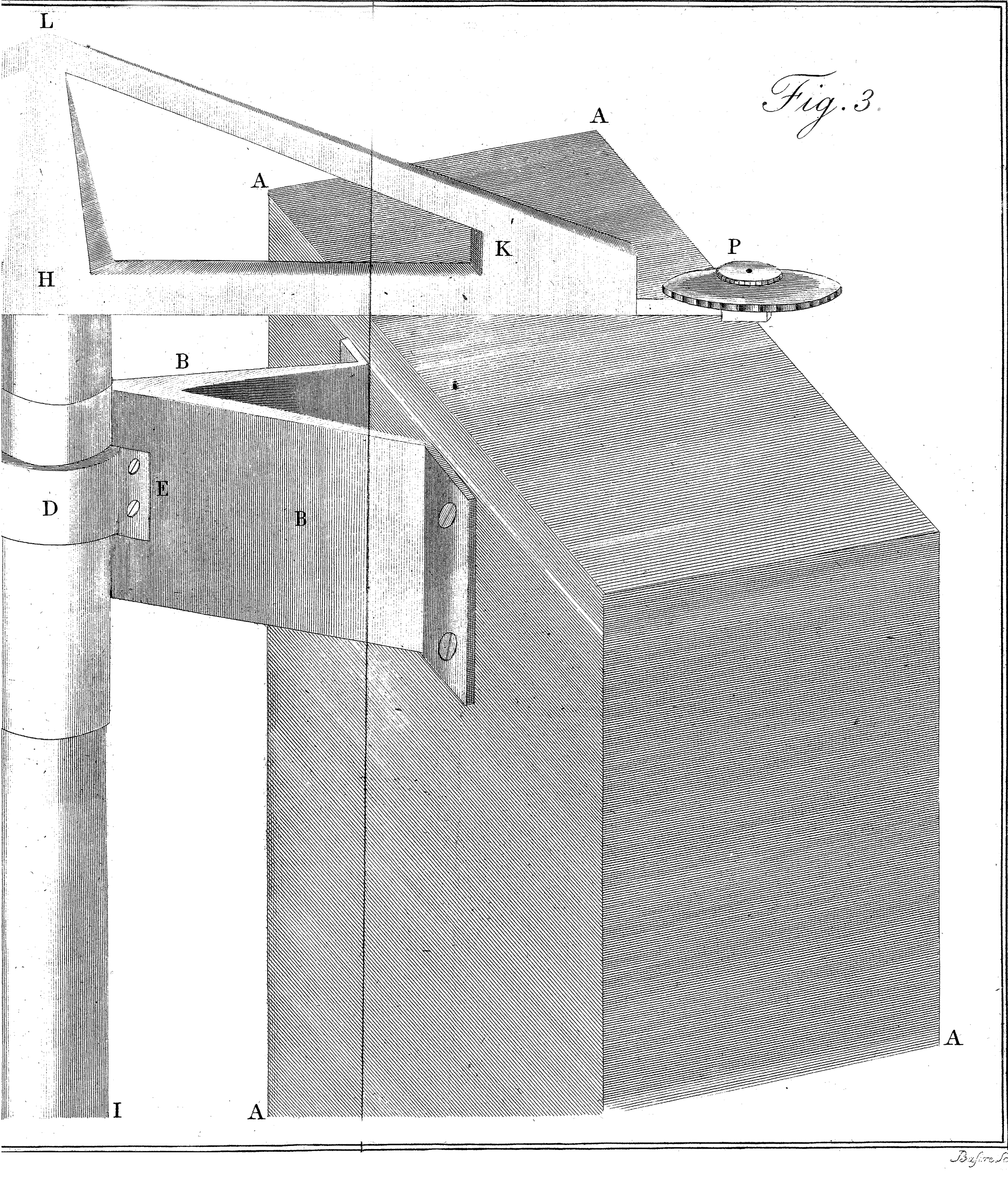
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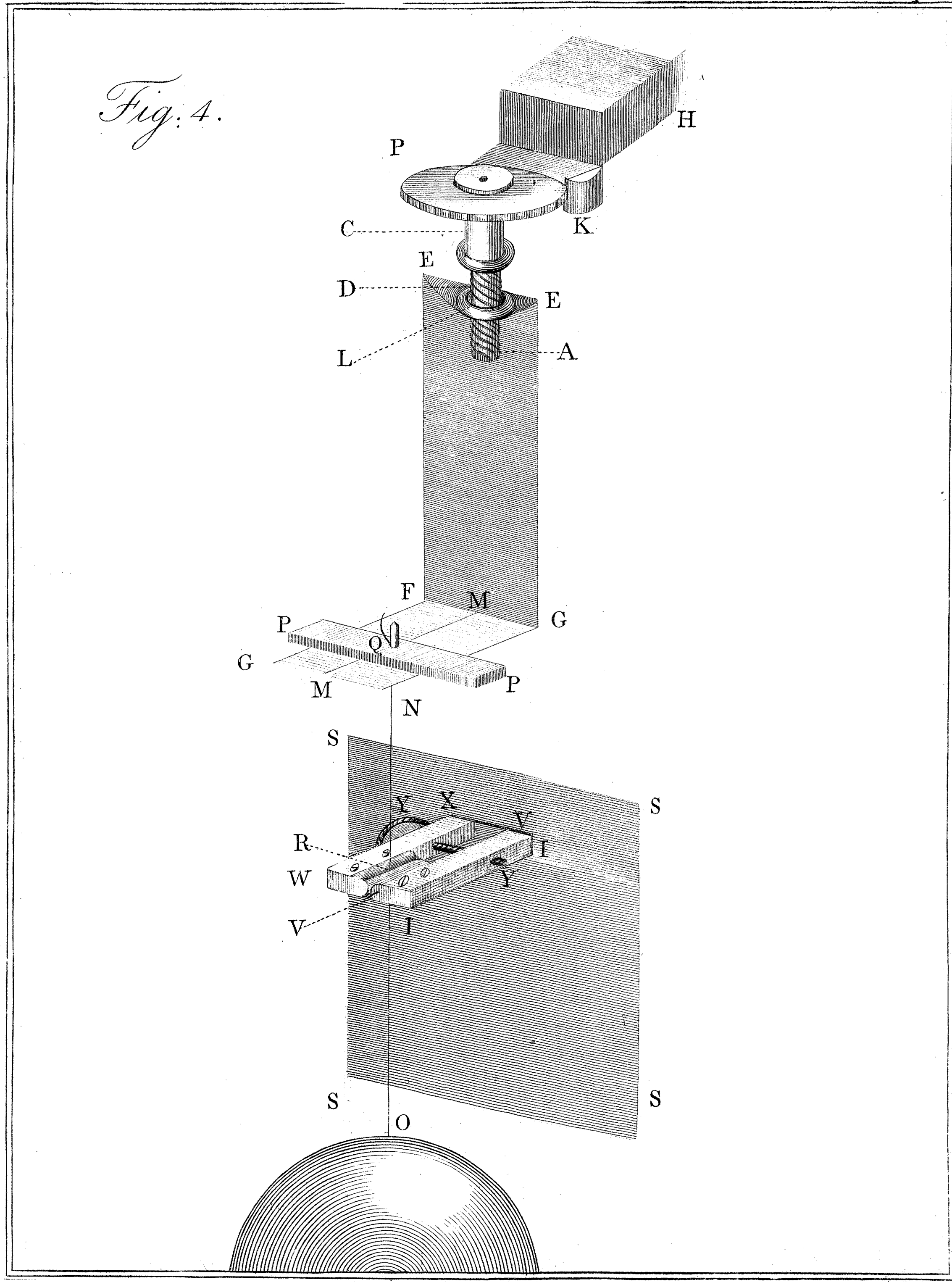

Basire Sc.

Fig. 3